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Occupational and Environmental Safety and Health V

Studies in Systems, Decision and Control

Volume 492

Series Editor

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ISSN 2198-4182

ISSN 2198-4190 (electronic)

Studies in Systems, Decision and Control

ISBN 978-3-031-38276-5

ISBN 978-3-031-38277-2 (eBook)

<https://doi.org/10.1007/978-3-031-38277-2>

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Preface

Occupational and Environmental Safety and Health V is a compilation of the most recent work of some selected authors from eight countries within the occupational safety, health and ergonomics domain.

This book represents the state of the art, and it is mainly based on research carried out at universities and other research institutions, as well as some on-field interventions and case studies. It also features a section dedicated to reviewing papers for the first time in this series. Recognised experts prepared the chapters that compose it, which allow the reader to have a comprehensive and in-depth view of various subjects quickly.

Due to the broad scope, relevance and originality of the contributions, it is expected that this book contains valuable and up-to-date information, and it presents fundamental scientific research that is being carried out on the subject, as well as contributes to the outreach of practical tools and approaches currently used by OSH practitioners in a global context. All the included contributions were selected based on their potential to show the newest research and practices, giving visibility to emerging issues and presenting new solutions in occupational safety, health and ergonomics.

This book is based on selected contributions presented at the 20th edition of the International Symposium on Occupational Safety and Hygiene (SHO 2023), held on 20–21 July 2023, in Porto, Portugal.

All the contributions included in this book were previously peer-reviewed by at least two of the 103 members from 13 countries of the International Scientific Committee of the 2023 edition. The event is organised annually by the Portuguese Society of Occupational Safety and Hygiene (SPOSHO).

Editors would like to take this opportunity to thank their academic partners, namely the School of Engineering of the University of Minho, the Faculty of Engineering of the University of Porto, the Faculty of Human Kinetics of the University of Lisbon, the Polytechnic University of Catalonia and the Technical University of Delft. The editors also would like to thank the scientific sponsorship of several academic and

professional institutions, the official support of the Portuguese Authority for Working Conditions (ACT), and the valuable support of several companies and institutions. Finally, the editors also wish to thank all the reviewers who contributed critically, without whom it would not be possible to develop and publish the current book.

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Ergonomics and Biomechanics

A Look at the Relationship Between Fatigue and Self-employed Truck Drivers



R. D. Soliani , L. B. da Silva , A. V. Brito Lopes , and F. Santiago 

Abstract The shift in the transportation industry towards hiring self-employed drivers rather than those with permanent employment has become a trend in order to reduce expenses and labor responsibilities. However, this practice, known as outsourcing, has been linked to a higher risk of accidents across various industries. The study aims to investigate the causes of fatigue in self-employed truck drivers. To do this, a literature review was performed to assess the impact of fatigue on self-employed truck drivers. Sleep, work-related factors, and health were found to be the main influences on fatigue with a lack of balance between work and rest time being the central issue. The intense pace of work for self-employed truck drivers results in physical and mental exhaustion, which affects their health and well-being. The demand for this type of work is driven by customers, suppliers, commercial agreements, and new business models, but it has led to precarious working conditions for many drivers. The manifestation of fatigue, such as slow response, decreased concentration, reckless behavior, or even falling asleep while driving, has been linked to numerous serious accidents. For these reasons, it is crucial to find ways to measure and control the factors that contribute to fatigue.

Keywords Health · Safety · Accidents · Outsourcing · Road transportation

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1 Introduction

The current trend in transportation companies involves shifting workers with a permanent employment relationship to outsourced or self-employed status, which results in lower costs for the companies [26]. This change in labor relations is due to adaptation to new trends in the globalized market. By opting to hire self-employed drivers for transportation, carriers reduce their operating expenses, such as fuel, vehicle maintenance, tire costs, among others, as well as their responsibilities and labor costs [35].

Outsourcing has been linked to increased risks of occupational health and safety (OSH) accidents across various sectors [27, 31, 32]. In the road transport industry, supply chains pressure contractors to reduce costs, leading carrier owners and drivers to make cuts and compromises that affect safety measures such as extended working hours, drug use, excessive speed, and reduced maintenance [4, 18, 22, 39].

Zhang et al. [46] found that 16.5% of fatal traffic accidents in the USA are caused by fatigue, and 20% of Canadian drivers reported having fallen asleep while driving. A study conducted in 19 European countries by [15] revealed that about 17% of the accidents were primarily due to drowsy driving. In Brazil, from 2014 to 2019, 76% of all recorded general traffic accidents were attributed to significant clinical factors such as fatigue, stress, and tiredness [1]. Fatigue is estimated to contribute to 20–30% of all global traffic accidents [10, 30].

Therefore, it is important to examine the players involved in the road freight transportation industry. This study, through a comprehensive examination of existing literature, aims to consolidate the evidence related to factors that contribute to fatigue among self-employed truck drivers. The objective is to gain insights that can help in the identification of strategies and development of countermeasures to minimize the risks associated with truck driving fatigue.

2 Methodology

The present study was conducted through a literature review (LR), a method that allows for a comprehensive analysis of published works and the systematic organization of a topic [11]. LRs are useful for both researchers and readers as they provide an up-to-date and structured overview of a specific area of knowledge [43]. This review aimed to identify the most relevant studies on the impact of fatigue on truck driving.

The methodology adopted, based on the study by Martins et al. [24], involves five stages, being: (1) Formulating the research question; (2) Studies location; (3) Selection and evaluation of studies; (4) Analysis and synthesis; and (5) Reporting and use of research results. Each step is explained in Fig. 1.

This study started with the formulation of the research question: What are the main factors that influence the manifestation of fatigue in the profession of selfemployed truck drivers? The subsequent step was determining the study's location, including

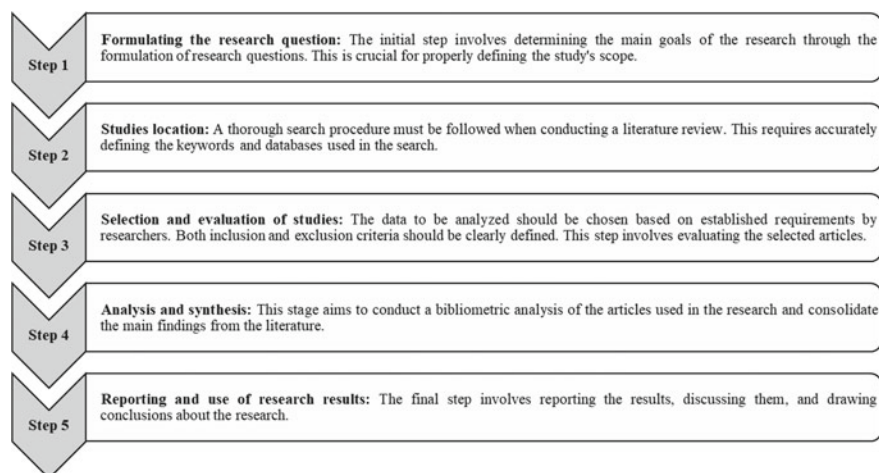


Fig. 1 Flowchart of the procedure's methodology. *Source* Adapted from Martins et al. [24]

the keywords utilized in the search and the consulted databases. The keywords were “Safety” OR “Health” OR “Truck Driver” AND “Traffic Accident” OR “Fatigue” OR “Truck Driver” AND “Occupational Risks” OR “Fatigue” OR “Self Employed Driver”. According to the study by Bramer et al. [5], in order to obtain the best results in literature reviews, it is recommended to include, at least, the databases: Embase, MEDLINE, Web of Science and Scopus in the search, a guideline followed in this study.

Regarding the selection and evaluation of the studies, only articles from international databases were considered for analysis. In order to ensure the inclusion of current and relevant publications on the subject, the search was restricted to works published in the last decade, covering the period from 2012 to 2022. The first exclusion round eliminated articles from congresses and studies that were not fully available. The second round eliminated documents that did not focus on the subject matter in question. Articles found in more than one database were only considered once. These articles included LR, case studies, surveys, and development of tools and models, but none had a similar objective as this study. In the analysis and synthesis step, the articles were sourced from a diverse range of journals.

The methodology employed in this study is characterized by being comprehensive, transparent, and uses specific search criteria. It covers all the pertinent studies in the analysis and each stage of the process is easily repeatable. Once the articles included in the LR were thoroughly read, the collected information was synthesized, linking the data obtained on the impact of fatigue on the job of self-employed truck drivers, contributing to the development of the discussion about occupational risks in the freight transport industry. Finally, the results of the review were established.

3 Results

The review process started with a bibliographic search that led to the selection of 195 articles. After applying the exclusion criteria, 156 studies were removed (type of publication, research subject and duplicate studies), leaving a total of 39 articles used in the review. Next, Fig. 2 presents the list of articles that were included in the study.

It was initially noted that the word fatigue generally indicates a subjective feeling of tiredness, but in scientific terms, it refers to the wear and tear caused by effort (mental or physical) that leads to decreased ability to work and reduced response efficiency [10]. Fatigue among truck drivers is a concern for both occupational and public health due to its connection to increased accident risk [46].

Several authors have pointed out that driver fatigue is a major cause of traffic accidents and is a pressing concern for road safety in many countries. Fatigue impairs a driver's ability to perform physically and mentally, resulting in slower and less effective driving performance [3, 7, 21, 28, 29, 33, 34, 38]. According to the Global Status Report on Road Safety [44], traffic accidents are the eighth leading cause of death globally and the leading cause of death for children and young adults aged 5–29 years old.

The impact of fatigue on safety while driving vehicles is complex to assess and manage [6, 36]. In the case of road freight transport, the focus of this work, the central question is the balance between working time and time to rest, in order to reduce the possibility of the driver to show up for work being affected by fatigue [45].

Working time is a crucial factor in the production and transport industry, but the focus on safety is often overshadowed by the commercial demands for flexible and timely goods transportation, which often requires 24/7 operations [19]. The demands of customers, suppliers, commercial contracts, and new production methods have contributed to the precarious working conditions of many drivers over the past 15 years [20, 40]. According to Cardoso et al. [7], given the consequences of fatigue, such as slow reaction time, decreased concentration, reckless behavior, and even falling asleep at the wheel, it is important to find ways to better monitor and control the factors that cause fatigue.

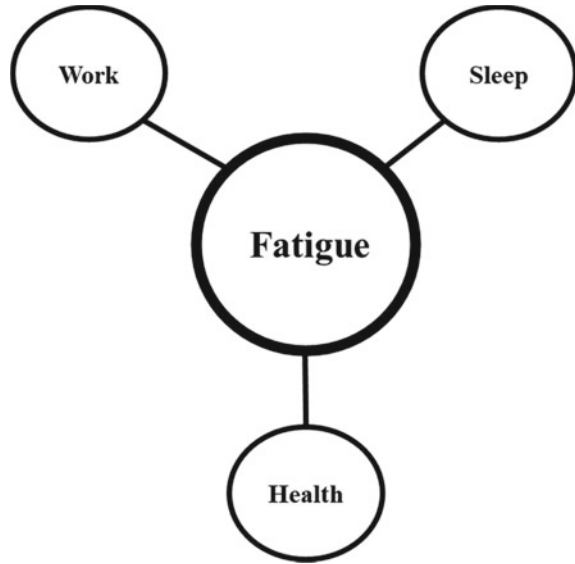
After analyzing the studies, the review identified three primary factors that lead to truck driver fatigue, namely sleep patterns (circadian rhythm dysregulation), work-related factors (prolonged working hours and insufficient rest time), and health-related factors (overall health and lifestyle). These aspects have guided the development of the current study. The interconnection of these three factors is illustrated in Fig. 3.

The health of truck drivers, particularly their mental health, is impacted by components such as extended working hours, disrupted sleep, social solitude, delivery pressures, stress, low compensation, and inadequate medical care [17, 41]. Furthermore, the transport process includes procedures that lengthen the workday and inhibit sleep, such as waiting in line for loading and unloading cargo, which have also been linked to driver fatigue [23].

Author	Year	Main contribution
Ağralı et al.	2017	Consider an employee scheduling problem in service industries with flexible employee availability and flexible demand.
Anderson et al.	2017	Positive psychological safety climate is associated with decreased likelihood of work-related injury.
Belzer and Sedo	2017	Shows the underlying economic force inducing long-haul truck drivers to work extremely long hours.
Caldwell et al.	2019	Excessive sleepiness on highways is a serious safety hazard, and insufficient or disrupted sleep results in numerous accidents and adverse mental and physical health outcomes.
Cardoso et al.	2019	Evaluate changes in fatigue, stress and vigilance amongst commercially licensed truck drivers involved in a prolonged driving task.
Chen et al.	2015	Presents the descriptive analysis showing results of the injury and safety component of the national survey of long-haul truck drivers.
Crizzle et al.	2017	Provide a comprehensive review of the literature related to the health and wellness of truck and bus drivers in Canada and the USA.
Davidović et al.	2018	Determine the influence of fatigue among bus and truck drivers in the Republic of Serbia.
Friswell and Williamson	2019	Management of queuing and waiting for loading/unloading can influence the risk of fatigue for heavy truck drivers if it extends work hours or hampers drivers' access to rest.
Garbarino et al.	2018	Descriptive review of the relationship between sleep and mental health and its impact on truck drivers.
Giroto et al.	2019	Identify the role of working conditions as predictors of sleepiness while driving among truck drivers.
Gonçalves et al.	2015	Emphasizes the importance of joint research and policy efforts to reduce the burden of sleepiness at the wheel for European drivers.
Guglielmi et al.	2018	Evaluate the prevalence of obstructive sleep apnea and poor sleep quality in truck drivers.
Hege et al.	2019	Explore the connections between work characteristics, job stress, sleep outcomes, health behaviors and physical and mental health outcomes among truck drivers.
Hege et al.	2015	Determine whether and to what extent long-haul trucker work schedules influence sleep duration and quality.
Jaffee and Bensman	2016	Examines the prevalence of precarious work in the logistics sector of the U.S. economy and the mechanisms facilitating these working conditions.
Lemke et al.	2016	Determine the degree to which sleep impacts safety-relevant performance among long-haul truck drivers.
Lemke et al.	2021	Identify factors associated with hours-of-service compliance and to determine the significance of HOS compliance in sleep-related safety risk.
Mahajan et al.	2019	Identify and model the role of payment incentives, driver work-rest patterns and other lifestyle habits influencing the drowsy driving behavior among long-haul truck drivers.
Mathews et al.	2012	Determine the independent effects of prior wake and time of day on driving performance under conditions of sleep restriction.
Messias et al.	2019	Garner an understanding of the perceptions that Brazilian truck drivers hold regarding themselves.
Min et al.	2019	Anticipate and prepare for occupational health and safety problems for workers in the era of the fourth industrial revolution.
Mizuno et al.	2020	Identify the relationship between autonomic nerve function as an objective parameter of fatigue and the extent of rear-end collision risk.
Narciso et al.	2017	Discuss the laws related to Brazilian professional drivers and their current amendments in relation to working hours at the wheel and rest breaks.
Nazari et al.	2017	Identify and appraise the published studies assessing interventions accounting for reducing fatigue and sleepiness while driving.
Nygren et al.	2017	Carry out a survey and analysis of research articles focusing on safety on multi-employer worksites in high-risk industries.
Park et al.	2020	Compared the occupational safety and health problems of employees and self-employed individuals in Korea according the type of work they performed.
Pourabadian et al.	2020	Investigate the effects of fatigue on the coping behavior of international truck drivers.
Reiman et al.	2018	Identify individual factors and combinations thereof that can contribute to truck drivers' occupational accidents.
Rocha et al.	2018	Discuss the consequences of recent transformations in the organization of work, particularly the laws that regulate the activity of truck drivers in Brazil.
Sadeghniai-Haghighi and Yazdi	2015	Illustrate concept of fatigue and its adverse effects in the workplace.
Schneider et al.	2019	Makes several contributions to the literature on the consequences of precarious employment.
Simonelli et al.	2018	Describe the hours of service provisions in continental Latin America.
Sinagawa et al.	2015	Investigate whether the use of the stimulants amphetamines and cocaine by truck drivers in Brazil was related to travel length.
Sofiani	2021	Present aspects of the concept of sustainability in the Brazilian road freight transportation sector.
Soliani and Bueno	2022	Analyze the main aspects of occupational health and safety that affect the category of self-employed drivers.
Stern et al.	2019	Identifies the various factors affecting driver fatigue and relating driver fatigue to crash risk and long-term driver health.
Wijngaards et al.	2019	Examines how various state-like and trait-like job demands and resources relate to truck drivers' momentary happiness at work.
Zhang et al.	2016	Analyze traffic accident data for the period 2006–2010 in Guangdong Province, China.

Fig. 2 List of studies selected for inclusion

Fig. 3 Intertwining factors influencing the manifestation of fatigue identified in LR



Fatigue is identified by feelings of physical and mental exhaustion and is considered pathological or chronic fatigue when rest and sleep do not relieve the tiredness [42]. Its symptoms include sleep disturbances, insomnia, irritability, feelings of discouragement, difficulty performing activities, loss of appetite, among others [25].

4 Discussion

Outsourcing has become a common practice in various industries; however, it has been linked to an increase in occupational health and safety incidents [27, 31, 32]. In the road transport sector, this trend is especially evident. Contractors in the supply chain often pressure carrier owners and drivers to cut costs, leading them to adopt dangerous practices, such as extended work hours, drug use, excessive speeding, and inadequate maintenance [4, 18, 22, 26, 39]. These actions negatively impact the safety of the drivers and others on the road.

These working conditions, characterized by low wages, unstable labor relations, temporary employment contracts, economic instability, lack of benefits, fixed working hours and legal protection, have been referred to as precarious by Jaffee and Bensman [20], Schneider and Harknett [37]. They also note that drivers often use their free time to increase their income.

Self-employed truck drivers are paid based on their output (per delivery or trip completed) rather than for the time they work [14]. This results in long wait times reducing their earning potential, causing drivers to drive longer hours in an attempt to make up for lost time [22].

According to a study by Davidović et al. [10], the previous night's sleep quality is the most crucial factor impacting the driver's level of alertness and wakefulness. The biological clock of the human body controls the organic functions of a person over a 24-h period, known as the circadian rhythm [21]. This rhythm is disrupted when the normal day and night cycle is reversed, such as when one works at night and sleeps during the day. This can lead to internal desynchronization of the biological and circadian rhythms [18, 38].

In developed countries, with a high demand for industrial and service sectors, there is a growing trend of using alternating and night shift schedules [2, 27]. Many professional drivers are therefore involved in operations that take place in shifts, either at night on a fixed schedule or in an irregular manner [12]. These drivers face a range of work environments and conditions, with many of them dealing with precarious work situations [8, 13, 17].

Shift work can greatly harm the well-being of workers, leading to physical and mental exhaustion as a result of disruptions in their biological rhythm. This mode of work arrangement is often challenging to adjust to, and can have a negative impact on the social and family life of workers [29]. Jeong et al. (2018) found that drivers who work a fixed schedule have a single sleep period in a 24-h span, but it is longer compared to those who work irregular hours. Those who frequently alter their sleep schedules often face sleep pattern interruptions, resulting in the emergence of disorders such as Obstructive Sleep Apnea (OSA) syndrome [16, 17, 23].

The research by [13] looks into how various factors can impact truck drivers' performance decline. Some factors, such as OSA, are linked to increased fatigue levels. Besides the potential safety concerns, lack of adequate sleep can also increase the likelihood of developing health issues such as high blood pressure, diabetes, obesity, depression, and cardiovascular disease [9].

Studies show that sleep deprivation slows reflexes, reaction time and limits decision-making skills [3, 13, 17, 18, 21–23, 25] (Jeong et al. 2018). Although lack of sleep affects the performance of all categories of workers, in the case of truck drivers, the aggravating effects of fatigue also increase the risk of accidents [6].

The demands of customers, suppliers, commercial agreements, and new production models have led to the need for this work schedule, however, in recent years, the working conditions of many drivers have become increasingly precarious [20]. Therefore, it is critical to investigate methods to effectively measure and regulate the causes of fatigue, as its manifestation, such as slow reactions, decreased focus, reckless behavior, and even falling asleep while driving, has been linked to numerous severe accidents.

5 Conclusions

The LR revealed that research regarding the working conditions of truck drivers is frequently insufficient when compared to research conducted in other sectors of the economy. Additionally, there is a shortage of studies that center on self-employed

drivers. The majority of current studies concentrate on the impact of work on the health of these workers, with a primary focus on measuring the frequency of illnesses.

The scientific studies analyzed in this research indicate that the three major factors contributing to fatigue among truck drivers are sleep patterns (circadian rhythm), work-related factors (extended driving hours and limited rest), and health (overall health and lifestyle factors).

Due to long driving hours, self-employed drivers are more prone to experiencing disrupted sleep patterns, leading to the development of fatigue. Moreover, driving during hours of the day when the body naturally craves sleep can exacerbate this problem, making it more challenging to maintain alertness and concentration on the road. Working conditions, such as long hours and shift work, can also contribute to the development of fatigue in self-employed truck drivers. Because of the nature of the job, these drivers may need to work long hours with little rest, leading to the accumulation of fatigue. In addition, drivers who suffer from conditions such as obesity or sleep apnea may be more prone to developing fatigue due to these conditions affecting their quality of sleep. The truck driver's job also contributes to unhealthy lifestyles, such as a sedentary lifestyle, poor dietary habits, and substance abuse.

A suggestion for future study is to track the work patterns and fatigue levels of self-employed drivers to assess the effect of fatigue on drivers' performance, safety, and well-being. The study would also investigate whether there are differences in the impact of fatigue on various types of self-employed drivers. The outcomes of this study could be used to design strategies and interventions to minimize the influence of fatigue on self-employed drivers and enhance their safety while driving.

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Influence of Postural Intervention During the Sleep Period on Back Pain, Quality of Life and Sleep Quality in Young Adults



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Abstract Human health may have several problems that occur when sleep disturbances are verified, causing a loss in the quality of life, autonomic dysfunction and decreased professional or academic performance. Objective: The aim is check if the ergonomic intervention can mean positive changes in the indices of back pain (BP) complains, quality of life (QOL) and sleep quality (SQ) in young adults. Methods: A sample of 21,560 observations (595 sleep hours) of 24 young adults (12 male military and 12 female undergraduate) were separated in three groups (Experimental [EG], Placebo [PG] and Control [CG]). The sleep behavior was classified into two Interaction Categories according to the iSEE methodology observation. For the carrying out, the Visual Analogue Scale, the abbreviated questionnaire of World Health Organization on quality of life and the Pittsburgh Sleep Quality Index was used before and after an ergonomic intervention program by physiotherapy. Results: EG improved self-perception of SQ ($p = 0.008$), QOL ($p = 0.000$), reduce the level of BP ($p = 0.001$) and change for an ideal posture while sleeping. Conclusion: The findings of this study allow us to suggest to health care professionals, in particular the rehabilitation professionals, new strategies for ergonomic postural behavior.

Keywords Musculoskeletal back pain · Sleep environment · Sleep behavior · Body ergonomics in bed · Physiotherapy intervention

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1 Introduction

Is there any influence of postural behavior (BP) on quality of life (QOL), sleep quality (SQ) and back pain (BP), when an ergonomic posture is adopted in bed during sleep?

It is found in literature a shortage of studies that relate the influence of the concepts covered in this study, in a systemic and ecological perspective.

The importance of sleep as a restorative and homeostatic agent has evident influence on the waking state of the individual. However, many people have occasional sleep disorders and the musculoskeletal back pain may be one of the factors that cause them [21, 40]. In some cases, these problems can become chronic, causing serious consequences in some domains of quality of life (e.g., physical and psychological).

Human health may have several problems that occur when sleep disturbances are verified, causing a loss in the quality of life, autonomic dysfunction and decreased professional or academic performance [7, 9, 19].

Certain sleep surfaces have resulted in complaints of lower back discomfort, pain, stiffness, or change in spinal alignment [27, 47]. An insufficiently adapted sleep system (i.e., mattress + support structure + head cushion) or an incorrect sleeping posture may cause back pain or sleep disorders in general [22].

According to many authors, one of the recommendations made to patients complaining of back pain is the cognitive behavioral therapy [33, 34] such as postural intervention [5].

Musculoskeletal back pain or sleep disorders in general are a leading cause of disability and this can interfere in some domains of quality of life (e.g. physical and psychological) and changes the personal status of other areas (e.g. social and environmental) [22, 29, 30, 38, 44].

Behavior analysis shows how environmental issues can influence the behavior. Although studies analyze some aspects of postural and sleep behavior, the context where it occurs is restricted, usually using laboratories [24, 25, 39, 40], but this analysis can generate a misunderstanding of data and the possible problems it entails [20, 23].

The postural behavior analyzed in a real situation of interaction with the environment has received scarce attention on research compared to other experimental methods [39] but it is considered the main element of good research.

This technique is typically used in ergonomic analysis studies [23].

Most methods (e.g. pictographic images) are used only for a small set of postures, and there are other general approaches to the analysis of postures (e.g. video analysis) [31, 48]. The analysis of the postural behavior and sleep rhythm are complex and the observation of these behaviors in real context is required. However, the observation methodology based Software iSEE [16] allows the classification and registration of postural behavior for long periods of time can be applied in this context [10]. The combination of more objective techniques (e.g. systematic observation) with more subjective techniques (e.g. questionnaires) which are usually qualitative, makes possible the global analysis of the individual [1, 14, 16, 43]

The influence of the sleep position on the physiological damage in the rest period is not very known. The results obtained with the use of an ergonomic recommendation method through the analysis of postural behaviors for long periods of time, such as the sleep period, are important to understand its influence on musculoskeletal pain, sleep quality and quality of life [11].

From this basic concept was defined the study problem where we aim to verify if the ergonomic intervention during sleep period can mean positive changes in the indices of BP complains, QOL and SQ in young adults.

This knowledge allows to: (a) understand the possible changes of indices of quality of life, sleep quality and back pain referred by participants in the day-by-day activities; and, (b) elaborate more specific recommendations to the changes in postural behaviors and product development.

2 Materials and Methods

For this study, which started on January, 2013 to February, 2014, we present the results of a tool approach considered mixed, using questionnaires on the perception of back pain, according to the Visual Analogue Scale (VAS) [2, 13, 15], the perception of quality of life according to the Abbreviated Quality of Life Questionnaire (WHOQOL-Brief) in all domains (Physical, Psychological, Social and Environmental Health) [4, 41], the perception of sleep quality according to the of Pittsburgh Sleep Quality (PSQI) [3] and observation methods through video analysis, of interaction patterns during the use of a specific set of Interaction Category—CI during sleep (8 h/night), to straight forward the methodology and produce robust results.

Data was collected from 24 young adults aged between 18 and 25 years old (Mean = 20.96 ± 1.899) who had chronic back pain, belonging to the air base n.5 of the Portuguese air force and to the Polytechnic Institute of Leiria of Portugal residing in dormitories. Twelve male soldiers, of different categories (1st Corporal, 2nd Corporal or Soldier) and twelve female university students, studying in the healthcare domain (physiotherapy, occupational therapy, speech therapy, nursing and dietary therapy), residing in dormitories of the air base and the university were selected.

The study lasted six (6) months, with three months of personal contact between the main researcher and the volunteers, and the remaining three months of impersonal contact through e-mails and cell phones.

In order to better understand the specific postural situation, it carried out a Postural Analysis (PA) in a sleep period. For this research will be presented only the PA results relevant to achieving their specific goals. The main postures observed in the pre-trial period are in line with the several studies [22, 25, 39].

This set of postural information enables better understanding the situation under study, in order to provide a basis for the development of the method and support the identification and ranking of observation categories of Software iSEE [9, 10, 38].

2.1 The Subjects and Night Activities

At the beginning, 66 soldiers (male) answered a questionnaire, but only 12 male (mean = 22.17 ± 1.749 years old) have volunteered to participate in this study. On the other hand, 89 students (28 male and 61 female) answered the same questionnaires, but only 12 females (mean = 19.75 years old ± 1.138) have volunteered to participate in this study.

Participants were informed about the study's objective and procedures through a group meeting in each study group. Finally, participants were instructed to perform their tasks as usual and to not change their schedule due to the presence of the cameras, respecting the habituation period to the video camera.

The participants' interactions with the bedroom equipment were video recorded on a normal rest period day. The digital video cameras turned on automatically from 10:00 p.m. to 8:00 a.m. and during the periods in which the subjects were asleep, awake, out of bed, doing activities, using a pillow, they were filmed using one plan (frontal superior) considering the best visualization of the participant and activity (Fig. 1).

The data, collected through video using a methodology proposed by [37] and [9, 10], analyzed the postural behavior in real situations, and we used this methodology in real situations in bed and was done using software iSEE developed for this purpose.

The fundamental aspect of this analysis using the software iSEE was: (a) evaluate the behaviors of interaction in a real environment and for long periods of time; (b) Allow sorting at the same event an impossible number of observations in other techniques; (c) Observe activities, actions, means of interaction (equipment) and postural behavior in the same event; (d) create hierarchies allow for observable; (e) to question the events in greater depth and detail and be able to sort all visible behaviors and test their viability during analysis by category.

All video collection was previously authorized by the management organs of the Polytechnic Institute of Leiria, and the Air Base No. 5 of the Portuguese Air Force, with prior permission of the General Staff of the Air Force, and authorized by the participants through a consent form and all procedures in this project is in line



Fig. 1 Images of the first plan (frontal superior) of the bed observations

with national and international guidelines for scientific research involving human subjects. The ethics committee of the Faculty of Human Kinetics, University of Lisbon ap-proved the experimental procedures with No. 13/2014. Approved Clinical Trial ACTRN12616000929404.

2.2 Experimental Study

A sample of 24 young adults (mean age = 20.96 + 1.899) participated in this study. 768 h of video analysis were performed (n = 27,840 observations), with 595 h of sleep (n = 21,560 observations), subsequently classified into six (6) Interaction Categories (CI's) through the iSEE observation method.

At the beginning of this study, we tested whether there were differences in postural behavior during the sleep period between the military and university groups across the 21,560 observed datasets.

This relationship was necessary due to the need to check in groups of people of the same age who sleep in the same conditions with the same equipment room in each residence and if there were any differences between genders in relation to postural behavior during the sleep period, regardless of the participants have different daily activity and opposite gender.

After an initial analysis of postural behaviors during sleep, which corresponded to 384 h of video analysis (n = 13,920 observations), of which 294 h of sleep (n = 10,670 observations), the 24 individuals were separated into 3 groups randomly chosen, 4 men and 4 women in each group: (i) Experimental Group (EG); (ii) Placebo Group (PG) and; (iii) Control Group (CG).

2.2.1 Experimental Group (EG)

Individuals in the EG were instructed regarding the method used in this study, which represents the recommendations of the ideal sleeping posture with the optimal quantity and place of use of pillows according to the pathological problems or the amount of back pain reported (Intervention program).

As was indicated by an initial lecture and weekly positive reinforcement (with sending the material presented and informal contact through email and phone), altered the initial body posture while sleeping too:

- The lateral decubitus right or left, with a pillow at the head/neck height of the distance between the shoulder and the neck of each participant, a pillow between the knees and a pillow between your arms or;
- The Supine, with a low pillow (5 cm) below the head/neck and a pillow or high roller (15 cm height) below the knees.

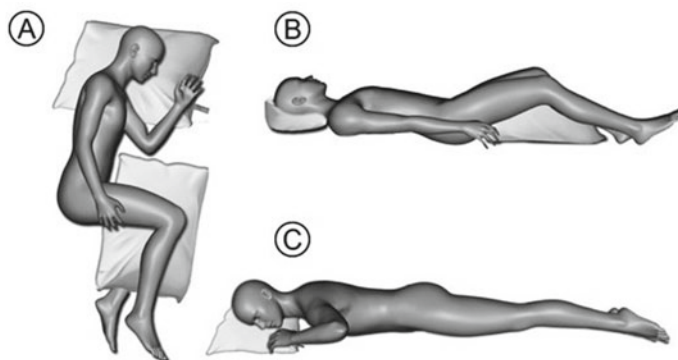


Fig. 2 Principal postural behaviors during the sleep [25]

These positions have been indicated in order to keep a good balance and alignment of the spine and distribute the body's weight over the entire surface of the mattress [11, 19, 22, 47].

According to the indications of authors such as [19, 22, 45], individuals in the experimental group were instructed to change their initial sleeping position according to the pathological problems or the amount of pain reported and use a pillow in mixed position. Figure 2 shows the two types of recommendations and, those who complained of dorsal or low back pain, were nominated for the posture "A" and those who possessed cervical complaints were oriented for posture "B". Those who possessed the habit of sleeping in Prone Position (Posture "C") were instructed to assume the position "A" or "B" (Fig. 2).

These indications will be held every day for the duration of this study, which provided a continuous reinforcement of the method through informal contact via email and mobile phone for any questions and issues.

2.2.2 Placebo Group (PG)

To prove the reliability of the method, an intervention will be performed considering a second experimental group that receives and perform the technique of progressive muscle relaxation Jacobson [27, 28, 46]. These details will also be held every day for the duration of the study. This relaxation technique was considered Placebo because the participants were informed that this intervention was shown for the relief of back pain. However, little or nothing is mentioned in the literature regarding the effectiveness of the technique of progressive muscle relaxation approach recommendations for aspects such as back pain or improve quality of life [6, 35, 46].

2.2.3 Control Group (CG)

With the third group will be held only a moment's interview with an indication of future surveys, subsequently appointed Group III Control.

2.3 Procedures

At the 1st phase, in the first week, some questionnaires were carried out: (a) the questionnaires of personal identification; (b) measurement of level of pain and quality of life at the moment of the response to the questionnaire; and (c) an informal questionnaire for the sleeping position.

In the second week, all 24 participants have been filmed during 3 consecutive days, with only two best days to capture images to verify the initial postural behaviour of all participants during sleep period was analysed.

After this initial analysis, at the 2nd phase, the individuals were separated into 3 groups chosen randomly: (i) Experimental Group (EG); (ii) Placebo Group (PG) and; (iii) Control Group (CG).

In the 1st month, the individuals selected for the EG and PG were given the recommendations and indications. The individuals selected for the CG were given an interview with the indication to maintain the same habitual posture and future questionnaires.

In the 2nd month, the participants of EG and PG groups were contacted to ask if the signs were being applied, whether there were any doubts about the recommendations and for reinforcing these indications.

At the end of the 3rd month, all subjects (EG, PG, CG) were re-filmed to analyse whether recommended changes were implemented.

Qualitative research produces large amounts of textual data in the form of transcripts. High quality analysis of qualitative research can produce vast amounts of data [36]. According to Sterne et al. [42], the smaller a study the larger the treatment effect necessary for the results to be significant.

All data were coded and computerized with quantitative statistical analysis performed with the Statistical Package for the Social Sciences (SPSS) program, version 24.0. The SHAPIRO WILK normality test was performed, where the result was $p > 0.05$ in the analysis of postures, QOL and SQ and $p \leq 0.05$ in the analysis of BP. One-Way ANOVA was used for the analysis of postures, QOL and SQ for parametric statistics (analysis of variance for different groups at different times). For the analysis of BP, the Mann-Whitney U test was used, setting the significance level at $p \leq 0.05$.

3 Results

At the first step of this study, we analyze whether there is any relationship between male sample from air force military and female sample of undergraduate students [8].

The first results showed no significant difference ($p = 0.119$) between the postures used during the sleep period ($n = 6960$ posture observations) between the two groups of participants (military men and women students) within the same age group (18–25 years old).

These data are consistent with those studies that indicate no significant differences between male and female when compared during the sleep period [17].

This balance data between military male and female students allows unifying the sample of 24 young adults (mean age = 20.96 ± 1.899).

The analysis of differences between the three groups (EG, PG and CG) in relation to the chronic back pain levels according Visual Analogue Scale (VAS) showed no differences ($p = 0.990$) at baseline. The second phase, after the period of postural intervention, the results showed significant differences ($p = 0.008$) between the three separate groups randomly.

The analysis of differences in relation to sleep quality indices showed no differences ($p = 0.152$) between the groups at baseline. The second phase, the results showed significant differences ($p = 0.003$) between groups.

The analysis of differences in relation to quality of life indices showed no differences ($p = 0.927$) between groups at baseline. The second phase, the results showed significant differences ($p = 0.000$) between groups.

3.1 Postural Behavior

In the first phase, the data of sleeping position presented higher incidence of supine, and this is the most common postural behavior during sleep with 25.9% ($n = 2754$), followed by the prone posture with 25.7% ($n = 2729$), left lateral position with 24.6% ($n = 2619$) and right lateral position with 20.8% ($n = 2212$). The other types of posture observation (mixed or at movement) in these analyses have 2.9% ($n = 317$).

The first analysis concerns the posture while sleeping, where the CG ($n = 4640$) presented higher incidence of prone position in the first phase and in the second phase ($n = 1041$, 32.1% and $n = 1041$, 32.2%, respectively) and presented no significant difference ($p = 0.488$) between the 1st and 2nd phases. The specific ergonomic position most used in this prone position is described in Table 1.

In the PG ($n = 4640$) presented significant difference ($p = 0.009$) between the 1st and 2nd phases. The data of sleeping position presented higher incidence of supine, and this as the most common postural behavior during sleep in the 1st phase with 30.2% ($n = 1129$), 2nd phase was 3rd with 24.4%, $n = 889$), followed by the prone

Table 1 Comparison of sleeping positions between groups *at each phase*

Group	Category	1st image pickup period			2nd image pickup period		
		N. events	Percentage	Order	N. events	Percentage	Order
Experimental	Sleeping in prone position using under head cushion, rotating head, rotating trunk, left shoulder shoulder upper limb (UL), right shoulder shoulder flexion, left knee flexion and right knee neutral	116	2.93	1st	Without registration		
	Sleeping in left lateral decubitus using mixed position cushions, head flexion, trunk in neutral position, upper limbs below shoulder line, loaded left flexion and right flexion lower limb (LL)	Without registration			369	8.44	1st
Placebo	Sleeping in left lateral decubitus using cushion under head, flexing head, semi-broken trunk, UL below shoulder line, loaded left flexed LL and right flexed LL	274	6.67	1st	260	6.46	2nd
	Sleeping in right lateral decubitus using cushion under head, flexing head, semi-inflected trunk, UL below shoulder line, flexed left LL, and loaded flexed right LL	250	6.09	2nd	464	11.53	1st
Control	Sleeping in right lateral decubitus using cushion under head, flexing head, semi-inflected trunk, UL below shoulder line, flexed left LL, and loaded flexed right LL	152	4.05	1st	279	7.38	1st

posture with 26% ($n = 974$) in the 1st phase and it was the higher incidence in the 2nd phase with 30.1% ($n = 1097$). The specific ergonomic position most used in this group is described in Table 1.

The analysis concerns the posture while sleeping in the EG ($n = 4640$) presented significant difference ($p = 0.000$) between the 1st and 2nd phases, as described in Table 1.

The data of sleeping position in the EG presented higher incidence of left lateral decubitus, and this is the most common postural behavior during sleep in both phases with 30.1% ($n = 1100$) and 36.2% ($n = 1458$), respectively.

The comparative analysis of the postural behaviors during the sleep period among groups at each stage is shown in Table 1.

3.2 Back Pain

A global analysis of the VAS questionnaire showed a prevalence of self-perceived of back pain as being MODERATE with a level $4.29 (\pm 1.443)$. The EG presented a significant reduction of the mean pain to the degree 2.25 ± 1.483 , $Z = -3.095$ ($p = 0.002$).

The PG presented a slight increase in the mean of pain, now situated the level of pain in the degree 4.50 ± 2.608 , and there was no significant difference between the study phase, $Z = -0.344$ ($p = 0.731$).

In the CG, this 2nd period showed a slight decrease in the pain level, now located in the degree 3.81 ± 1.682 , but with no significant difference between the study phases, $Z = -0.247$ ($p = 0.805$). These data are represented Fig. 3.

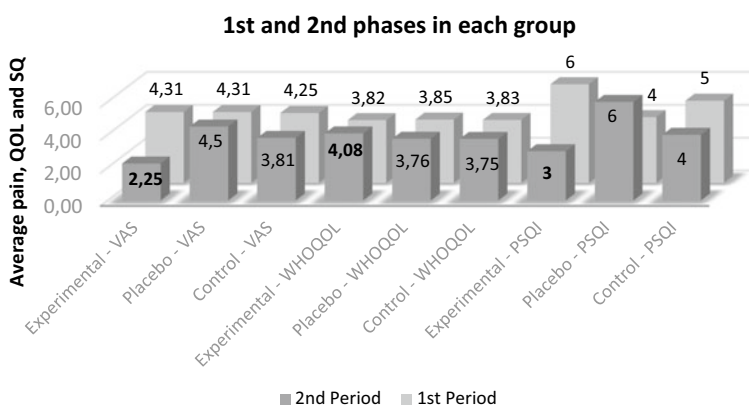


Fig. 3 Comparison between the 1st and the 2nd phases for average pain according to VAS, for SQ level according to PSQI and for QOL according to WHOQOL-Bref questionnaire in each group

3.3 Sleep Quality

A global analysis of the sleep quality (SQ) questionnaire showed a prevalence of self-perceived sleep quality as being BAD with 6 points, on the first image capture. The EG showed in the 1st period in the set of values, a total of 6 points, which means a bad quality sleep. When the values reported in the 2nd Period, his was an improvement over the 1st period, total 3 values, which is a good quality sleep at the end of the study and a significant difference between the phases ($p = 0.008$).

The PG showed that at baseline (1st period), participants showed a good quality of sleep (4 values), but these data changed to decreased quality of sleep, standing in the 2nd period on 6 values, which is a poor-quality sleep, this group presented an inversely significant difference ($p = 0.018$), as this difference is a worsening in sleep quality.

The CG has a reference good sleep quality in the 2 periods (5 and 4 points, respectively 1st and 2nd period) but no significant difference between the phases ($p = 0.273$). These data are represented Fig. 3.

3.4 Quality of Life

A global analysis of the QOL questionnaire responses showed a prevalence of self-perceived as being REGULAR with 67.5% (mean = 3.83 ± 0.771).

The EG showed in the 1st phase 76.4% (mean = 3.82 ± 0.771) with the level of QOL as being REGULAR. The result of the 2nd phase showed a higher incidence of levels of QOL with 81.6% (mean = 4.08 ± 0.669), which represents a GOOD quality of life ($p = 0.000$).

The PG showed a lower incidence rate of QOL in the 2nd phase (75.2%, mean = 3.76 ± 0.791) compared with the 1st phase (77%, mean = 3.85 ± 0.752), with the level of QOL as being REGULAR in the both phases ($p = 0.281$).

The CG, showed a lower incidence rate of QOL in the 2nd phase (75%, mean = 3.75 ± 0.875) compared with the 1st phase (76.6%, mean = 3.83 ± 0.792), with the level of QOL as being REGULAR ($p = 0.379$). The analysis comparing the QOL indices among groups at each stage is shown in Fig. 3.

These final indications were used to start the following discussion, according to the main objectives of this study.

4 Discussion

The main advantage of sleeping in a supine position, according to [22], is the fact that body weight is distributed over a large surface, resulting in optimal stability. Most authors suggest that a neutral position of the spine is optimal for spinal health, some others suggest a supine position [18].

These data allow us to fill in some references in the literature that observe static posture through pictographic images [22, 39, 47] or by analyzing pressure mattresses [25, 47], or simply by subjective indications through questionnaires [9], which do not allow an analyzing the global behavior during the sleep period in a real environment, but simulated structures in the laboratory, which do not represent the real postural condition in a systemic and ecological perspective.

Another important aspect to be examined is the reference to the QOL index, where the results according to the WHOQOL-Brief questionnaire allowed us to verify a REGULAR QOL index in the 1st period of the study.

So far, no studies have been found that refer to the relationship between postural behavior during the sleep period and the indications of the QOL index in young adults that would allow a direct comparison between the results found in the present thesis and the results found in similar studies.

The relationship between postural behavior during the sleep period and the sleep quality index according to the PSQI assessment instrument allowed us to verify in.

Group I Experimental an improvement in sleep quality indicators, with a reference of good sleep quality at the end of the study ($p = 0.013$), compared to Poor sleep quality referenced at sleep onset.

There are many factors evaluated in the quality of sleep, but when compared with the appearance of pain, namely in the spinal region, it is possible to verify a direct relationship between these two factors, as indicated in some studies [26, 27], but few studies refer to the postures adopted during the sleep period as a factor of direct influence on the sleep quality index [10, 22, 32].

The data referring to the classification of pain according to the VAS, the quality of life index according to the WHOQOL-Brief and the sleep quality index according to the PSQI allow us to define a direct relationship between the method of postural intervention in the postural behavior performed during the period of sleep and its influence on indicators of pain in the spinal region, quality of life and sleep quality [9, 11, 12].

This data can be associated to the increase of the musculoskeletal problems, which can be found among young adults when these remain in bad postures for long periods of time in bed.

5 Conclusions

The results could prove the mean of the study, in which we wanted to check if there is any influence on the level of pain, indices of quality of life and indices of sleep quality in young adults during daily activity, when performed a program of physiotherapy recommendation using postural behaviors during sleep in the residences' bedrooms, according to ecological and environmental approach.

The main result of this study can be seen in the group receiving physiotherapy recommendation (Experimental group) compared to the group that received the indicating relaxation technique (Placebo group) and the group that did not receive any indication (Control group).

This data is essential for health care professionals, in particular the rehabilitation professionals, who can use this information to improve the quality of life and sleep quality indices and on musculoskeletal conditions and obtain tools to measure postural behavior. However, the researcher defines the observation categories in iSEE software methodology, called categories of interactions, and the software to quantify them. This software is essential to analyze the data. Without it, it would be necessary to directly observe the video with notes on paper or a computer record of every change without the application of categories for the purpose and with a loss of important information.

Acknowledgements (1) The authors would like to thank the Portuguese Air Force and in particular its Air Base n.5 and the Portuguese Polytechnic Institute of Leiria. (2) The authors want to thank Ana Parreira for their excellent contribution to the article literature review.

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PostureMind—Postural Education in Back Pain and Postural Habits of Children and Teenagers



Gustavo Desouzart and Ernesto Filgueiras

Abstract Is there a common agent between postural behavior, flexibility and back pain (BP), when a posture intervention during the school period is adopted? Many postural problems begin in the period of growth and body development. The objective of this study is to verify if postural education can mean improvements in BP indices and postural habits in children and teenagers. **Materials and methods:** The postural education program was applied to the 2nd cycle students in Portugal schools, aged between 9 and 16 years old. 268 students were divided into 3 groups (Experimental [EG], Experimental with reinforcement [ErG] and control [CG]). The intervention through cognitive-motor teaching lasted 15 min, twice a week for 12 weeks with pre-test (T0) and post-test (T1). The ErG relied on the reinforcement of teachers during the school period. **Results:** The EG presented significantly ($p = 0.015$) fewer complaints of BP and increasing the number of subjects with the ideal posture ($p = 0.041$). The ErG had greater BP reduction ($p = 0.003$) and greater increase in the number of subjects with the ideal posture ($p = 0.006$). **Conclusion:** This study allows us to suggest to health care professionals, in particular the rehabilitation professionals, new strategies for ergonomic postural behavior in school environment.

Keywords Back pain · Posture · Physiotherapy intervention · Cognitive-motor teaching

1 Introduction

Is there a common agent between postural behavior, flexibility and back pain, when a posture intervention during the school period is adopted?

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It is found in literature a shortage of studies that relate the influence of the concepts covered in this study, in a systemic and ecological perspective.

Many postural problems begin in the period of growth and body development, coinciding with the phase in which children attend school. Among these problems, there are pains in the back region, changes in the morphology of the spine resulting from the inadequate use of body mechanics in activities of daily living as well as the transportation of school supplies, namely school backpack [21].

The great transformation of the child's posture occurs between 7 and 14 years, in order to reach a balance compatible with the new body proportions, as this period is marked by rapid bone and muscle growth, where several physical changes occur generating musculoskeletal imbalances [5, 6, 16].

However, not only does postural transformation occur due to body development, but also among associated risk factors, which potentiate pain and postural problems due to the use of inadequate school supplies, inadequate standing, sitting and lying postures, and consequently to body posture adopted in certain activities of daily living [19].

The fact that they remain seated in the same position evidences an excessive study workload, adopting bad positioning habits that can trigger various types of postural changes, leading to modifications of its structural forms and marked misalignment, causing back pain and adjacent anatomical regions [5].

Given this situation, early diagnosis increases the chances of an efficient intervention, especially in children, where the musculoskeletal system is most compliant [12].

It is important for young people to have early postural awareness in an attempt to potentiate proper postures [14, 20] to prevent the occurrence of pain or discomfort characteristic of school age postural disorders [6].

According to many authors and to the American College of Physicians and American Pain Society, one of the recommendations made to patients complaining of back pain is the cognitive behavioral therapy [13, 22] such as postural intervention [3, 9].

Thus, the postural intervention has a great contribution in the school environment promoting postural education, body awareness, and guidance in favor of health in order to enhance the proper postures, and the intervention performed in childhood brings benefits to the health of the individual in adulthood [1, 2].

From this basic concept was defined the study problem where we aim to verify this relationship and examine whether, in different environmental and personal contexts (children from the interior and coastal region in Portugal), we get the same type of postural behavior during school period and if this postural behavior can change with the guidance and training of new postural behaviors recommended by the reference literature.

To this end, it is intended to identify the main postural changes present in children of the 2nd cycle of basic education, aged between 9 and 16 years, to analyze reality and guide the development of interventions at the level of education, so that there is a change in postural habits.

This knowledge allows to: (a) understand the possible changes of indices of back pain referred by participants in the day-by-day activities; and, (b) elaborate more specific recommendations to the changes in postural behaviors.

The research questions were:

1. Is there a common agent between postural behavior, flexibility and back pain?
2. Can postural education mean a decrease in the rates of BP complaints and improvements in postural habits in children and adolescents during the school period?

2 Materials and Methods

2.1 Design

This is an experimental study, with pre and posttest evaluation, through the method of direct observation through image, evaluation of BP complaints and postural habits. This study started on the 01st of March and finished on the 31st of July 2019.

For the collection of data we used an elaborate questionnaire containing posture habits, information on health problems and sociodemographic data of the participants and the image capture of the static posture and that will be done in two parts. According to the measurement instrument, this form was applied individually.

This study has taken one month from participant selection process, personal identification questionnaire fill, which included:

Sociodemographic Questionnaire: This questionnaire contained 7 questions, with the following parameters: the year of schooling, date of birth, gender, weight and height; the occurrence, intensity and location of musculoskeletal pain assessment according to Body discomfort questionnaire [4] in order to verify and categorize the pain felt (where 0 corresponded to no pain and 5 to the full amount of pain felt by the subject), and its duration (acute pain—under one month, subacute—from 1 to 3 months, and finally, chronic pain—over a 3 month period) and; **Postural habits assessment questionnaire (PHAQ)** constituted by 13 questions, with lines, through which the postural habits of the students are evaluated. The original questionnaire was written by [18], and was validated for the Portuguese population by [7],

Photographic images: Image collection in the static standing posture in posterior and lateral position (Fig. 1) and, sitting in lateral position (Fig. 2), with posterior postural analysis through the images of the students performed by two specialists, one in the area of Physiotherapy and another in the area of Human kinetics (later called experts) and compared with the participants' self-perceived posture response.

An authorization request was made to the representative elements of the school group concerned with the study, where all the steps of the intervention were explained, so that it can be performed through a questionnaire, as well as the intervention in postural education in the school context.

An authorized by the participants and their guardians, taking into account their age, through a consent form and all procedures in this project is in line with national and international guidelines for scientific research involving human subjects, and including the Declaration of Helsinki in 2013 on Ethical Principles for Medical

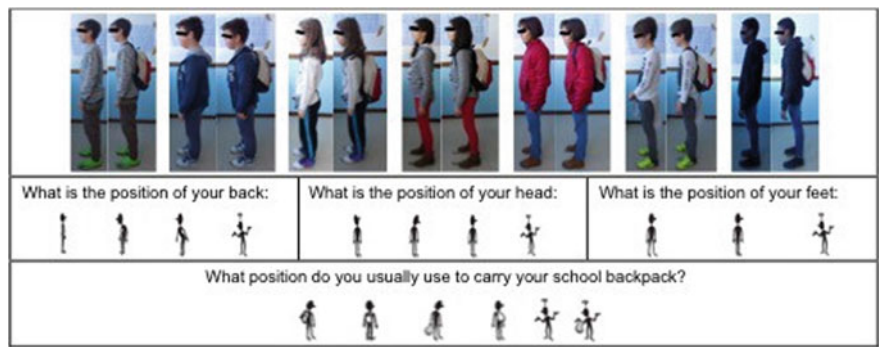


Fig. 1 Comparison between the real image and the self-perception of standing posture by the participants through PHAQ

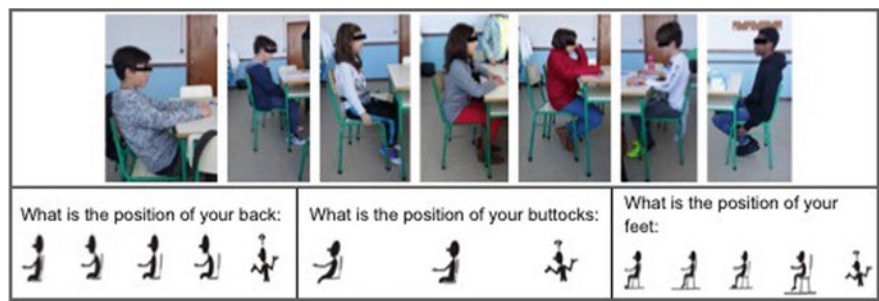


Fig. 2 Comparison between the real image and the self-perception of sitting posture by the participants through PHAQ

Research Involving Human Subjects, and the 1997 Convention on Human Rights and Biomedicine (the “Oviedo Convention”).

This study was submitted and approved by the Australian New Zealand Clinical Trials International Ethics Committee (ANZCTR) under number ACTRN12618000720213.

2.2 Procedures

2.2.1 Participants

The sample of this study was made up of students attending the Viseu (children from the interior region in Portugal) and Leiria Schools (children from the coastal region in Portugal), the 2nd cycle of basic education, namely the 5th and 6th years of schooling, between 9 and 15 years old, of both gender.

In the scope of this research, the sampling plan is of the non-probabilistic type and convenience. The sample was selected according to the following inclusion criteria: age between 9 and 15 years old; to be students of the 2nd cycle of basic education of schools in Viseu and Leiria; participate voluntarily in the study; perform walk.

As exclusion criteria, the following were outlined: students with surgical procedure; with intellectual developmental difficulties; in the process of physical rehabilitation.

2.2.2 Intervention

After initial evaluation, the participants were randomly assigned and for convenience in three groups, one control and two experimental. The control group (CG) served as a comparison model and did not participate in the exercise plan while the experimental group (EG) performed an exercise protocol through postural education and while the Experimental with reinforcement group (ErG) performed the same exercise protocol with the reinforcement of teachers' day-to-day school.

The duration of the intervention with the EG and ErG was twelve consecutive weeks.

In the first phase, some questionnaires were carried out and the EG and ErG subjects were randomly selected.

From the 2nd month, on the 2nd phase, the individuals selected for the EG and ErG were given the recommendations and indications of the ideal sit, standing, sleeping position, as well as the ideal quantity, height and place for the positioning of the pillow when sleeping, as well as the postures of using the backpack and lifting and carrying cargo.

According to the indications of authors such as [8] and [17, 18], individuals in the experimental group were instructed to perform the Back School program postural training method. This program includes the following aspects [1]:

- (a) basic notions of spine anatomy and physiology;
- (b) epidemiology and factors causing low back pain;
- (c) information on how to reduce the intensity and frequency of back pain with modification of posture in activities of daily living;
- (d) the value of exercises to maintain a healthy spine
- (e) postural training used in the prevention and treatment of patients with spinal musculoskeletal pain, composed of theoretical and educational information, containing therapeutic exercises for the spine, ideal sitting, standing, lying, carrying a backpack and weight.

For the EG and ErG to adopt new patterns of postural behavior while school period, 12 weeks of adaptation were given.

At the end of the 12th week, In the 3rd phase, a reassessment was performed where the data will be compared before (T0) and after the intervention (T1), thus verifying its effectiveness.

2.2.3 Outcome Measures

Primary outcome: In the first phase, some questionnaires were carried out and the EG, ErG and CG subjects were randomly selected.

Secondary outcome: On the 2nd phase, the individuals selected for the EG and ErG were given the recommendations and indications of the ideal sit, standing, sleeping position, as well as the ideal quantity, height and place for the positioning of the pillow when sleeping, as well as the postures of using the backpack and lifting and carrying cargo.

Tertiary outcome: At the end of the 12th week, In the 3rd phase, a reassessment was performed where the data will be compared before (T0) and after the intervention (T1), thus verifying its effectiveness.

2.2.4 Data Analysis

Data were analysed using a statistical analysis program Statistical Package for the Social Sciences (SPSS), version 25.0. The Kolmogorov-Smirnov normality test was used to define the analysis of the variables by both groups and consequently their distribution using the non-parametric test (Mann-Whitney U test) were used (comparing the same group at different times), setting the level of significance at $p \leq 0.05$.

3 Results

Dating from March 2019, there were 29,782 students enrolled in the school in Viseu and Leiria, 1532 of which attending the 2nd Basic Education Cycle, of whom 730 were in the 5th and 6th grade.

A sample of 268 elementary school students (mean age = 12.21 ± 2.023 years old) participated in this study, 52.2% male and 47.8% female, 47.8% ($n = 128$) in the 5th grade and 52.2% ($n = 140$) in the 6th grade, with Body Mass Index (BMI) 19.29 ± 3.399 .

Through the evaluation of the images of the students, the results of the observation of the real image were compared in the lateral and posterior view of the sitting and standing positions and was compared with the responses of the postural self-perception performed through the PHAQ performed by the students and, thus, it is demonstrated that there were no statistically significant differences [7].

As there were no differences between the results of the image analysis and posture indicated by the participants, all postural analyzes will be performed through the questionnaire PHAQ.

By the real image of the standing posture in the lateral position with and without backpack with 10% of body weight (According to the recommendation of the World

Table 1 Mann-Whitney U-test, comparative analysis of ideal and inadequate posture

	Ideal posture	Inadequate posture	<i>p</i>
Musculoskeletal pain	1.40 ± 1.291	1.58 ± 1.233	0.308
Frequency of pain	1.62 ± 1.439	1.84 ± 1.323	0.004

Health Organization [15]), through direct observation, there was a change in posture in this standing position in 100% participants. This change can be seen in Fig. 1 comparing the image with and without a backpack.

After this first analysis, the participants were randomly separated into 3 groups (Experimental [GE], Experimental reinforcement [GEr] and control [GC]) according to the class they belonged to, with no statistical differences between the groups regarding ideal posture ($p = 0.642$), the amount of reported pain ($p = 0.187$).

3.1 Research Question 1

In the beginning (T0), 70.9% of the participants presented musculoskeletal pain, with the highest incidence in the back, with 73.1% of the complaints, followed by headaches with 15.8%, lower limbs with 6.9% and upper limbs with 4.3%. Regarding pain complaints, 49.3% of participants indicate that pain is in 2 places and 25% indicate that pain is in 3 or more places in the body.

The average pain reported by participants was 2.19 ± 0.901 , with 74.9% of participants indicating that this pain is chronic with an average weekly pain frequency of 2.31 ± 1.381 and they felt more when they were sitting (41.2%), standing or walking (22.9%) or carrying a backpack (13%).

Regarding Posture, 78.8% of participants had an inadequate posture, and those who had an inadequate posture had a higher average pain and a higher frequency of pain (1.58 and 1.84 respectively) than those who had an ideal posture (1.40 and 1.62 respectively), which did not represent statistical difference in relation to the amount of pain ($p = 0.308$) but that represented difference in the frequency of pain ($p = 0.004$) (Table 1).

3.2 Research Question 2

In the 1st phase of the study, regarding musculoskeletal pain reported by the participants, the EG obtained an average pain of 2.27 ± 0.924 , the GEr of 2.29 ± 0.901 and the CG of 2.04 ± 0.867 .

Regarding flexibility, the EG showed an average of 72.06 ± 11.692 cm, the GEr an average of 75.41 ± 10.928 cm and the CG an average of 71.34 ± 13.189 cm. When the ideal posture of the participants was analysed, the EG presented 26% of

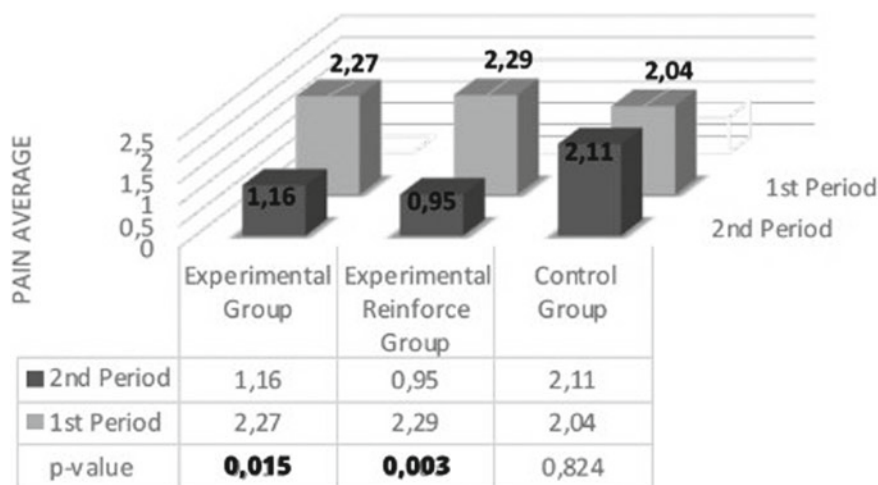


Fig. 3 Pain average in the 1st and 2nd period of evaluation

the participants with an ideal posture (mean pain 2.25), the GER presented 22.1% of the participants (mean pain 2.33) and the CG 20.2% of participants (mean pain 2.08).

After 12 weeks of postural intervention, the EG showed significantly ($p = 0.015$) fewer complaints of musculoskeletal pain with an average of 1.16 ± 1.204 , the GER also showed a decrease in pain, with a more pronounced decline to 0.95 ± 1.134 ($p = 0.003$) and the CG showed a slight increase in the pain reference, with an average of 2.11 ± 0.866 ($p = 0.824$), but without statistical difference (Fig. 3).

Regarding ideal postures, the EG increased the number of subjects with an ideal posture to 41.6% ($p = 0.041$) and an average pain of 0.81 ± 1.148 after postural education, the GER obtained a greater increase in the number of subjects with the ideal posture for 42.9% ($p = 0.006$) and average pain of 0.85 ± 1.064 after postural education with reinforcement from teachers and guardians and the CG showed a decrease in the number of subjects with the ideal posture to 15.8% ($p = 0.391$) and mean pain 2.03 ± 0.874 (Fig. 4).

4 Discussion

The indications provided to the participants were related to having a recommended posture in the school period, taking into account the loads and forces that influence the human body at all moments in life.

The application of the study had some significant results, in the experimental and experimental reinforcement group, in the references of pain intensity in different body regions and in the ideal posture before and after the application of educational

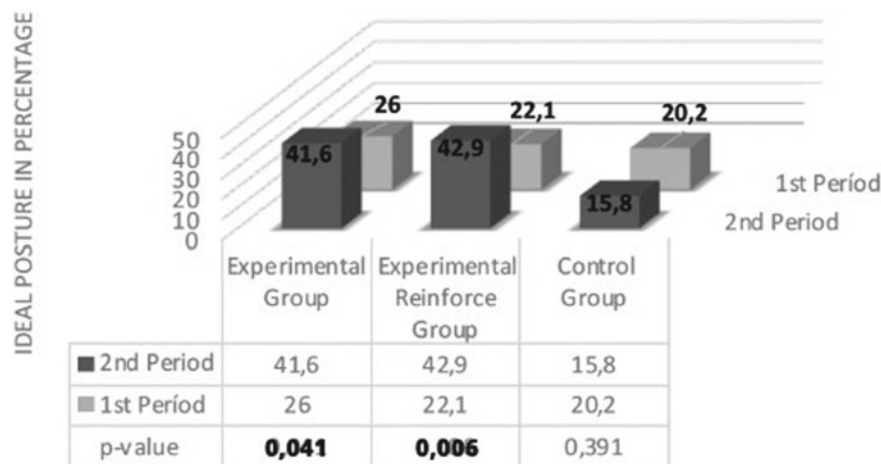


Fig. 4 Ideal posture in percentage in the 1st and 2nd period of evaluation

interventions. Regarding flexibility, there were improvements from the 1st to the 2nd Phase, but they were not significant.

These positive results were similar to those presented by other studies, for example, [10, 11] and [18], observed a decrease in the prevalence of back pain among students who participated in the Backschool program.

One of the contributing factors to this difference in results was the fact that the program developed by these authors was applied by the students' teachers, who in other classes could reinforce the idea for adopting more ideal postures.

Another aspect to be taken into account and which was not analysed and worked on in this study was the fact that the furniture is not suitable for the children's anthropometric measurements. The observation of chair-table sets in the school studied showed tables and low chairs, which could cause pain in different body regions, thus leading to the adoption of inappropriate postures, and consequently shortening the posterior chain, thus decreasing flexibility.

The strategy proved to be effective in the sense of teaching and monitoring the concepts of postural habits.

4.1 Limitations

It should be noted that there were some limitations that emerged during the study, such as the fact that the sample had a large number of participants, which made data collection difficult, since it was a school population that we needed to meet with the educational institution in the collection of data, since it was not possible to "interrupt the school in some way".

Finally, it is worth mentioning that the time factor was a restriction for the entire study, which did not allow us to expand our data collection in other districts.

In future studies, the application of the questionnaire to assessment posture habits in a sample that covers more schools in different districts of the country, as the intervention according to postural education can integrate the school context of all districts, of all study cycles.

5 Conclusions

The goal of Physiotherapy in child health is to help children reach their maximum potential for functional independence through analysis, evaluation, promotion of health and well-being and through the implementation of a wide variety of interventions and supports.

The results presented are in line with the objective of the study, where there is a relationship between the indication of musculoskeletal pain and postural habits in children and adolescents of the 2nd cycle of basic education and if there are changes in these factors when a postural intervention occurs.

These results point to a prevalence of moderate/severe pain in subjects with inadequate postural habits, with a significant reduction in this prevalence of pain after a postural intervention and an increase in subjects with ideal postures.

We can conclude that the intervention of Physiotherapy in children and adolescents with postural changes is an asset in terms of maintaining an ideal posture, as well as in reducing complaints of musculoskeletal pain.

There is the proposal to continue the study in a more comprehensive way and to awaken this theme for future studies, on the postural habits of school-age children and adolescents.

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Comparison Between Anthropometric Equipment and Scanners in Hand Measurement



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Abstract Anthropometric studies have influenced the design of apparel, accessories, medical prostheses, equipment, workstations, and tools. Particularly, hand anthropometry is related to safety and adequacy of hand tools and devices. Different equipment and methods can be used to obtain body measurements with different precision and reliability levels. However, precision and reliability are not the only aspects to be considered. The present study aims to evaluate the agreement of four different

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pieces of equipment for anthropometric measurement of the hand, namely, anthropometer, anthropometric tape, 2D scanner, and 3D scanner. These measurement methods were compared in terms of required time, precision, complexity, and cost, for the case of two-dimensional hand measurements. Data was collected on hand length and breadth from 25 workers in North Portugal. Among the main findings, we can highlight a relatively low accuracy and higher measurement times for 2D and 3D scanners due to scanning, processing, digitalization, and calibration steps. Traditional direct measurement methods were considered the most appropriate to obtain hand length and breadth measures, as they required less time and were more accurate, less costly and complex than 2D and 3D scanner methods. These results emphasize the caution required when selecting anthropometric methods.

Keywords Physical ergonomics · Anthropometry · Upper limb · Measuring methods

1 Introduction

Anthropometric studies influence the design of apparel, accessories, medical prostheses, equipment, workstations, and tools. They have been applied to the prevention of occupational injuries at workplaces and to ethnical and gender comparisons across populations, for instance. As in most areas of modern life, anthropometric and ergonomic studies have experienced the effects of technological development. Among the methods used to measure body-related parts, one can cite 1D methods (i.e., Direct Manual measurements), 2D and 3D methods [10]. However, some studies have shown that different anthropometric measurement methods can have significantly different results (e.g., [4, 5, 12, 19]). On the other hand, some studies have demonstrated a high agreement across methods (e.g., [6, 26, 34, 35]).

In a systematic literature review performed by [36], the authors concluded that 3D scanners were more accurate than other methods in approximately 60% of the studies. Among the advantages of 3D scanners, the authors highlighted the reproducibility, reliability, and accuracy of collected data. Also, [16] when collecting measures of 473 children and adolescents underscored the high reliability of 3D scanners for some measures (e.g., waist and hip circumference), and its low performance for others, such as head circumference. Focused on hand anthropometric data collection for custom-made gloves, [45] compared the accuracy of tape and caliper measurement, 2D and 3D image analysis based on 33 hand dimensions. The authors concluded that there was no significant difference between the 3D image analysis and the manual measurement. This study focus on hand anthropometry since it has been used in different design applications, such as hand tools, gloves, hand-held devices, and machine access spaces [21]. Moreover, it can have serious implications for safety aspects and the adequacy of tools [15, 18]. These reasons have motivated many studies to have hand anthropometry as their main target. Examples include [41] doctorate thesis, which evaluated forty dimensions related to the hands of 150 residents of

North Portugal, and [33] who investigated the effects of wearing different gloves on strength and concluded that wearing gloves significantly affected the maximum grip strength. Other studies include those of [13, 28], and [31].

From this background and considering the dominance of studies focused on the precision and reliability of methods, the present study aims to compare four anthropometric hand measurement methods, namely anthropometer, measuring tape, 2D scanner, and 3D scanner, in terms of required time, precision, cost, and complexity. In practical terms, the goal of this study is to aid the selection of appropriate measurement methods for the specific case of two-dimensional hand measurements. Accordingly, the two dimensions considered were the hand length (HL) and the hand breadth metacarpals (HB) due to their relevance for hand tool design and workers' safety [44].

2 Materials and Methods

2.1 Sample

This study consisted of collecting HL and HB dimensions from a working population (white and blue collars). Data was collected from a manufacturing company in Northern Portugal and relied on the participation of 25 employees with no deformity or disability in their hands.

2.2 Data Collection

This study considered secondary and primary anthropometric data. Secondary data was obtained from the company's anthropometric database and provided for HB and HL anthropometer measurements. The primary data collection took place from June to October 2021 and gathered measurements with the measuring tape, 2D and 3D scanners. All anthropometric data collected was stored in Microsoft Excel 2016. The data analysis process was performed using both SPSS Statistics software, version 27 (SPSS Inc., Chicago, IL, USA) and Excel 2016 (Microsoft®).

2.2.1 Hand Measurement

According to ISO 7250 [24], HL is “the distance from the tip of the middle finger, along its long axis, to a line connecting the radial and ulnar styloid processes”, while HB is “the distance between radial and ulnar metacarpals at the level of the metacarpal heads from the second to the fifth metacarpal, measured perpendicular to the long axis of the middle finger”, as illustrated in Fig. 1.

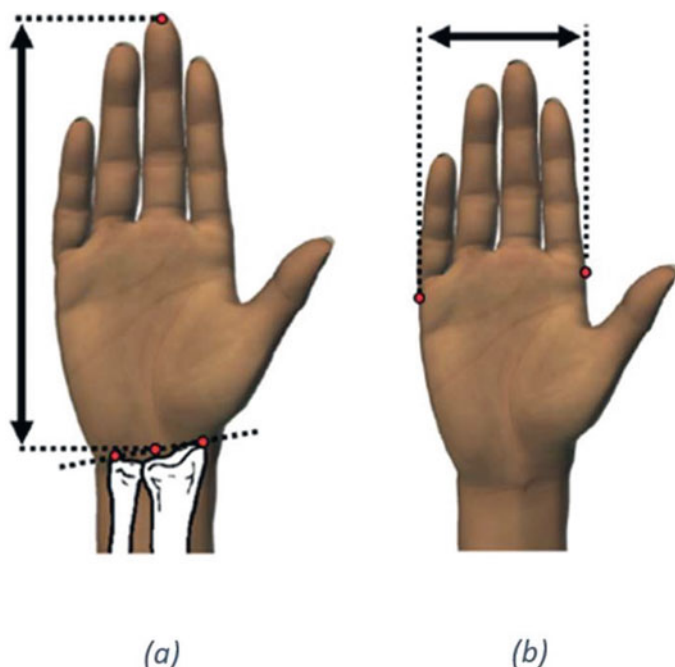


Fig. 1 **a** Hand length (HL) and **b** hand breadth metacarpals (HB). *Source* ISO 7250 [24]

During the collection of HL and HB, all ISO 7250 [24] guidelines were applied except for the body side, since the left body side had to be considered to allow comparison with the secondary data available from the company's anthropometric database. The same is true for not marking anthropometric landmarks on the hands of participants, as recommended by the International Society for the Advancement of Kinanthropometry [22].

Nonetheless, the utilization of the right or the left body side has implications for skinfold measuring and not for the length of body segments [27]. Therefore, measuring HL and HB from the left hand instead of the right has not compromised the results. Additionally, measures were taken from the palmar side given differences between palmar and dorsal hand measurements [42].

Participants had their hand dimensions measured by the equipment displayed in Fig. 2: (a) anthropometer (Holtain Ltd®, Harpenden Anthropometer, Crymych, UK), (b) anthropometric tape (Holtain Ltd®), (c) 3D Scanner (Model EVA, Artec®), (d) 2D scanner (model MFC 820 CW, Brother ®).

One evaluator with previous experience in anthropometry and ergonomics measurements took all measures. The left hand of each individual was measured only one time using all the four methods. No marks (i.e., reference points) were made in the hands of the subjects. The subjects adopted different positions according to the method used. As for the 3D scanner, subjects had to seat on an adjustable



Fig. 2 Equipment used to measure participants' hand dimensions: **a** anthropometer; **b** measuring tape; **c** 3D scanner and **d** 2D scanner

seat on top of a turntable while the evaluator held the scanner. The recommended distance to capture 3D dimensions was followed, ranging from 520 to 760mm [3]. Figure 3 shows the HL and HB of the same subject measured in the (a) 3D and (b) 2D scanners after digitalization and image processing.

2.2.2 Time Measurement

The time-related factor was assessed in relation to the time spent during the digitalization, image processing, measuring, and calibration steps. Digitalization times refer to the time that 3D and 2D scanners require to digitalize the image and are intrinsic to the equipment. As for image processing and measuring, the 3D-scanner requires a complementing software to process and measure the 3D images, the Artec Studio 15 Professional. Concerning the 2D-Scanner, the equipment itself processed the images, while the Kinovea 0.9.5 software was used to take measures. In all cases, time measurements of each step were collected using a digital chronometer.

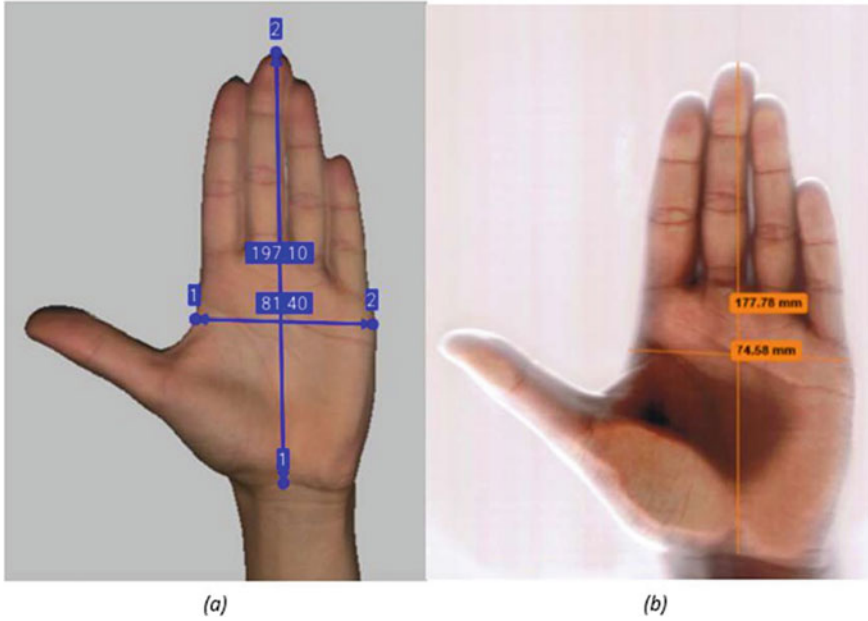


Fig. 3 Measurement process in the **a** 3D scanner and **b** 2D scanner digital images

2.3 Measurement Error and Reliability

Measurement error in anthropometry comes from different sources [17]. The first aspect is the instrumental error. The anthropometer and the anthropometric tape have an instrumental error of 0.5 mm. However, scanners can be associated to different errors. For example, the manufacturer of the 3D scanner shows that the equipment's accuracy is up to 0.1 mm and resolution is up to 0.2 mm [2]. Also, according to ISO 20685 [23], the maximum mean difference between traditional methods and 3D scanners should be 1 mm for hand dimensions. Therefore, error limits (i.e., reference values) were elevated to 2 mm for all equipment, as proposed by [17].

To determine inter-method precision, two numerical tests were used: the technical error measurement (TEM) and the mean absolute difference (MAD), as recommended by [17]. In particular, TEM is calculated using the following formula (Eq. 1):

$$TEM = \sqrt{\frac{\sum D^2}{2N}} \quad (1)$$

where $\sum D^2$ represents the differences between repeated measures (summation of the deviations raised to the second power) and N the number of volunteers measured

[1]. The lower the TEM, the better the precision [14]. In this test, the anthropometer was used as the reference equipment given its greater reliability [43].

To ease the comparison between different anthropometric measurements, the TEM is converted into a relative technical error of measurement (%TEM), which is displayed in Eq. (2).

$$\%TEM = \frac{TEM}{\bar{x}} \times 100 \quad (2)$$

There are several range definitions of TEM in the published literature that vary according to the evaluator's level of experience (e.g., [1, 14, 25]). For the purpose of this study, the range for skilful anthropometrists proposed by [30] was considered, where the acceptable maximum values of %TEM is lower than or equal to 7.5% for skinfolds and %TEM $\leq$ 1.5% for other measures.

Additionally, the MAD can describe the absolute variation in a dataset, i.e., how spread out are the values in a dataset. The MAD is especially useful to determine the variability between scan-derived and manual measurements. It is calculated using Eq. (3).

$$MAD = \frac{1}{n} \sum_{i=1}^n \left(\left| \frac{1}{r} \sum_{j=1}^r X_{ij} - \frac{1}{r} \sum_{j=1}^r Y_{ij} \right| \right) \quad (3)$$

where:

X_{ij} jth scan-derived measurement of the ith participant

Y_{ij} jth manual measurement of the ith participant

n number of participants

r number of repetitions

Next, the coefficient of reliability (R) (Eq. 4) and the interclass correlation coefficient (ICC) were calculated as measures of inter-method reliability. Values of ICC $\leq$ 0.50 represent a weak correlation, $0.50 < \text{ICC} \leq 0.75$ moderate, and ICC > 0.75 a strong reliability [32]. The anthropometer was once again the reference method for these two tests.

$$R = 1 - \left(\frac{TEM^2}{SD^2} \right) \quad (4)$$

R is dimensionless and vary from 0 to 1 so that higher values of R imply greater reliability [1, 38, 40].

Table 1 Comparing anthropometric measurement methods: HL and HB

	Equipment	Avg	SD	Min	Max	Range
HL (mm)	Anthropometer	198	10	177	218	41
	Anthropometric tape	184	10	167	208	41
	3D scanner	184	10	168	202	34
	2D scanner	168	9	150	184	34
HB (mm)	Anthropometer	93	5	83	105	22
	Anthropometric tape	88	7	80	110	30
	3D scanner	81	6	72	92	20
	2D scanner	74	5	65	85	20

Table 2 Average times required to obtain measures

Equipment	Average time				
	Digitalization	Image processing	Measure	Calibration	Total (t)
Anthropometric tape	0	0	15	0	15
Anthropometer	0	0	16	0	16
2D scanner	90	35	31*	15	171
3D scanner	120	319*	11*	55	505

*Time related to the software used in tandem with scanners: Kinovea 0.9.5 for the 2D scanner; Artec Studio 15 Professional for the 3D scanner

3 Results

3.1 Anthropometric and Time Measures

The average age of the sample was 35.20 ± 10.71 years old. The 13 males were 35.33 ± 11.46 years old, in average, while the 12 females were 35.08 ± 10.44 years old. Accordingly, Table 1 presents the HL and HB average values (Avg), standard deviation (SD), minimum (Min) and maximum (Max) values, and ranges obtained with each method. Table 2 shows the average time required to obtain measures.

3.2 Technical Variability

Table 3 shows the results obtained when comparing relative TEM (% TEM) values with the anthropometer as the reference method, considering its scientifically proven reliability and wide use [43]. It also displays MAD values comparing scan-derived and manual measurements and inter-equipment precision measures with R and ICC values.

Table 3 %TEM, MAD, R, ICC values

<i>Relative TEM (% TEM)</i>			
Equipment	% TEM (HL)	% TEM (HB)	Reference values (%) ¹
Anthropometer v. Anthropometric tape	5.39	4.981	1.5
Anthropometer v. 3D Scanner	5.23	10.35	1.5
Anthropometer v. 2D Scanner	11.51	16.41	1.5
<i>MAD</i>			
Equipment	MAD (HL) (mm)	MAD (HB) (mm)	Reference values (mm) ²
Anthropometer v. 3D Scanner	13.94	12.45	2
Anthropometric tape v. 3D Scanner	2.60	7.53	2
Anthropometer v. 2D Scanner	29.58	19.07	2
<i>R values</i>			
Equipment	R (HL)	R (HB)	Reference values
Anthropometer v. Anthropometric tape	−0.06	0.80	0 to 1
Anthropometer v. 3D Scanner	0.00	0.19	0 to 1
Anthropometer v. 2D Scanner	−3.93	−1.09	0 to 1
<i>ICC values</i>			
Anthropometric dimensions	HL	HB	
Anthropometer v. Anthropometric tape	0.665	0.762	
Anthropometer v. 2D scanner	0.294	0.176	
Anthropometer v. 3D scanner	0.677	0.397	

¹ Reference values from [30]²Reference values refer to the instrumental error associated with the anthropometer and anthropometric tape [17]

4 Discussion

4.1 Precision and Reliability Factor

As it can be seen in Table 2, the average HB and HL values obtained with the anthropometer were larger than the other methods. This is also reported by [29] when comparing a manual measurement (calliper) with 3D scanning. On the other hand, [19] found larger average values when using 3D scanning measurement. [12] when comparing ear dimensions found that 3D scanning measures provided a slightly smaller ear length and slightly larger ear width than traditional measurements.

In relation to inter-method precision, the %TEM highlights that all comparisons made to the anthropometer were above the reference values of 1.5% [30]. The precision of the 3D and 2D scanners when measuring HL were also close to the acceptable limits, while HB was largely off-limits. When comparing scan-based and manual measurements, results show a large discrepancy between all methods except for the HL in anthropometric tape v. 3D scanner, since the MAD is 2.60 mm and the reference values are 2mm [17]. For inter-method reliability, R values were not conclusive since they assumed negative values for the anthropometer v. 2D scanner and the HL in anthropometer v. anthropometric tape. However, a negative reliability can simply mean that correlations between equipment’s measures are low or weak. Sometimes, a small sample may also result into negative reliability [11]. For values within reference values, it was observed a good reliability between the anthropometer and the anthropometric tape’s HB measurements, which was confirmed by high ICC values, and a weak reliability between the anthropometer and the 3D scanner.

On the other hand, the R sample size-related issue to assess inter-method reliability could be overcome by the ICC test. The ICC showed a high reliability between the anthropometer and the anthropometric tape for HB (ICC = 0.762) and a moderate for HL (ICC = 0.665). A moderate reliability was also found between the anthropometer and the 3D scanner for HL (ICC = 0.677). Remaining comparisons displayed a weak correlation (ICC < 0.50). Results of tests applied to assess intermethod precision and reliability are summarised in Table 4 except for MAD values.

Table 4 Summary of technical variability tests

Test	HL			HB		
	Ant. tape	2D	3D	Ant. tape	2D	3D
TEM	R	NR	R	R	NR	NR
R	NR	NR	NR	R	NR	NR
ICC	Moderate	Weak	Moderate	High	Weak	Weak

R—Reliable; NR—non-reliable

4.2 Time Factor

While most anthropometric studies refer to the time required to train evaluators (e.g., [8, 9]), this study intended to compare the time required to obtain final measures. Given extra steps in the measurement process, the 3D scanner required the largest time to obtain measures ($t = 505$ s), followed by the 2D scanner ($t = 171$ s). On the other hand, the anthropometer and the anthropometric tape had similar measuring times of 16 s and 15 s, respectively.

4.3 Cost Factor

The cost factor was determined considering the purchasing price of the pieces of equipment in the European market. Particularly, the anthropometer price referred to a kit including the anthropometer, a calliper, and the measuring tape, which costed EUR3,399.00 [37]. The 3D scanner price includes the scan, the Artec Studio 15 Professional software, and a turntable, which costed EUR14,440.00 [2]. As for the 2D scanner, the model used in the data collection process was discontinued by Brother®, so the price of an equivalent equipment from the same brand was considered, namely the model DCP-J1200W Brother®, EUR124.67 [7]. The Kinovea software was operated under a free license. Prices were primarily obtained from sellers' official websites in June 2022. On the other hand, the anthropometric tape's price was estimated by searching for prices online on Amazon, EUR4.99. Even though its price is likely to vary significantly across sellers, it provides a dimension of the price scale.

As expected, the most expensive equipment was the 3D scanner. This can be explained by the relative newer technology availability. Particularly, the use of a scanner 3D can be justified when it is needed to represent volumetric human body parts and circumferences [16, 19, 26].

4.4 Complexity Factor

The complexity factor refers to how difficult it is to collect measures with each one of the pieces of equipment. For that, it was considered the time needed for the technical training related to each equipment handling and the time spent practicing the measurements until reaching accuracy (i.e., low SD). It was estimated by the evaluator that the anthropometer and the measuring tape would require less than 0.5h of training, against 1.0h for the 2D scanner and 10.0h for the 3D scanner.

4.5 Comparative Analysis

In this section, pieces of equipment are comprehensively evaluated according to all factors discussed above. Particularly, a score from 1 to 5 was attributed to each one in relation to time, cost, precision and reliability, and complexity factors, following linear intervals from minimum to maximum values, as shown in Table 5. For precision and reliability, numerical values were assigned to the qualitative results from Table 4. Since the employed scale implies that the larger the score, the worse the performance, ‘non-reliable’ values from Table 4 were computed as 1 and ‘reliable’ as 0. Also, ‘weak’ ICC values are equal to 3, ‘moderate’ to 2, and ‘high’ to 1 because 0 refers to the anthropometer. After taking the average values between HL and HB, values ranged from 0 to 5.

The proposed classification can be visually represented in a radar chart (Fig. 4). The 3D scanner was the worst performing method in the cost, time, and complexity factors. It performed better than the 2D scanner in terms of reliability and precision. The 2D scanner was in the same complexity category as the anthropometer and the measuring tape, while pertaining to the same cost category as the measuring tape. It also required more time to obtain measures than the manual traditional methods, but less than the 3D scanner. The time factor for the 2D and 3D scanner related not only to the equipment scanning itself but also to the associated software, as images had to be digitalized, processed, measured, and calibrated. The anthropometer was used as the reference of precision and reliability (score = 0), followed by the anthropometric tape, the 3D scanner, and the 2D scanner. The anthropometer and the anthropometric tape had similar measurement times ($t = \sim 15s$). It is worth underscoring the fact that obtained results refer to the particular equipment employed in the study and could vary from software to software.

The traditional measurement methods were the most accurate, less time-consuming methods, and the best suited to obtain HL and HB measures from a relatively small population size ($n = 25$). The lower cost and simplicity of conventional methods has been constantly reported in the literature, but they are not free of disadvantages (e.g., [36]). That is why 3D scanners have been suggested as suitable methods in terms of cost and accuracy depending on the application (e.g., [18, 39]).

Table 5 Classification of factors

Factors				
Score	Time (s)	Cost (€)	Precision and reliability	Complexity (h)
1	$16 \leq x \leq 114$	$4.49 \leq x \leq 2,883.59$	$0.0 \leq x \leq 1.0$	$0 \leq x \leq 2$
2	$114 < x \leq 212$	$2,883.59 < x \leq 5,762.69$	$1.0 < x \leq 2.0$	$2 < x \leq 4$
3	$212 < x \leq 310$	$5,762.69 < x \leq 8,641.79$	$2.0 < x \leq 3.0$	$4 < x \leq 6$
4	$310 < x \leq 408$	$8,641.79 < x \leq 11,520.89$	$3.0 < x \leq 4.0$	$6 < x \leq 8$
5	$408 < x \leq 506$	$11,520.89 < x \leq 14,440.00$	$4.0 < x \leq 5.0$	$8 < x \leq 10$

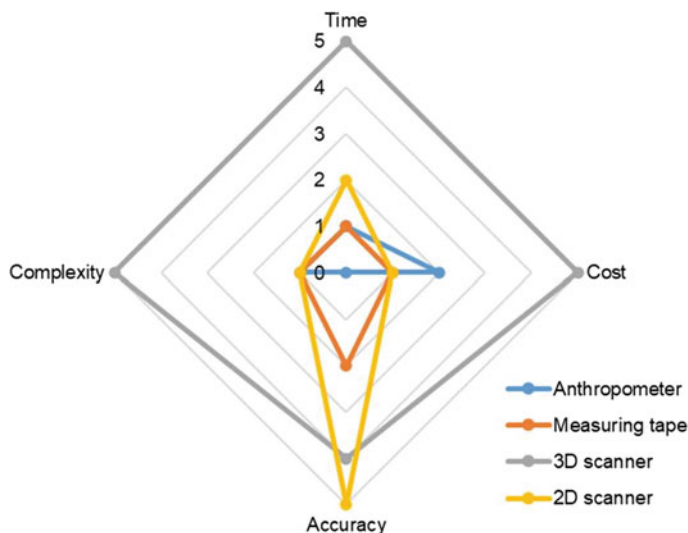


Fig. 4 Comparing anthropometric equipment in terms of time, cost, precision and reliability, and complexity

5 Conclusions

The purpose of this study was to compare different anthropometric measurement methods in terms of time, cost, precision and reliability, and complexity for the case of two-dimensional hand measures (HL and HB). Among main findings, we can highlight the relative low precision and reliability of 2D and 3D scanners and higher measurement times due to required scanning, processing, digitalization, and calibration steps. Traditional direct measurement methods were considered the most appropriate methods to obtain HL and HB measures, as they required less time, were less expensive, more precise and reliable, and less complex than 2D and 3D scanner methods. Results highlight the caution that is required when deciding to invest in more technological equipment and anthropometric methods.

Limitations include the lack of landmarks on the hands of participants [18, 34] and the use of the left hand instead of the right given secondary data availability. Moreover, the absence of light-blocking technologies when using the 2D scanner [20], the lack of control over participants' hand hyperextension and involuntary [4, 5], the absence of intra-measurer reliability calculation, and a small sample size can be pointed out as limitations of the present study. Other methods could also have been included in the comparative analysis, such as the segmometer.

Concerning a future research agenda, machine learning can be a powerful ally to treat artefacts (i.e., noise), missing data (i.e., incomplete data), and scanning errors during the digitalisation and treatment process. In addition, machine learning can help researchers conciliate data obtained from different anthropometric measurement methods. The authors have also noticed that, while there is a trend to use some

methods, there is no framework to aid the selection of anthropometric methods. Therefore, a framework to help practitioners choose the most suitable anthropometric method would be useful and save resources.

Acknowledgements This work is supported by FCT—Fundação para a Ciência e Tecnologia within the R&D Units Project Scope: UIDB/00319/2020.

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Risk Assessment Associated with Nursing Staff in an Operating Room



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Abstract Currently, nurses are daily exposed to a series of occupational risks that can result in serious consequences for their safety and health. The objective of this study was to identify the ergonomic risks associated with nursing staff assigned to the Operating Room of an hospital located in the metropolitan area of Porto, and, consequently, to suggest preventive measures to avoid the occurrence of injuries and work accidents. To this end, hazards were identified by direct observation of the activities carried out, and risks were evaluated using the most appropriate methodologies for each situation. The conclusions prove the lack of preventive measures in this workplace and the need for them to be implemented in the short term, in order to avoid harming the health of nurses and patients.

Keywords Health · Hospital · Operating room · Nurses · Safety

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1 Introduction

1.1 Background

Nurses in Portugal represent a very significant number in the universe of health professionals, with 80,238 professionals counted in 2021 [1]. This large group of nursing professionals is essential for the good performance of the healthcare system, both public and private. Due to the importance of this job, it is essential to ensure the health and well-being of nurses, whose function has a significant impact on the quality of service provided to patients.

These professionals are daily exposed to a series of occupational risks that, if not properly identified and rigorously evaluated, can result in serious safety and health consequences. The work environment where healthcare is provided reflects various types of risks: physical, chemical, biological, ergonomic, and even psychosocial risks.

In addition, nurses are subject to rotating shifts, muscle injuries, fatigue, stress, and overwork [2, 3]. The constant stressful and responsible environment, long and consecutive shifts, constant standing posture, and carrying heavy materials are other risk factors associated with this workplace [4].

Specifically, the Operating Room of a hospital is responsible for accommodating surgical operating rooms and nurses are the main actors in this scenario. This hospital sector presents various risk factors surrounding operations, infrastructure, and people, requiring a focused analysis of the tasks performed there.

A culture of workplace safety and the promotion of occupational health must be ensured and directed to all workers in order to prevent risks that may cause work accidents and occupational diseases.

1.2 Objectives

The objective of this present study is to identify hazards and evaluate risks associated with the Operating Room, focusing on ergonomic risks, as well as identifying some corrective and preventative measures to protect nurses' safety and health.

2 Materials and Methods

To gain a general understanding of the musculoskeletal disorders related to the work of nursing professionals, in the first phase, the Nordic Musculoskeletal Questionnaire, in the version translated and validated for the Portuguese population by Mesquita et al. [5], based on the original version of [6], was applied to 21 nurses in the Operating Room (Annex 1).

Table 1 Methods for risk assessment

Tasks	Risks	Method
Surgical operation	Ergonomic (working posture)	RULA
Lifting the load (surgical material)	Ergonomic (overload and lower back efforts)	NIOSH Equation and KIM
Lowering the load (surgical material)	Ergonomic (overload and lower back efforts)	KIM

The second stage focused on identifying the most common tasks performed by nurses in the Operating Room, in order to identify the sources of ergonomic risks. For each of the tasks performed, the most appropriate risk assessment method was identified for each of them (Table 1).

3 Results

The sample consisted of 21 nurses between the ages of 33 and 63, 71% being female and 29% male. This sample indicates professionals with an average of 21 years of professional experience and an average weekly schedule of 40 h. The results of the application of the Nordic Musculoskeletal Questionnaire revealed that in the last 12 months, 57% of professionals experienced pain and discomfort in the lumbar region, while 43% reported pain and discomfort in the neck, hands, and wrists. These indicators suggest the need to implement measures aimed at eliminating and/or minimizing this type of symptomatology.

3.1 Manual Handling Operations (MHO)

MHO is one of the most common activities carried out in workplaces and is consequently one of the most common causes of work-related injuries [7]. In the hospital context, according to a study, Operating Room nurses report lower back pain due to heavy lifting and transfer of materials during surgery preparation and assistance [8]. Additionally, nurses are also exposed to patient handling, however in this study only the handling of surgical material would be assessed.

Based on this, it is easy to understand the importance of risk assessment. Among the existing methods for ergonomic risk assessment of these types of tasks, the Key Indicator Method (KIM) and the NIOSH equation were chosen.

The NIOSH equation is a method for risk assessment, based on the assumption that MHO activities do not require significant energy expenditure, especially when repetitive lifting tasks are performed [9].

Fig. 1 Load weight subject to lifting



By applying the NIOSH Equation, the risk of lifting the load was evaluated. The calculations can be found in Annex 2. The weight of the load being handled is 13 kg and corresponds to the movement of orthopedic materials in the Operating Room.

The weight of the boxes depends on the type of surgery, but 13 kg were chosen as an average (Fig. 1).

To evaluate the risk, the necessary information/measurements were taken to calculate the RWL (Recommended Weight Limit). Regarding the vertical measurement, as the load can be placed on shelves at different heights, it was decided to calculate two RWLs, Figs. 2 and 3. As observed in Annex 2, the RWLs obtained were 9,671 kg to the height of 19 cm and 8,202 kg for the maximum height of 57 cm.

The second part of this method was to calculate the Lifting Index (LI) that provides an estimate of the risk involved on the task. A LI greater than 1 denotes that the task is high risk for the nurses and if it's less than 1 then there's no risk. The results on Annex 2, show a LI of 1,34 for the height of 19 cm and 1,48 for the other.

For the same task, lifting the load, and to compare the obtained results with the NIOSH equation, the KIM was, as well, used. KIM was introduced in 1996 and is a method used to study tasks such as lifting, lowering, holding, and carrying loads [10]. The assessment should be made for 8 h of work and should be based on a scoring system. Through the score, it is possible to conclude about the effects of the load on the musculoskeletal system.

The form used was done by [10] and is in Annex 3. To fill out this form, an interview was conducted with one of the auxiliary nurses responsible for this task in the Operating Room. The first image of the Annex 3 shows that the lifting column takes 2 points regarding the number of liftings per day (more than 10, but it depends on the number of surgeries). For the second step and considering Fig. 1, the load rating point has 4 points. Observing the Fig. 2, the posture takes 4 points and finally the work conditions take 0 points, because there's no drawbacks. This gives a total of 16 points.

The next step involved studying the potential risk in the task of lowering the material. For this purpose, only the KIM was used (because NIOSH Equation don't

Fig. 2 Lifting the load

evaluate lowering loads). The method is attached in Annex 3 and the execution of this movement was observed (Fig. 4).

Observing the second image on the Annex 3, in step 1, the holding column was considered, and a score of 2 points (total duration of 5 to 15 min in a workday) was assigned. For step 2 and considering that the worker was a female and stated that for this movement, the boxes had a weight of less than 5 kg, the load score was 1. Regarding the posture and position of the load, there is a downward inclination, and the load is far from the body, as shown in Fig. 4, so the assigned score was 4. Finally, in terms of working conditions, there are no unfavorable factors, so the score was zero.

Adding up the scores of the three key indicators (load, posture/position of the load, and working conditions) yields a total of 5 points which, when multiplied by time, results in a total risk score of 10 points.

Fig. 3 Shelf levels

3.2 *Body Posture*

Another imminent danger is the body posture adopted and maintained for several hours during the work period. In the Operating Room, nurses have to maintain a specific posture for a period of time that varies from surgery to surgery. According to [11, 12], nurses experience more occupational health problems than any other professional group, with lower back pain being the most recurrent injury in these professionals. This data is corroborated by the results obtained in the Nordic Musculoskeletal Questionnaire, which was in the first part of this study. The factors that lead to this type of injury are mainly patient transfer and lifting between stretchers, incorrect or constant standing posture, and surgical material handling [13–15]. Low back pain can lead to psychological stress in nurses and also to a reduction in their productivity and job satisfaction [16, 17].

Furthermore, injuries in the neck, shoulders, and knees are also common, as observations show that a large portion of nurses suffer from muscle injuries due to incorrect body mechanics [18]. According to Abdollahzade et al. [19], little attention has been given to body posture in an Operating Room during work, and consequently, little is known about possible effects.



Fig. 4 Lowering the load

In this study, three different postures were evaluated, which according to nursing professionals, are the most common (Fig. 5).

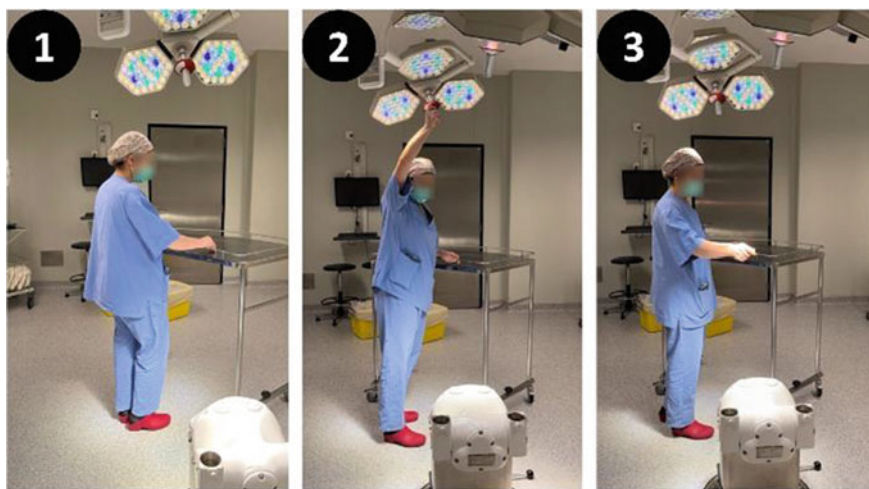


Fig. 5 Working body postures

The RULA Rapid Upper Limb Assessment method was chosen to assess postural risk. RULA is a method developed to be used in ergonomic investigations and in workspaces where upper limb problems are reported [20]. According to [21], by using the RULA method, all body movements are considered, whether they are shorter or wider, which allows for more precise details and a more accurate assessment of musculoskeletal disorders.

The adopted postures were classified into the required categories by the method in Annex 4 of McAtamney and Nigel Corlett [22]. For the first posture, a total score of 5 points was obtained with a score of 5 for wrist and arm and a score of 4 for the neck, trunk and leg. For the second it was determined a score of 5 for wrist and arm and a score of 3 for neck, trunk and leg and, finally, for the third posture a score of 4 for wrist/arm and a score of 4 for neck/trunk/leg, obtained a total of 4 points for these two, with all three positions falling in the yellow region, an intermediate risk region according to the method's Table C of Annex 4. This means that there is a risk, although it is not a high one.

4 Discussion

4.1 *Manual Handling Operations (MHO)*

Based on the values of the lifting index (LI) being greater than 1 (Annex 2), it is possible to conclude that there is a risk in the activity for both levels. It is therefore understood that for the weight of the 13 kg box to be handled, it should be reduced to a more suitable value, in the order of the RWL values obtained. If this is not possible, other solutions can be studied, such as adjusting the height of the trolley to reduce the value of V , or training the nurse regarding the body positioning they should have in order to reduce the angle of rotation. Another alternative would be to introduce mechanical devices such as mobile lifting tables/platforms to assist in lifting loads, which, according to research, cost between six hundred and seven hundred euros. Comparing the results between the NIOSH equation and the KIM for lifting the load, their conclusions are very similar because KIM indicates that 16 points is an increased load situation, where physical overload is possible for less resilient people. Additionally, it indicates that the redesigning of workplace is recommended. However, the KIM is not so strict compared with NIOSH because this method attributes points regarding the actual situation and doesn't give attention to the real measures.

In the study of MHO, and with the application of only the KIM in load lowering, it can be understood that the 10 risk points obtained indicate that an action is necessary, as values equal to or greater than 10 may indicate a situation of increased load, with likely physical overload for people with less strength. One of the actions to be implemented may involve reorganizing the storage location in order to allow

the heaviest load to be placed on shelves located between elbow and wrist height, reducing the effort in handling these loads.

4.2 *Body Posture*

As the number of working hours of a nurse in an Operating Room increases, the need to maintain a certain posture, which is practically static, for a long time can become painful. With the application of the RULA method, three frequent positions were analyzed, and it was found that they represent risks, as they are located in the yellow zone of Table C of the method (Annex 4).

The risk represented by the body posture can be mitigated or eliminated through nurse rotation by function, knowing that not all operations allow it. A slight increase in the height of the operating table that reduces neck movement can also be a positive measure. Reorganizing the workplace can also bring favorable results, such as placing materials in locations with a lower reach, contributing to a lower risk of injury, as movements will be of smaller effort.

5 **Conclusions**

The risks identified for the Operating Room nurses throughout this study reinforce the need for corrective ergonomic measures to be introduced in order to reduce potential accidents and/or occupational diseases, as evidenced by the results obtained.

With regards to the activity of MHO, measures to reduce the load being handled to suitable levels have been proposed, provide instructions to the nurses on adopting a more appropriate positioning, lower the height of the transport cart, and/or introduce mechanical devices to assist with lifting the load. Furthermore, reorganizing the location can also help reducing the effort required for handling the load. In terms of body posture, measures such as rotating nurses based on their functions and adjusting the height of the operating table to suit the team have been proposed, as well as reorganizing the workplace to promote proper body posture.

The effectiveness of the proposed measures discussed throughout the results section, after implementation, should be validated through a new risk assessment. This should be carried out in a future stage based on the results obtained in this study. This study could and should be complemented with the identification, evaluation, and analysis of other types of risks present in the workplace of these healthcare professionals (physical, chemical, and biological), which was not possible due to the limited time frame for the study.

It is worth noting that the data was collected in this institution to ensure the anonymity of the study participants.

Acknowledgements To be included in the resubmission phase.

Annex 1: Nordic Musculoskeletal Questionnaire

Musculoskeletal Discomfort Form

(Based on the Nordic Questionnaire (Kourinka et al. 1987))

Employee ID:

Job/Position:

Gender: M F

Age:

Height:

ft.in.

Weight:

How long have you been doing this job?

yearsmonths

How many hours do you work each week?

How to answer the questionnaire:

Picture: In this picture you can see the approximate position of the parts of the body referred to in the table. Limits are not sharply defined, and certain parts overlap. You should decide for yourself in which part you have or have had your trouble (if any).

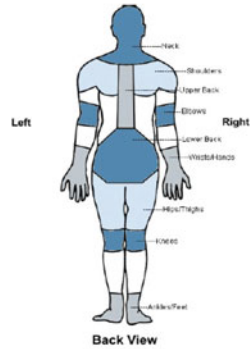


Table: Please answer by putting an "X" in the appropriate box - one "X" for each question. You may be in doubt as to how to answer, but please do your best anyway. Note that column 1 of the questionnaire is to be answered even if you have never had trouble in any part of your body; columns 2 and 3 are to be answered if you answered yes in column 1.

To be answered by everyone	To be answered by those who have had trouble	
Have you at any time during the last 12 months had trouble (ache, pain, discomfort, numbness) in:	Have you at any time during the last 12 months been prevented from doing your normal work (at home or away from home) because of the trouble?	Have you had trouble at any time during the last 7 days?
Neck ☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
Shoulders ☐ No ☐ Yes, right shoulder ☐ Yes, left shoulder ☐ Yes, both shoulders	☐ No ☐ Yes	☐ No ☐ Yes
Elbows ☐ No ☐ Yes, right elbow ☐ Yes, left elbow ☐ Yes, both elbows	☐ No ☐ Yes	☐ No ☐ Yes
Wrists/Hands ☐ No ☐ Yes, right wrist/hand ☐ Yes, left wrist/hand ☐ Yes, both wrists/hands	☐ No ☐ Yes	☐ No ☐ Yes
Upper Back ☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
Lower Back (small of back) ☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
One or Both Hips/Thighs ☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
One or Both Knees ☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
One or Both Ankles/Feet ☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes

Annex 2: Niosh Equation

The equation allows the calculation of the Recommended Limit Weight (RWL), based on a constant load value and six critical measurements, Table 2.

$$RWL = LC \times HM \times VM \times DM \times AM \times CM \times FM$$

First, variables necessary for calculating the multipliers were taken:

Table 2 Metrics for calculating RWL

Multiplier	Metric
Load constant (LC)	23 kg
Horizontal mult. (HM)	25/H
Vertical mult. (VM)	1 – (0.003) × V – 75
Distance mult. (DM)	4.5 0.82 + (D)
Asymmetric mult. (AM)	1 – (0.0032 × A)
Coupling mult. (CM)	Table 3
Frequency mult. (FM)	Table 4

Table 3 Data for calculating the coupling multiplier (CM)

Coupling type	Coupling multiplier	
	V < 75 cm	V ≥ 75 cm
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

Table 4 Data for calculating the frequency multiplier (FM)

Frequency multiplier table						
Work duration						
Lifts/ min (F)	<1 h		>1 h and <2 h		>2 h but <8 h	
	VM < 75 cm	VM > 75 cm	VM < 75 cm	VM > 75 cm	VM < 75 cm	VM > 75 cm
<0.2	1.00	1.00	0.95	0.95	0.85	0.85
0.5	0.97	0.97	0.92	0.92	0.81	0.81
1	0.94	0.94	0.88	0.88	0.75	0.75
2	0.91	0.91	0.84	0.84	0.65	0.65
3	0.88	0.88	0.79	0.79	0.55	0.55
4	0.84	0.84	0.72	0.6	0.45	0.45
5	0.80	0.80	0.60	0.60	0.35	0.35
6	0.75	0.75	0.50	0.50	0.27	0.27
7	0.70	0.70	0.42	0.42	0.22	0.22
8	0.60	0.60	0.35	0.35	0.18	0.18
9	0.52	0.52	0.30	0.30	0.00	0.15
10	0.45	0.45	0.26	0.26	0.00	0.13
11	0.41	0.41	0.00	0.23	0.00	0.00
12	0.37	0.37	0.00	0.21	0.00	0.00
13	0.00	0.34	0.00	0.00	0.00	0.00
14	0.00	0.31	0.00	0.00	0.00	0.00
15	0.00	0.28	0.00	0.00	0.00	0.00
>15	0.00	0.00	0.00	0.00	0.00	0.00

$$W = 57.5 \text{ cm}$$

$$V = 105 \text{ cm}$$

$$A = 30^\circ$$

$$H = 20 + \frac{57.5}{2} = 48.75 \text{ cm}$$

$$D_1 = 19 \text{ cm}$$

$$D_2 = 57 \text{ cm}$$

Once the auxiliary variables were taken, the next step was to calculate the multipliers:

$$HM = \frac{25}{48.75} = 0.513$$

$$VM = 1 - (0.003) \times |105 - 75| = 0.91$$

$$AM = 1 - (0.0032 \times 30) = 0.9$$

$$MP = 1$$

$$FM = 0.94(1 \text{ lift} / \text{min e } T \leq 1h)$$

$$DM_1 = 0.82 + \left(\frac{4.5}{19} \right) = 1.06$$

$$DM_2 = 0.82 + \left(\frac{4.5}{57} \right) = 0.89$$

With the multipliers obtained, it was possible to calculate the RWL for the two proposed height levels.

$$RWL_1 = 23 \times 0.513 \times 0.91 \times 1.06 \times 0.90 \times 1 \times 0.94 = 9.671 \text{ kg}$$

$$RWL_2 = 23 \times 0.513 \times 0.91 \times 0.89 \times 0.90 \times 1 \times 0.94 = 8.202 \text{ kg}$$

To analyze the obtained RWLs, below is the calculation of the Lifting Index (LI) for the two proposed height levels:

$$LI_1 = \frac{13}{9.671} = 1.34$$

$$LI_2 = \frac{13}{8.202} = 1.48$$

Annex 3: Kim

ASSESSMENT OF MANUAL HANDLING TASKS BASED ON KEY INDICATORS Version: 2001
There are a number of factors that can affect the risk of injury from manual handling tasks. They must be taken into account.

Workplace Activity: Lifting the load

1st step: Determination of time rating points (check only one column)

Lifting or displacement operations (> 5 kg)	Time rating points	Time duration or working time (> 5 min)	Time rating points	Carrying (> 5 m)	Time rating points
Number of working days					
< 10	1	< 5 min	1	< 300 m	1
10 to < 40	2	5 to 15 min	2	300 m to < 1 km	2
40 to < 200	4	15 min to < 1 hr	4	1 km to < 4 km	4
200 to < 500	8	1 hr to < 2 hrs	8	4 to < 8 km	8
500 to < 1000	8	2 hrs to < 4 hrs	8	8 to < 16 km	8
> 1000	10	> 4 hrs	10	> 16 km	10

2nd step: Determination of rating points of load, posture and working conditions

Effective load ^a for men	Load rating point	Effective load ^b for women	Load rating point
< 10 kg	1	< 5 kg	1
10 to < 20 kg	2	5 to < 10 kg	2
20 to < 30 kg	4	10 to < 15 kg	4
30 to < 40 kg	7	15 to < 25 kg	7
> 40 kg	25	> 25 kg	25

3rd step: Evaluation

The rating points relevant to this activity are to be entered and calculated in the diagram.

Load rating points: 4
+
Posture rating points: 4
+
Working conditions rating points: 0
= Total: 8

Time rating points: 2
x
Total: 8 = Risk score: 16

On the basis of the rating calculated and the table below it is possible to make a rough evaluation. ^a Regardless of this provision of the Machinery Directive, full apply.

Risk range	Risk score	Description
1	< 10	Low risk situation, physical overload unlikely to appear.
2	10 to < 25	Increased load situation, physical overload is possible for less resistant persons. For that group redesign of workplace is helpful.
3	25 to < 50	Highly increased load situation, physical overload also possible for normal persons. Redesign of the workplace is recommended.
4	> 50	High risk situation, physical overload is likely to appear. Workplace redesign is necessary.

Reasons it must be assumed that as the number of points rating rises, the risk of overloading the musculo-skeletal system increases. The boundaries between the risk ranges are not because of the individual working techniques and performance conditions. The classification may therefore only be regarded as an orientation aid. More exact analyses require specialist ergonomic knowledge.

Less resistant persons in this context are persons older than 40 or younger than 21 years, newsmen in the job or people suffering from illness.

Design requirements can be determined with reference to the number of points in the table. By reducing the weight, improving the execution conditions or shortening the action time, avoided cases can be avoided.

Check of the workplace necessary for other reasons: ☐

Reasons: _____

Date of assessment: _____ Assessed by: _____

By: *Federal Institute for Occupational Safety and Health and *Committee of the German for Occupational Safety and Health (BfArM) and *Bundesinstitut für Arbeitsschutz und Arbeitsmedizin - BfArM und *Bundesinstitut für Arbeitsschutz und Arbeitsmedizin - BfArM

ASSESSMENT OF MANUAL HANDLING TASKS BASED ON KEY INDICATORS Version: 2001
There are a number of factors that can affect the risk of injury from manual handling tasks. They must be taken into account.

Workplace Activity: Lowering the load

1st step: Determination of time rating points (check only one column)

Lifting or displacement operations (> 5 kg)	Time rating points	Time duration or working time (> 5 min)	Time rating points	Carrying (> 5 m)	Time rating points
Number of working days					
< 10	1	< 5 min	1	< 300 m	1
10 to < 40	2	5 to 15 min	2	300 m to < 1 km	2
40 to < 200	4	15 min to < 1 hr	4	1 km to < 4 km	4
200 to < 500	8	1 hr to < 2 hrs	8	4 to < 8 km	8
500 to < 1000	8	2 hrs to < 4 hrs	8	8 to < 16 km	8
> 1000	10	> 4 hrs	10	> 16 km	10

2nd step: Determination of rating points of load, posture and working conditions

Effective load ^a for men	Load rating point	Effective load ^b for women	Load rating point
< 10 kg	1	< 5 kg	1
10 to < 20 kg	2	5 to < 10 kg	2
20 to < 30 kg	4	10 to < 15 kg	4
30 to < 40 kg	7	15 to < 25 kg	7
> 40 kg	25	> 25 kg	25

3rd step: Evaluation

The rating points relevant to this activity are to be entered and calculated in the diagram.

Load rating points: 1
+
Posture rating points: 4
+
Working conditions rating points: 0
= Total: 5

Time rating points: 2
x
Total: 5 = Risk score: 10

On the basis of the rating calculated and the table below it is possible to make a rough evaluation. ^a Regardless of this provision of the Machinery Directive, full apply.

Risk range	Risk score	Description
1	< 10	Low risk situation, physical overload unlikely to appear.
2	10 to < 25	Increased load situation, physical overload is possible for less resistant persons. For that group redesign of workplace is helpful.
3	25 to < 50	Highly increased load situation, physical overload also possible for normal persons. Redesign of the workplace is recommended.
4	> 50	High risk situation, physical overload is likely to appear. Workplace redesign is necessary.

Reasons it must be assumed that as the number of points rating rises, the risk of overloading the musculo-skeletal system increases. The boundaries between the risk ranges are not because of the individual working techniques and performance conditions. The classification may therefore only be regarded as an orientation aid. More exact analyses require specialist ergonomic knowledge.

Less resistant persons in this context are persons older than 40 or younger than 21 years, newsmen in the job or people suffering from illness.

Design requirements can be determined with reference to the number of points in the table. By reducing the weight, improving the execution conditions or shortening the action time, avoided cases can be avoided.

Check of the workplace necessary for other reasons: ☐

Reasons: _____

Date of assessment: _____ Assessed by: _____

By: *Federal Institute for Occupational Safety and Health and *Committee of the German for Occupational Safety and Health (BfArM) and *Bundesinstitut für Arbeitsschutz und Arbeitsmedizin - BfArM und *Bundesinstitut für Arbeitsschutz und Arbeitsmedizin - BfArM

ASSESSMENT OF MANUAL HANDLING TASKS BASED ON KEY INDICATORS Version: 2001
There are a number of factors that can affect the risk of injury from manual handling tasks. They must be taken into account.

Workplace Activity: Lowering the load

1st step: Determination of time rating points (check only one column)

Lifting or displacement operations (> 5 kg)	Time rating points	Time duration or working time (> 5 min)	Time rating points	Carrying (> 5 m)	Time rating points
Number of working days					
< 10	1	< 5 min	1	< 300 m	1
10 to < 40	2	5 to 15 min	2	300 m to < 1 km	2
40 to < 200	4	15 min to < 1 hr	4	1 km to < 4 km	4
200 to < 500	8	1 hr to < 2 hrs	8	4 to < 8 km	8
500 to < 1000	8	2 hrs to < 4 hrs	8	8 to < 16 km	8
> 1000	10	> 4 hrs	10	> 16 km	10

2nd step: Determination of rating points of load, posture and working conditions

Effective load ^a for men	Load rating point	Effective load ^b for women	Load rating point
< 10 kg	1	< 5 kg	1
10 to < 20 kg	2	5 to < 10 kg	2
20 to < 30 kg	4	10 to < 15 kg	4
30 to < 40 kg	7	15 to < 25 kg	7
> 40 kg	25	> 25 kg	25

3rd step: Evaluation

The rating points relevant to this activity are to be entered and calculated in the diagram.

Load rating points: 1
+
Posture rating points: 4
+
Working conditions rating points: 0
= Total: 5

Time rating points: 2
x
Total: 5 = Risk score: 10

On the basis of the rating calculated and the table below it is possible to make a rough evaluation. ^a Regardless of this provision of the Machinery Directive, full apply.

Risk range	Risk score	Description
1	< 10	Low risk situation, physical overload unlikely to appear.
2	10 to < 25	Increased load situation, physical overload is possible for less resistant persons. For that group redesign of workplace is helpful.
3	25 to < 50	Highly increased load situation, physical overload also possible for normal persons. Redesign of the workplace is recommended.
4	> 50	High risk situation, physical overload is likely to appear. Workplace redesign is necessary.

Reasons it must be assumed that as the number of points rating rises, the risk of overloading the musculo-skeletal system increases. The boundaries between the risk ranges are not because of the individual working techniques and performance conditions. The classification may therefore only be regarded as an orientation aid. More exact analyses require specialist ergonomic knowledge.

Less resistant persons in this context are persons older than 40 or younger than 21 years, newsmen in the job or people suffering from illness.

Design requirements can be determined with reference to the number of points in the table. By reducing the weight, improving the execution conditions or shortening the action time, avoided cases can be avoided.

Check of the workplace necessary for other reasons: ☐

Reasons: _____

Date of assessment: _____ Assessed by: _____

By: *Federal Institute for Occupational Safety and Health and *Committee of the German for Occupational Safety and Health (BfArM) and *Bundesinstitut für Arbeitsschutz und Arbeitsmedizin - BfArM und *Bundesinstitut für Arbeitsschutz und Arbeitsmedizin - BfArM

ASSESSMENT OF MANUAL HANDLING TASKS BASED ON KEY INDICATORS Version: 2001
There are a number of factors that can affect the risk of injury from manual handling tasks. They must be taken into account.

Workplace Activity: Lowering the load

1st step: Determination of time rating points (check only one column)

Lifting or displacement operations (> 5 kg)	Time rating points	Time duration or working time (> 5 min)	Time rating points	Carrying (> 5 m)	Time rating points
Number of working days					
< 10	1	< 5 min	1	< 300 m	1
10 to < 40	2	5 to 15 min	2	300 m to < 1 km	2
40 to < 200	4	15 min to < 1 hr	4	1 km to < 4 km	4
200 to < 500	8	1 hr to < 2 hrs	8	4 to < 8 km	8
500 to < 1000	8	2 hrs to < 4 hrs	8	8 to < 16 km	8
> 1000	10	> 4 hrs	10	> 16 km	10

2nd step: Determination of rating points of load, posture and working conditions

Effective load ^a for men	Load rating point	Effective load ^b for women	Load rating point
< 10 kg	1	< 5 kg	1
10 to < 20 kg	2	5 to < 10 kg	2
20 to < 30 kg	4	10 to < 15 kg	4
30 to < 40 kg	7	15 to < 25 kg	7
> 40 kg	25	> 25 kg	25

3rd step: Evaluation

The rating points relevant to this activity are to be entered and calculated in the diagram.

Load rating points: 1
+
Posture rating points: 4
+
Working conditions rating points: 0
= Total: 5

Time rating points: 2
x
Total: 5 = Risk score: 10

On the basis of the rating calculated and the table below it is possible to make a rough evaluation. ^a Regardless of this provision of the Machinery Directive, full apply.

Risk range	Risk score	Description
1	< 10	Low risk situation, physical overload unlikely to appear.
2	10 to < 25	Increased load situation, physical overload is possible for less resistant persons. For that group redesign of workplace is helpful.
3	25 to < 50	Highly increased load situation, physical overload also possible for normal persons. Redesign of the workplace is recommended.
4	> 50	High risk situation, physical overload is likely to appear. Workplace redesign is necessary.

Reasons it must be assumed that as the number of points rating rises, the risk of overloading the musculo-skeletal system increases. The boundaries between the risk ranges are not because of the individual working techniques and performance conditions. The classification may therefore only be regarded as an orientation aid. More exact analyses require specialist ergonomic knowledge.

Less resistant persons in this context are persons older than 40 or younger than 21 years, newsmen in the job or people suffering from illness.

Design requirements can be determined with reference to the number of points in the table. By reducing the weight, improving the execution conditions or shortening the action time, avoided cases can be avoided.

Check of the workplace necessary for other reasons: ☐

Reasons: _____

Date of assessment: _____ Assessed by: _____

By: *Federal Institute for Occupational Safety and Health and *Committee of the German for Occupational Safety and Health (BfArM) and *Bundesinstitut für Arbeitsschutz und Arbeitsmedizin - BfArM und *Bundesinstitut für Arbeitsschutz und Arbeitsmedizin - BfArM

Annex 4: Rula Method

RULA Employee Assessment Worksheet based on RULA: a survey method for the investigation of work-related upper limb disorders, McAtamney & Corlett, Applied Ergonomics 1993, 24(2), 91-99

A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position:

Step 1a: Adjust:
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Step 2: Locate Lower Arm Position:

Step 2a: Adjust:
If either arm is working across midline or out to side of body: Add +1

Step 3: Locate Wrist Position:

Step 3a: Adjust:
If wrist is bent from midline: Add +1

Step 4: Wrist Twist:
If wrist is twisted in mid-range: +1
If wrist is in at or near end of range: +2

Step 5: Look-up Posture Score in Table A:
Using values from steps 1-4 above, locate score in Table A.

Step 6: Add Muscle Use Score
If posture mainly static (i.e. hold-10 minutes), Or if action repeated occurs <5% per minute: +1

Step 7: Add Force/Load Score
If load = 4-8 lbs (1.8-3.6 kg): +0
If load = 9-16 lbs (4.1-7.3 kg): +1
If load = 17-22 lbs (7.7-10.0 kg): +2
If more than 22 lbs or repeated or shocks: +3

Step 8: Find Row in Table C
Add values from steps 5-7 to obtain Wrist and Arm Score. Find row in Table C.

SCORES

Table A: Wrist Posture Score

Upper Arm	Lower Arm	Wrist			
		1	2	3	4
1	1	1	2	2	3
1	2	2	2	2	3
1	3	2	3	3	4
1	4	2	3	3	4
2	1	2	3	3	4
2	2	3	3	3	4
2	3	3	4	4	5
2	4	3	4	4	5
3	1	3	3	4	5
3	2	3	4	4	5
3	3	4	4	4	5
3	4	4	4	4	5
4	1	4	4	4	5
4	2	4	4	4	5
4	3	4	4	4	5
4	4	4	4	4	5
5	1	5	5	5	6
5	2	5	5	5	6
5	3	5	5	5	6
5	4	5	5	5	6
6	1	7	7	7	8
6	2	8	8	8	9
6	3	9	9	9	9
6	4	9	9	9	9

Table B: Neck, Trunk and Leg Score

Neck	Trunk	Legs	Neck				Trunk				Legs			
			1	2	3	4	1	2	3	4	1	2	3	4
1	1	1	1	1	1	1	1	1	1	1	1	1	1	
1	2	1	1	1	1	1	1	1	1	1	1	1	1	
1	3	1	1	1	1	1	1	1	1	1	1	1	1	
1	4	1	1	1	1	1	1	1	1	1	1	1	1	
2	1	1	1	1	1	1	1	1	1	1	1	1	1	
2	2	1	1	1	1	1	1	1	1	1	1	1	1	
2	3	1	1	1	1	1	1	1	1	1	1	1	1	
2	4	1	1	1	1	1	1	1	1	1	1	1	1	
3	1	1	1	1	1	1	1	1	1	1	1	1	1	
3	2	1	1	1	1	1	1	1	1	1	1	1	1	
3	3	1	1	1	1	1	1	1	1	1	1	1	1	
3	4	1	1	1	1	1	1	1	1	1	1	1	1	
4	1	1	1	1	1	1	1	1	1	1	1	1	1	
4	2	1	1	1	1	1	1	1	1	1	1	1	1	
4	3	1	1	1	1	1	1	1	1	1	1	1	1	
4	4	1	1	1	1	1	1	1	1	1	1	1	1	
5	1	1	1	1	1	1	1	1	1	1	1	1	1	
5	2	1	1	1	1	1	1	1	1	1	1	1	1	
5	3	1	1	1	1	1	1	1	1	1	1	1	1	
5	4	1	1	1	1	1	1	1	1	1	1	1	1	
6	1	1	1	1	1	1	1	1	1	1	1	1	1	
6	2	1	1	1	1	1	1	1	1	1	1	1	1	
6	3	1	1	1	1	1	1	1	1	1	1	1	1	
6	4	1	1	1	1	1	1	1	1	1	1	1	1	

Table C: Neck, trunk and leg score

Wrist and Arm Score	Neck				Trunk				Legs			
	1	2	3	4	1	2	3	4	1	2	3	4
1	1	2	3	4	5	6	7	8	9	10	11	12
2	2	3	4	5	6	7	8	9	10	11	12	13
3	3	4	5	6	7	8	9	10	11	12	13	14
4	4	5	6	7	8	9	10	11	12	13	14	15
5	5	6	7	8	9	10	11	12	13	14	15	16
6	6	7	8	9	10	11	12	13	14	15	16	17
7	7	8	9	10	11	12	13	14	15	16	17	18
8	8	9	10	11	12	13	14	15	16	17	18	19
9	9	10	11	12	13	14	15	16	17	18	19	20

Scoring: (Final score from Table C)
1 or 2 = acceptable posture
3 or 4 = further investigation, change may be needed
5 or 6 = further investigation, change soon
7 = investigate and implement change

Task name: Posture 1 **Reviewer:** _____ **Date:** _____

RULA Employee Assessment Worksheet based on RULA: a survey method for the investigation of work-related upper limb disorders, McAtamney & Corlett, Applied Ergonomics 1993, 24(2), 91-99

A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position:

Step 1a: Adjust:
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Step 2: Locate Lower Arm Position:

Step 2a: Adjust:
If either arm is working across midline or out to side of body: Add +1

Step 3: Locate Wrist Position:

Step 3a: Adjust:
If wrist is bent from midline: Add +1

Step 4: Wrist Twist:
If wrist is twisted in mid-range: +1
If wrist is in at or near end of range: +2

Step 5: Look-up Posture Score in Table A:
Using values from steps 1-4 above, locate score in Table A.

Step 6: Add Muscle Use Score
If posture mainly static (i.e. hold-10 minutes), Or if action repeated occurs <5% per minute: +1

Step 7: Add Force/Load Score
If load = 4-8 lbs (1.8-3.6 kg): +0
If load = 9-16 lbs (4.1-7.3 kg): +1
If load = 17-22 lbs (7.7-10.0 kg): +2
If more than 22 lbs or repeated or shocks: +3

Step 8: Find Row in Table C
Add values from steps 5-7 to obtain Wrist and Arm Score. Find row in Table C.

SCORES

Table A: Wrist Posture Score

Upper Arm	Lower Arm	Wrist			
		1	2	3	4
1	1	1	2	2	3
1	2	2	2	2	3
1	3	2	3	3	4
1	4	2	3	3	4
2	1	2	3	3	4
2	2	3	3	3	4
2	3	3	4	4	5
2	4	3	4	4	5
3	1	3	3	4	5
3	2	3	4	4	5
3	3	4	4	4	5
3	4	4	4	4	5
4	1	4	4	4	5
4	2	4	4	4	5
4	3	4	4	4	5
4	4	4	4	4	5
5	1	5	5	5	6
5	2	5	5	5	6
5	3	5	5	5	6
5	4	5	5	5	6
6	1	7	7	7	8
6	2	8	8	8	9
6	3	9	9	9	9
6	4	9	9	9	9

Table B: Neck, Trunk and Leg Score

Neck	Trunk	Legs	Neck				Trunk				Legs			
			1	2	3	4	1	2	3	4	1	2	3	4
1	1	1	1	1	1	1	1	1	1	1	1	1	1	
1	2	1	1	1	1	1	1	1	1	1	1	1	1	
1	3	1	1	1	1	1	1	1	1	1	1	1	1	
1	4	1	1	1	1	1	1	1	1	1	1	1	1	
2	1	1	1	1	1	1	1	1	1	1	1	1	1	
2	2	1	1	1	1	1	1	1	1	1	1	1	1	
2	3	1	1	1	1	1	1	1	1	1	1	1	1	
2	4	1	1	1	1	1	1	1	1	1	1	1	1	
3	1	1	1	1	1	1	1	1	1	1	1	1	1	
3	2	1	1	1	1	1	1	1	1	1	1	1	1	
3	3	1	1	1	1	1	1	1	1	1	1	1	1	
3	4	1	1	1	1	1	1	1	1	1	1	1	1	
4	1	1	1	1	1	1	1	1	1	1	1	1	1	
4	2	1	1	1	1	1	1	1	1	1	1	1	1	
4	3	1	1	1	1	1	1	1	1	1	1	1	1	
4	4	1	1	1	1	1	1	1	1	1	1	1	1	
5	1	1	1	1	1	1	1	1	1	1	1	1	1	
5	2	1	1	1	1	1	1	1	1	1	1	1	1	
5	3	1	1	1	1	1	1	1	1	1	1	1	1	
5	4	1	1	1	1	1	1	1	1	1	1	1	1	
6	1	1	1	1	1	1	1	1	1	1	1	1	1	
6	2	1	1	1	1	1	1	1	1	1	1	1	1	
6	3	1	1	1	1	1	1	1	1	1	1	1	1	
6	4	1	1	1	1	1	1	1	1	1	1	1	1	

Table C: Neck, trunk and leg score

Wrist and Arm Score	Neck				Trunk				Legs			
	1	2	3	4	1	2	3	4	1	2	3	4
1	1	2	3	4	5	6	7	8	9	10	11	12
2	2	3	4	5	6	7	8	9	10	11	12	13
3	3	4	5	6	7	8	9	10	11	12	13	14
4	4	5	6	7	8	9	10	11	12	13	14	15
5	5	6	7	8	9	10	11	12	13	14	15	16
6	6	7	8	9	10	11	12	13	14	15	16	17
7	7	8	9	10	11	12	13	14	15	16	17	18
8	8	9	10	11	12	13	14	15	16	17	18	19
9	9	10	11	12	13	14	15	16	17	18	19	20

Scoring: (Final score from Table C)
1 or 2 = acceptable posture
3 or 4 = further investigation, change may be needed
5 or 6 = further investigation, change soon
7 = investigate and implement change

Task name: Posture 2 **Reviewer:** _____ **Date:** _____

RULA Employee Assessment Worksheet Adapted from RULA: a survey method for the investigation of work-related upper limb disorders. Mathiassen & Corlett, Applied Ergonomics 1991, 24(2): 91-99

A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position: **3** Upper Arm Score

Step 2: Locate Lower Arm Position: **3** Lower Arm Score

Step 3: Locate Wrist Position: **2** Wrist Score

Step 4: Wrist Twist: **1** Wrist Twist Score

Step 5: Look-up Posture Score in Table A: **3** Posture Score A

Step 6: Add Muscle Use Score **1** Muscle Use Score

Step 7: Add Force/Load Score **0** Force/Load Score

Step 8: Find Row in Table C **4** Wrist and Arm Score

SCORES

Table A: Wrist Posture Score

Upper Arm	Lower Arm	Wrist	Twist	Score
1	1	1	1	1
1	2	2	2	2
1	3	3	3	3
1	4	4	4	4
1	5	5	5	5
1	6	6	6	6
1	7	7	7	7
1	8	8	8	8
1	9	9	9	9
2	1	1	1	2
2	2	2	2	3
2	3	3	3	4
2	4	4	4	5
2	5	5	5	6
2	6	6	6	7
2	7	7	7	8
2	8	8	8	9
2	9	9	9	10
3	1	1	1	3
3	2	2	2	4
3	3	3	3	5
3	4	4	4	6
3	5	5	5	7
3	6	6	6	8
3	7	7	7	9
3	8	8	8	10
3	9	9	9	11
4	1	1	1	4
4	2	2	2	5
4	3	3	3	6
4	4	4	4	7
4	5	5	5	8
4	6	6	6	9
4	7	7	7	10
4	8	8	8	11
4	9	9	9	12
5	1	1	1	5
5	2	2	2	6
5	3	3	3	7
5	4	4	4	8
5	5	5	5	9
5	6	6	6	10
5	7	7	7	11
5	8	8	8	12
5	9	9	9	13
6	1	1	1	6
6	2	2	2	7
6	3	3	3	8
6	4	4	4	9
6	5	5	5	10
6	6	6	6	11
6	7	7	7	12
6	8	8	8	13
6	9	9	9	14
7	1	1	1	7
7	2	2	2	8
7	3	3	3	9
7	4	4	4	10
7	5	5	5	11
7	6	6	6	12
7	7	7	7	13
7	8	8	8	14
7	9	9	9	15
8	1	1	1	8
8	2	2	2	9
8	3	3	3	10
8	4	4	4	11
8	5	5	5	12
8	6	6	6	13
8	7	7	7	14
8	8	8	8	15
8	9	9	9	16
9	1	1	1	9
9	2	2	2	10
9	3	3	3	11
9	4	4	4	12
9	5	5	5	13
9	6	6	6	14
9	7	7	7	15
9	8	8	8	16
9	9	9	9	17

Table B: Neck, Trunk and Leg Scores

Neck	Trunk	Legs	Score
1	1	1	1
1	2	2	2
1	3	3	3
1	4	4	4
1	5	5	5
1	6	6	6
1	7	7	7
1	8	8	8
1	9	9	9
2	1	1	2
2	2	2	3
2	3	3	4
2	4	4	5
2	5	5	6
2	6	6	7
2	7	7	8
2	8	8	9
2	9	9	10
3	1	1	3
3	2	2	4
3	3	3	5
3	4	4	6
3	5	5	7
3	6	6	8
3	7	7	9
3	8	8	10
3	9	9	11
4	1	1	4
4	2	2	5
4	3	3	6
4	4	4	7
4	5	5	8
4	6	6	9
4	7	7	10
4	8	8	11
4	9	9	12
5	1	1	5
5	2	2	6
5	3	3	7
5	4	4	8
5	5	5	9
5	6	6	10
5	7	7	11
5	8	8	12
5	9	9	13
6	1	1	6
6	2	2	7
6	3	3	8
6	4	4	9
6	5	5	10
6	6	6	11
6	7	7	12
6	8	8	13
6	9	9	14
7	1	1	7
7	2	2	8
7	3	3	9
7	4	4	10
7	5	5	11
7	6	6	12
7	7	7	13
7	8	8	14
7	9	9	15
8	1	1	8
8	2	2	9
8	3	3	10
8	4	4	11
8	5	5	12
8	6	6	13
8	7	7	14
8	8	8	15
8	9	9	16
9	1	1	9
9	2	2	10
9	3	3	11
9	4	4	12
9	5	5	13
9	6	6	14
9	7	7	15
9	8	8	16
9	9	9	17

Table C: Neck, Trunk and Leg Scores

Neck	Trunk	Legs	Score
1	1	1	1
1	2	2	2
1	3	3	3
1	4	4	4
1	5	5	5
1	6	6	6
1	7	7	7
1	8	8	8
1	9	9	9
2	1	1	2
2	2	2	3
2	3	3	4
2	4	4	5
2	5	5	6
2	6	6	7
2	7	7	8
2	8	8	9
2	9	9	10
3	1	1	3
3	2	2	4
3	3	3	5
3	4	4	6
3	5	5	7
3	6	6	8
3	7	7	9
3	8	8	10
3	9	9	11
4	1	1	4
4	2	2	5
4	3	3	6
4	4	4	7
4	5	5	8
4	6	6	9
4	7	7	10
4	8	8	11
4	9	9	12
5	1	1	5
5	2	2	6
5	3	3	7
5	4	4	8
5	5	5	9
5	6	6	10
5	7	7	11
5	8	8	12
5	9	9	13
6	1	1	6
6	2	2	7
6	3	3	8
6	4	4	9
6	5	5	10
6	6	6	11
6	7	7	12
6	8	8	13
6	9	9	14
7	1	1	7
7	2	2	8
7	3	3	9
7	4	4	10
7	5	5	11
7	6	6	12
7	7	7	13
7	8	8	14
7	9	9	15
8	1	1	8
8	2	2	9
8	3	3	10
8	4	4	11
8	5	5	12
8	6	6	13
8	7	7	14
8	8	8	15
8	9	9	16
9	1	1	9
9	2	2	10
9	3	3	11
9	4	4	12
9	5	5	13
9	6	6	14
9	7	7	15
9	8	8	16
9	9	9	17

Task name: Posture 3 **Reviewer:** **Date:**

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The Importance of Ergonomics in Improving the Quality and Productivity Indicators of a Work Process in the Automotive Industry



Regina Silva and Paula Carneiro 

Abstract Work-related musculoskeletal disorders are increasingly prevalent in our societies. Approximately 1710 million people have musculoskeletal disorders worldwide. The costs caused by this problem are enormous for companies and representing a very serious issue. The objectives of this work were the ergonomic analysis of some of the operations with the aim of defining a model to improve working conditions and indirectly improve productivity and quality rates. The diagnostic tools used were the EWA Method, Corlett diagram, and simple observational methods to respond through ergonomics to the problems detected. The operations analysed were sewing, heat application and rings assembly. The ergonomic methods applied were RULA, KIM-MHO, and RSI, having shown that all operations presented WMSD risk. After the obtained results analysis, improvements were made, namely; changing the type of lighting, carrying out the operation at an adjustable station with compressed air, fixing the dryer, implementing an axle for rings assembly. After making the changes, their effectiveness was evaluated, repeating the use of the techniques and methods used in the diagnostic phase, having found that the measures were effective and therefore the proposed objectives achieved.

Keywords Ergonomics · Manual work · Musculoskeletal disorders

1 Introduction

The incompatibility between the anthropometric characteristics of the operators and the dimensions of their workstation may constitute a risk factor for work-related musculoskeletal disorders (WMSD). Operators are often confronted with

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non-adjustable work stations, which can lead to the prevalence of injuries [8]. Musculoskeletal disorder (MSD) is one of the major health problems that are related to physical labor especially in jobs requiring manual work [13]. This work was developed in the automotive industry, in a manual wrapping activity. The wrapping activity, in addition to being manual (is difficult to automate it) is characterized by inappropriate postures, repetitive movements and manual force application. The automotive industry is one of the sectors with the highest risk of MSD in the workplace [1]. It is characterized by mass production and automation. Despite this strong trend, human labor is still a profitable option in some contexts [17] and in others, manual labor is the only option due to the lack of technology to replace it, and also because of the flexibility it represents. When there is manual work, and as the operators are not infallible, quality and productivity problems end up arising. Due to the current socioeconomic context and globalization, the increased workload and quality requirements threaten the workers health, leading to significant productivity losses [1]. The distinction cannot be made between human factors, operators health, quality, and productivity and even accidents at work. An operator who has good working conditions, in which these are compatible with his condition and individual factors, will perform better in his activity, as well as the likelihood of injuries and health problems will be reduced. Volvo Corporation in 2003, carried out an Ergonomics program, as part of the global corporate strategy, with the final objective to improve product quality [15]. In 1989, Ford, in collaboration with the University of Michigan, also implemented a corporate program with purpose to become a global leader in providing highly productive and safe work, free from injury or illness for all employees in the world that facilitated continuous and total cost improvement for today and the future [4]. Erdinc and Vayvay [7] also proved through their case study that the ergonomic and quality integration culminates in an improvement in quality and working conditions. The objective of this work is the ergonomic analysis of a wrapping process in the production of steering wheels in the automotive industry, creating a standard to improve work conditions and quality indicators, productivity increase and prevent occupational diseases such as WMSD.

2 Materials and Methods

This work had three main steps. Step 1 consisted of researching quality, productivity, and absenteeism data, as well as sample characterization to be studied. In step 2, the Ergonomic Workplace Analysis (EWA) method and the Corlett Diagram were applied. Stage 3 focused in observe the operations with video method and in the selection and application of suitable ergonomic research methods.

Finally, and with the results obtained in the different stages, an action plan was defined to improve the diagnosed aspects. Quality, productivity, and ergonomic assessment was compared before and after measures implementation.

2.1 Step 1

Step 1 consisted of verifying existing data. It was found that rejection and productivity data were recorded globally, additionally those data were not object of analyze. For this reason, it was implemented a defect record per operator and a production daily follow-up. It was also found that absenteeism data did not exist, which did not allow relating absenteeism to possible problems related to the WMSD. The characterization of the sample was carried out in terms of operator's age, height, and seniority.

2.2 Step 2

In stage 2, the EWA Method [2] was applied on the wrapping workstation, due to its scope and complementarity. The application of this method, as in the study carried out by [5] allows to initiate the bases for a discussion with the operators about the job strengths and weaknesses. An interview was also carried out with the operators using the Corlett diagram, asking the operators if they felt any pain and/or discomfort in any part of the body. If so, operators were asked to rate their pain and/or discomfort on a scale of 1–5; where (1) means no pain or discomfort, (2) some pain/discomfort, (3) moderate pain/discomfort, (4) severe pain/discomfort, and (5) extreme pain/discomfort.

3 Step 3

After a detailed analysis of the process using the video method, where the main risk factors were analyzed (posture, strength and repetitiveness), it was decided to select the operations that appeared to be more demanding at an ergonomic level: sewing operation, heat application, and rings assembly. It has yet been verified that these operations are also those with the greatest quality problems. RULA Method was used in the three operations analyzed, since it is a method that evaluates the static activity of the muscles and the force exerted by the upper limbs (McAtamney and Nigel Corlett 1993). RULA, when used in combination with other methods or tools, provides better and more reliable results, making it possible to identify different risk factors and evaluate various body areas [14]. RULA score ranges between 1 and 7, where 1 and 2 means acceptable posture, 3 and 4 means investigation is needed, 5 and 6 needs to be investigated and action taken quickly, and 7 means investigation and action is needed immediately. In the sewing operation and rings assembly the RULA method was complemented with the KIM-MHO [16]. KIM-MHO is a method typically used when there is repetitive movement and when there is force exerted by the upper extremities using instruments. Typical activities are, among other activities, assembly, sewing and wrapping, which are exactly the tasks under study. KIM-MHO

has four levels of risk; green, yellow, orange and red. The green level corresponds to a low risk (risk < 20 points), the yellow level corresponds to a slightly increased risk [20;50] points, the orange to a substantially increased risk [50;100] points and finally the red level corresponds to a high risk (>100 points). Concerning the heat application operation, RULA method was complemented with the Revised Strain Index (RSI) method [9], as it is a method indicated for tasks with a predominance of manual work and repetitive efforts in which workers are continuously exposed to the risk of developing WMSD of the Distal Extremities of the Upper Limbs (EDS) [9]. RSI presents a set of tables to determine the multiplier associated with each of the five variables. RSI value results from the product of the five multipliers and is interpreted as follows: $RSI \leq 10$ points, the job is probably safe, $RSI > 10$ points, work is probably dangerous [9].

4 Results and Discussion

The sample studied was entirely female ($n = 20$). Several studies concluded that women have a higher prevalence of WMSD because they are more exposed to physical and psychosocial risks at work (Hussain et al., 2016). It was observed that 55% of the sample is in the age range of 40 years old, 25% in the age range of 50 years old, 15% aged between 30 and 39 years old and finally 5% in the range of 60–69 years old. Regarding the seniority in the sewing operation, we can see that the population studied has been in the function for a considerable time, with 55% performing this task for more than 21 years. Five of these operators have been in the role for between 26 and 30 years and only two have been doing it for less than 10 years. Jia et al. [10], state that the prevalence of WMSD increases with age and years of work.

The use of the EWA method, as in a case study carried out by [6] in an industrial environment, allowed an initial characterization of the problem by identifying the risk factors that compromising the well-being and health of workers. The results obtained in the EWA evidence that the most penalizing element is the thermal environment, in which 85% of the operators classify it as very bad. Lighting is also an element that, according to the operator's evaluation, was highlighted, 55% consider it bad and 10% very bad, which may eventually be contributing to the level of defects made and their non-detection. Postures and movements are classified as bad by 30% of operators and as reasonable by the rest. The elements evaluated with 4 points were the workspace, the postures and movements and the thermal environment. In the case of postures and movements, the video method was used to assess the evaluation. It was verified that the operators have to bend over, incline, in order to carry out the operation. Through the video method, it was also verified that the workstation does not allow any adjustment, to avoid deviation from the natural position. The more detailed evaluation of the “posture item” will be the object of a complementary analysis through ergonomic evaluation methods. The analysis of the results obtained through interviews with each of the operators, using the Corlett diagram, shows that the parts of the body in which the operators say they have more pain/discomfort

are the hands followed by the shoulders. In the case of the hands, basically, almost the entire population reports discomfort/pain in this part of the body, although both hands are critical, it appears that globally the left hand is worse than the right. The discomfort/pain in the hands is most likely because it is manual work and the repetitive movements associated with this type of work. Sixteen people reported having pain or discomfort in the left hand, including 3, with the highest grade 5, followed by three with grade 4. The left shoulder also has more complaints than the right shoulder. Eleven people reported having pain and discomfort in their left shoulder, of which 55% had grade 4 pain. The results obtained evidence the need of an ergonomic intervention because they affect a significant amount of the studied population. The intensity of the pain combined with the age of the operators suggests that we may be facing an important problem.

Ergonomic analysis methods were applied in sewing operation, with regard to the final result of the RULA method, score 7 and 6 were obtained. This means that for score 7 the workstation must be the object of immediate intervention and score 6 it is need an intervention soon, respectively. The highest score was obtained for the two shortest operators, possibly suggesting that the task is more penalizing for shorter operators. The KIM-MHO assessment indicated for this operation a risk of 2 meaning that the load intensity is slightly increased. There may be a physical overload for less resilient people, fatigue, a low degree of adaptation problems, which can, however, be compensated with break times. The KIM-MHO method for this level of risk recommends that for less resilient people, there is a redesign of the workstation, or preventive measures are taken.

The heat application operation is considered the most demanding operation by operators, which seems to confirm the results of the RULA assessment, which obtained a score of 7, which means that it requires investigation and immediate intervention. The evaluation of the heat application operation by the RSI method, indicates that only one evaluated operator has the RSI index greater than 10, so in this case we are facing a probably dangerous task.

The ring assembling operation has the shortest cycle time, probably for this reason, the KIM method did not give very penalizing results. The results of the RULA method for the assembling rings operation were 6 (an intervention is needed soon) and 7 (an immediate intervention is needed).

5 Proposal for Improvement, Validation, and Limitations

This section presents the improvement proposals, describes how it were validated and finally the limitations found.

6 Proposal for Improvement

Concerning to the referenced global aspects, it was highlighted the thermal environment and lighting. Regarding thermal environment; where temperature and relative humidity are included, at the closing date of this work it was not possible to take a corrective action, due the cost that the energy losses in the building represents. In order to mitigate the risk it was implemented an anti-fatigue mat, that in addition to its function to minimizing fatigue plays an important role in avoiding the cooling the feet and minimizing the thermal discomfort. Regarding lighting, the type of lamps used was changed from fluorescent to LED and the illuminance values were increased in order to be within the specified in the organization's internal standard. It is suggested the inclusion of the luminaires in the Preventive Maintenance plan, so that they are cleaned periodically to prevent that, over time, dirt and possible insects, affect the current lighting conditions. To improve the posture relative to the operators in sewing and heat application operations, it was implemented, an individual workstation as represented in Figs. 2 and 3, instead of a table as illustrated in Fig. 1. The individual workstation allows, through compressed air, to adjust the steering wheel positioning arm more effectively, by activating the pedals, with a better adaptation of the operator position.

With regards to the heat operation, the front part of the dryer was eliminated as it is not necessary for this model, which represents handling less 104 g. The dryer, which as previously loose at the workstation, was supported with a stretcher with an adjustable pressure to minimize the impact of the weight. Operators can pre-adjust this force, according to their characteristics to facilitate the task. Fixing the dryer also allows for the minimization of possible accidents at work due to burns, by accidental touching, a risk identified in the EWA questionnaire. Overall, the station was also equipped with supports for placing the tools and materials used during the process, allowing the workstation organization and being a facilitator for defects reduction



Fig. 1 Workstation before improvements implementation



Fig. 2 Workstation after improvements implementation

and dirt caused by glue/loctite. Additionally, in order to maintain conditions, it is recommended to implement a quick checklist at the beginning of the shift, so that it can be verified that the post maintains the appropriate conditions.

Concerning to the ring's assembly, the operation difficulty penalizes the posture of the operators. To solve the problem, it is necessary to change the PU injection mold, to facilitated the insertion of the rings and as well eliminate the GAP. This change is feasible and is in the process of being implemented. To facilitate assembly, an arm was placed on the steering wheel positioning post, which allows one of the hands used to fix the steering wheel to be freed, improving the assembly posture, and finding the best assembly angle.

Replication is recommended for the remaining workstations. It is suggested that when replicating workstations, the layout will be taken into account and that it be the closest to the current situation, in order to continue to allow the communication between the operators. The aspect of having free communication is highly valued by the operators, and it is of crucial importance to safeguard it, to avoid additional resistance to the new workstation.

Fig. 3 Workstation after improvements implementation



7 Results Validation

The impact of the interventions was evaluated by the monetarization of quality results, productivity, applying again the EWA, the Corlett diagram and re-evaluate the operations with ergonomic methods. The verification of the effectiveness of the implemented measures was made only for one operator because there is only one station modified. The operator chosen was the operator with the worst quality results. There was a period of testing the improvements of 1.5 weeks, during this period some readjustments were made; for example, in the height and type of luminaires, position of the dryer, implementation of additional supports to facilitate the operation. After this readjustment period, the station was used for another two weeks.

Concerning the quality data, rejection rate passed from 25.4% (before the intervention) to 8% (after the intervention). Therefore, ergonomic interventions can improve human performance, reducing errors, resulting in better quality [7]. Ford, in its corporate ergonomics program, was also able to correlate the reduction of ergonomic risk in workstations with an improvement in product quality [4]. Additionally, Zare et al.

(2015), reviewed 25 studies, of which 13 in the automotive industry and concluded that there is strong evidence between ergonomics and quality results. Regarding productivity, the cycle time of 6 steering wheels was measured and the average of their times was calculated. After implementing the improvements, a decrease in the cycle time of 4.25 min was found. There are several reports that confirms an increase in productivity after interventions in terms of illuminance [12]. Through the EWA questionnaire, before and after the implementation of the measures, it was verified that the thermal environment, the classification changed from very bad to good, a classification that has to do with the implementation of the foot mat that prevents direct contact with it, but above all because the first application of the questionnaire was in January (Winter) and this second application in June (Summer) when there was a substantial increase in the interior temperature of the building, which the analyst's assessment confirms. Regarding lighting, both assessments (operator and the analyst) coincide. This improvement in the score is because the type of lamps were changed and the illuminance values were adjusted to the established values at the level of the internal procedure. The items of repeatability of work and communication also show improvement, from the point of view of the operator's perception, however, the analyst does not confirm the improvement in these items, since there is no change in these items. Physical activity in general goes from very bad to good according to the assessment carried out by the operator, and this improvement is confirmed by the analyst's assessment. The analyst also confirms the postures and movements improvements as well as the workspace; the tools are now more organized and accessible within the operator's reach. The pain diagram does not reveal any change between the months of January and June, which in a way turns out to be normal, due to the short time that the worker is at the post with the improvements implemented. It is expected that with continued use of this station, the symptoms currently existing will improve and not evolve into more serious conditions and, above all, not manifest themselves in workers who do not currently have symptoms.

For the three operations, sewing, heat application and rings assembly that were the subject of the diagnosis in Sect. 3, the same ergonomic evaluation methods were applied after the improvement, with a comparison of the results before and after the improvements implementation. The evaluation using the KIM-MHO method was excluded, because it was verified not to be the most appropriate method for evaluating these operations, as explained in the results.

For the sewing operation, the final score of the Rula Method, shows that the implemented measures contributed to improving the risk level of WMSDs, given that the final score went from 6 to 4, that is, it was no longer required an investigation and intervention soon, indicating now only the need for further investigation. There was an improvement of one point in the position of the arm and wrist, however the item that most contributed to the improvement was the position of the neck and trunk. The improvement in this score is because the operator can now move and position the steering wheel by pressing a pedal (hydraulic system) and therefore it is not necessary for the operator to adjust his posture to steering wheel position. Also, Arunkumar et al. [3] in their study in the automotive industry improved the RULA scores through the implementation of hydraulic systems, reducing the ergonomic

risk. Kogi et al. [11], refers that improving the luminosity conditions on the surface of work, helps to decrease operators' slouching and reduce neck and back strain. The final score of the RULA Method indicates that for the dryer operation, there is also an improvement, although this is not as expressive as that obtained for sewing operation. It goes from a situation scored 7, in which immediate intervention is required, to a score of 6, which requires intervention soon. The improvement of the overall results in the sewing operation is in terms of the position of the arm, wrist, neck, and torso. Although an improvement is noted, another solution would have to be studied to optimize these results. It is recommended to invest in the training of glue application in the steering wheel glue to avoid the formation of wrinkles and reduce the need of heater usage. The RSI evaluation indicated that it was a probably safe task before the improvement, results that are maintained after the improvements application, not appreciating significant changes in the different multipliers. The final score of the RULA assessment for the ring assembly operation goes from 6 (before the improvement) to 3 (after implementing the improvements), i.e. there is no longer any need for an intervention soon. This improvement in the score is due to the fact that an axis was implemented for positioning the steering wheel, which improves the operator's posture; having eliminated the postures of great flexion of the trunk and neck adopted when the operation was performed in the table.

8 Limitations

The main limitation of this work was related to two aspects.

The first one was the application of improvements at a single station, with the results only being valid for one operator.

The second limitation had to do with the resistance of the operators. They are people with many years in the job, used to carrying out the task in one way, making it quite difficult to introduce improvements, as a simple change causes a great source of entropy.

It was also found that in the new station, although it's adjustable, the adoption of postures used in the station before the improvement was frequent. Therefore, for the measures to be maintained over time, continuous monitoring and postural re-education would be necessary. It would be interesting to implement a program of labor gymnastics to mitigate some of the current symptoms perceived through the Corlett Diagram.

9 Conclusions

The objectives of this work were achieved. The evaluation of the effectiveness of the implemented improvements confirmed it. The quality and productivity indicators have improved, and the ergonomic evaluation of the workstations also shows a

significant improvement. The work pattern created can also be easily adapted to any model and/or operator.

The characterization of the population and the results obtained in terms of diagnosis showed that it was imperative to carry out a massive intervention in this activity, to mitigate the risk of musculoskeletal diseases progression and, to a certain extent, guarantee the sustainability of the business. It is also concluded that from the methods used; RULA, RSI and KIM-MHO, the method that was most adapted to the diagnosis of this activity was the RULA method, since it was the most penalizing method. In other words, compared to the other methods used, the RULA method was the one that best identified the risk and the need for intervention, which in a way is in line with the literature, which was referenced throughout this work.

The application of the EWA questionnaire was an excellent complementary tool for diagnosing additional problems, such as illuminance, a vital variable for this type of activity. The Corlett diagram allowed highlighting the risk that currently exists. It was also verified that the three operations studied, sewing, heat application, and rings assembly have an associated risk.

The set of all the improvements applied to a station made it possible to reduce the risk, but not to solve the currently existing problems. It would be necessary to continue to carry out improvements. It would also be necessary to do the analysis of the remaining tasks before replicating and transversalizing the created model to the rest of the activity.

Acknowledgements This work has been supported by FCT—Fundação para a Ciência e Tecnologia within the R&D Units Project Scope: UIDB/00319/2020.

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Development of a Rapid Assessment Method of the Potentiality to Transform Manufacturing Workstations into an Assistive Collaborative System



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Abstract Work-related musculoskeletal disorders, and the aging of the workforce are two of the major issues that the industry is facing nowadays. A possible solution to reverse this situation could be the implementation of an assistive flexible solution such as collaborative robots (cobots). Although, most of the implementation of these technologies in the industry is not taking advantage of the main strengths of cobots, such as their flexibility. This work aims at developing a methodology to evaluate the potentiality for the implementation of an assistive collaborative system in existing workstations. The selection of parameters for this methodology is presented, as well as an example of its application on a furniture assembly workstation. The method considers the following criteria: physical ergonomics, cognitive ergonomics, health and safety, product and process quality, collaboration, economics, and technical requirements. The results show the relevance of the developed assessment method, namely, its success in pointing out the main critical issues of the existing

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workstation. Further work will include the validation of the methodology throughout a focus group and the development of a digital tool to ease its application.

Keywords Ergonomics · Health and safety · Productivity · Collaborative robotics · Potentiality assessment

1 Introduction

Industry 5.0 is the new industrial paradigm understood to recognize the power of industry to achieve societal goals, by making production respect our planet's boundaries and putting the well-being of workers at the core of the production process [22]. At present, workers and industries face two major problems. One of them is work-related musculoskeletal disorders (WMSD), which is one of the most serious occupational health issues in industrialized societies, accounting for a significant portion of occupational absenteeism and decreased productivity [8]. The other problem is related to the aging of the working population, along with raising of workforce' retirement age. The issue here is that as people age, their ability to perform a task that requires both physical and mental effort tends to deteriorate [3]. This requires the re-design of the workstation, accounting for the physical and cognitive limitations of their users.

Collaborative robots (cobots) are one of the enabling technologies of Industry 5.0, providing a technological solution for adaptive workstations, promising to solve the issues related to physical and cognitively demanding tasks [4]. Cobots have been developed to assist workers in demanding tasks since they were intended at assistive joint actions with human workers [17].

A traditional workstation should be analyzed during the conversion process to determine whether it is possible and appropriate to convert it into a collaborative system. On this topic, [18] presented a framework for agent allocation (human or robot), considering task completion time and human physical strain. More recently, [9] proposed a method to assess the potentiality for the implementation of cobots. This method considers different criteria. Each one presents a limited number of sentences to assess its score for the final assessment of the potentiality. This type of assessment is becoming increasingly important to be able to support the decision to implement cobots. Their implementation needs to account for their strengths to increase their potential application. Otherwise, they may be coming to be used as traditional robots, performing simple repetitive tasks near the worker (due to their improved safety features) without taking advantage of their characteristic flexible application [14].

This study is the preliminary phase of a research project whose goal is to develop an assistive joint action interaction between a human and a cobot, in which the latter adapts to the physical and cognitive human constraints. This will be based on the results of a real-time ergonomic assessment framework further developed. The current work is a pilot study, conducted to evaluate the feasibility of the changes

proposed to a method developed by Gualtieri et al. [9] to assess the potentiality for a collaborative workstation. The main changes are the addition of new categories, as well as the inclusion of precise guidelines which help to score each considered category. Thus, this work focuses on the adaptation of a methodology to support the assessment of the workstations' potentiality for the implementation of an assistive collaborative system.

2 Materials and Methods

The proposed method was tested in a furniture assembly workstation of a Portuguese company in the civil construction sector. We assessed one workstation (with one worker allocated). The subject in this study signed an informed Consent Term in agreement with the Committee of Ethics for Research in Social and Humans Sciences of the University of Minho (approval number CEICSH 038/2020), respecting the Declaration of Helsinki. To collect relevant data (such as production process and workstation organization), the worker and the managers were interviewed. Additionally, a video recording was made, contemplating numerous work cycles.

2.1 Proposed Method to Assess the Potentiality for an Assistive Collaborative Workstation

This method can be divided into two steps: (i) characterization of the existing workstation; (ii) Assessment of the potentiality for an assistive collaborative system.

2.1.1 Initial Characterization of the Existing Workstation

The characterization of the existing workstation has the purpose to gather information related to the production process, as well as the working conditions. The method that best suits this purpose is the Ergonomic Workplace Analysis (EWA) developed by the Finnish Institute of Occupational Health (FIOH) [1]. This is among the best-known methods to achieve a systematic and comprehensive assessment of the workstations. It covers 14 topics, such as general physical activity, risk of accidents, and work content. For this article, we only considered the first eleven topics. It includes both workers' and expert's opinions. On each topic, workers subjectively assess their workstation on a four-level rating scale, while the expert evaluates the same topics using a 4 or 5 scale (some topics have a 4-level scale while others have a 5-level scale, only for the expert assessment). In this case, a score of 5 (or 4 for some topics) reflects the greatest risk for the worker on the topic under consideration. Additionally, in this method, the data collected, not only include information required to complete all

topics assessments, but also other useful information (such as manual tools utilized, variety and complementarity of task functions, and shift length) [6]. All terms on each topic were defined and explained to the worker, to ensure that he understood what needed to be evaluated. Given the scope of the EWA, it will support the decision of the score of each category of the method following presented.

2.1.2 Assessment of the Potentiality of an Assistive Collaborative System

This novel method is an improvement of a previous one developed by Gualtieri et al. [9]. The original method includes the following categories: safety and ergonomics, production and process quality (PPQ); and economics (EC). We decide to divide the first category into physical ergonomics (PE), cognitive ergonomics (CE), and health and safety (HS). We maintained PPQ and EC categories. Additionally, we added new categories: technical requirements (TR) and collaboration (CL). TR is because as been shown that the technical features of a cobot are of major importance for their feasibility in the workplace [20]. The inclusion of the CL category is justified by the fact that cobots were developed to work along with workers. Although previous studies show that in industry, they have been used as traditional robots that can be close to humans due to their safety features [14]. Therefore, the inclusion of this category is intended to assess whether a task is complex enough to be performed jointly by a human and a cobot.

Each category has a predefined weight according to its relative importance for the calculi of the potentiality (Fig. 1). Only the TR category has not a weight attributed once it is an eliminatory category. That is if an activity can't be efficiently executable by a cobot the potentiality for an assistive Human–Robot Collaboration (HRC) system of that task must be 0.

Greater weight was given to the PE, CE, and HS categories, according to Industry 5.0 principles, which puts the human worker's well-being at the core of the production process [22]. After that, this methodology considers both CL and PPQ categories. The CL category is mainly because we aim for assistive joint action between the human worker and the cobot, and therefore this factor has a relatively high importance. The PPQ category is a crucial issue for most companies [9]. The factor with less weight is related to economic factors since has been proven that the best way to reduce costs in industrial manufacturing is by considering the well-being of the workers (already considered in the first three categories) [21].

Additionally, each category has an intrinsic score to define within a category their importance for the final score. To help in this scoring a set of checklists/decision trees related to each category was defined. This improvement has been made since we considered that the proposed changes were relevant to better assess the score of each category. In the original method, each category was assessed according to a limited number of sentences, according to a simple scale. In this novel method, the score can range from 0 to 3, according to the number of issues/situations related to each topic found in the existing workstation (Fig. 1).

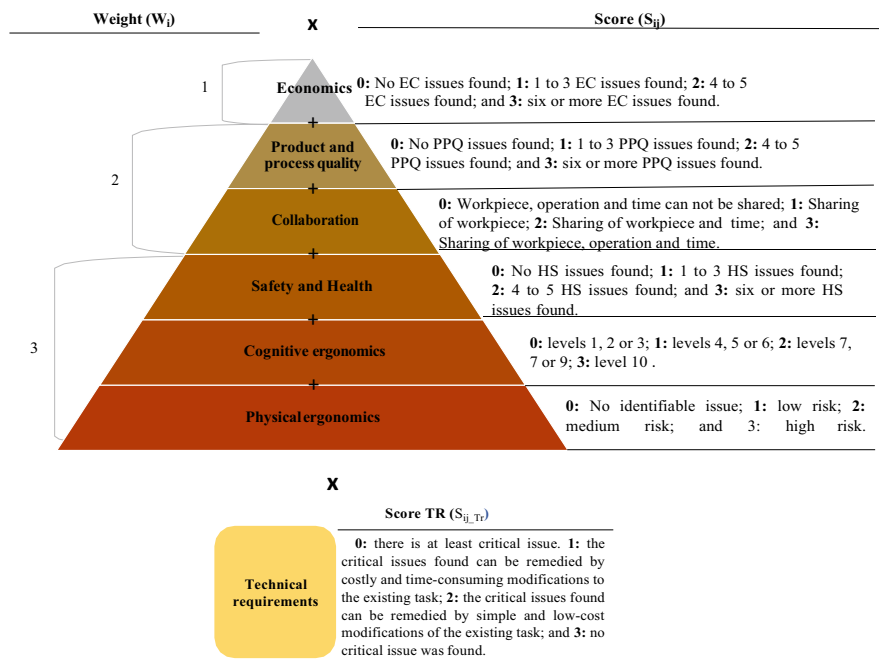


Fig. 1 Method weights and scores for the assessment of the potentiality for the conversion of an existing workstation into an assistive collaborative system

PE scoring can be done with the help of a checklist developed by the Occupational Safety and Health Administration (OSHA) [15]. Lin et al. [12] have shown that this checklist provides an easy surveillance instrument to assist in the early identification of WMSD discomfort.

CE scoring was made according to the Bedform Workload Scale [19]. This scale was designed to identify workers' spare mental capacity while concluding a task. Originally, it was constituted 10 different levels. For this specific case, we turn these levels into four scores categories ranging from 0 to 3, according to [5].

HS scoring is based on the premise that if a task puts the operator under dangerous conditions the score of this category will be greater, leading to an eventual higher score for potentiality for HRC. This is due to be advised to use the cobot for hazardous and unhealthy tasks to protect the workers from potential risks that may develop during the manufacturing process [10]. With this in mind, we used the statements from topic five 'risk of accident' from the EWA method [1] to help in the selection of unsafe conditions.

CL scores were assigned based on the task's complexity. That is, to what extent does the existing task allows for the sharing by the human and the robot of three criteria: workpiece, operation, and time. This is in line with the four types of collaborative modes [11] that a cobot can perform. When it is possible to share the same workpiece during the same operation at the same time, the higher the score.

PPQ scoring was done according to a list of factors established by Barnes [2] and Pal Singh [16] related to not constant/satisfactory product quality due to product design defects or the use of inappropriate production methods. Examples of these factors are ‘the lack of standardization prevents series production’ or ‘use of inappropriate tools’. Automation is an effective method for improving process control and uniformity, which in turn improves quality by lowering process variability and instability [10]. When a task under evaluation presents more issues, means its PPQ score is lower, which indicates the need for automation.

EC category is related to productivity. Several internal and external factors can impact an organization’s productivity, and thus an individual workstation. The first one is within the control of managers and includes several limitations within the operations of an organization. The latter is beyond the control of any employer, and for that reason is not included in this method. The scoring of this category was done according to a list of factors stated by Barnes [2] and Pal Singh [16] related to unproductive times factors attributable to management and workers. Examples of these factors are ‘excessive variety of products’ and ‘breakdowns’.

TR is of major importance when implementing a system. A production system’s primary goal is to deliver product on time, within budget, with high quality, and with flexibility [7]. Hence the technical requirements of a collaborative work cell are related to handling requirements, process requirements, and production requirements [13]. A list of critical issues related to these TR is presented by Gualtieri et al. [10]. To this list, we added, ‘the component weight is greater than the cobot or gripper payload’.

The Eq. (1) for calculating the potentiality (P_{assis_colab}) is presented below, along with method’s final score levels. The rationale for this scale’s division was done linearly, by dividing the maximum possible score by four.

$$P_{assis_colab} = \left(\sum_{i=1}^6 S_{ij} \times W_i \right) \times S_{ij_Tr} \quad (1)$$

The final score (P_{assis_colab}) demonstrates the potentiality for the implementation of an assistive collaboration system, and it is segmented into five levels:

- No potential: $P_{assis_colab} = 0$;
- Low potential: $1 \geq P_{assis_colab} > 31.5$;
- Modest potential: $31.5 \geq P_{assis_colab} > 63$;
- Good potential: $63 \geq P_{assis_colab} > 94.5$;
- High Potential: $94.5 \geq P_{assis_colab} > 126$.

3 Results and Discussion

This section shows the results of the application of the proposed method in a furniture assembly workstation. We first present the findings from workstation' characterization, followed by the findings from their potentiality for conversion into an assistive collaborative workstation.

3.1 *Results of the Characterization of the Furniture Assembly Workstation*

The furniture assembly workstation is composed of 5 different tasks, namely, T1: placing the rails in the drawers; T2: fixing the gutters with screws, T3: placement of the drawers; T4: placement of the drawer' mirror; and T5: fixing the drawer' mirror.

Related to EWA results (Table 1), from the worker's point of view, the worst topics of his workstation are 'work postures and movements', 'restrictiveness', 'decision-making', and 'level of required attention'. The expert agrees with the worker's classification in the following topics 'work postures and movements' (mainly due to trunk rotation and inclination without support, and upper arm in extreme positions), and 'decision-making' (due to the several levels of instructions needed to assemble different types of furniture manually). These results reveal that the main concerns in this workstation are related to physical and cognitive ergonomic issues.

3.2 *Results of the Evaluation of the Potentiality for an Assistive Collaborative System*

Regarding the results of the potentiality for an assistive collaborative system (Table 2), most of the tasks assessed have a modest potential. The only task that has a low potential is T4.

The highest score for PE is mainly due to the neck, back, and upper limb positions adopted during the work. In T1-2, the worker presents back and neck extreme flexions and deviations of the wrist.

Related to CE, the highest score is attributed to the almost inexistence of spare capacity due to the high decision-making (high level of information required). This happens in T2 and T5 since the worker needs to measure the right spot to fix the gutters and the drawer' mirror, respectively.

HS score (1 point for all tasks) is attributed due to the absence of more than three health and safety issues. The HS issues are related to the fall of work objects, a fall due to a slippery floor, and/or the existence of conditions to cause an accident due to incorrect movement or posture.

Table 1 EWA results

	Worker	Expert	Justifications of the expert assessment
1. Workspace	3	2	Despite the necessary compromises, the postures and movements carried out are adequate considering the requirements of the activity
2. General physical activity	2	2	The activity depends in some way on the methods of production or the organization of work. There are some work peaks but no risk of causing overload
3. Lifting tasks	3	3	Heavier load weights 19 kg
4. Work postures and movements	4	4	Trunk rotation and inclination without support, and upper arm in extreme positions
5. Risk of accident	1	2	It is possible that a bump, blow, or fall is caused by a protruding part (low severity, considerable probability)
6. Work content	1	3	The worker only performs a part of the work entity
7. Restrictiveness	4	2	Tasks or work methods are sometimes constrained by process requirements or production methods
8. Workers' communication	1	2	Communication and contact with people are possible but limited due to noise
9. Decision-making	4	5	The worker involves several levels of education. A wrong decision can lead to material damage
10. Work repetitiveness	3	2	Cycle duration between 20–30 min
11. Level of required attention	4	3	Medium level of attention in less than 60% of the cycle

Table 2 Potential for an assistive collaborative system result

	T1	T2	T3	T4	T5
PE	3	3	2	1	2
CE	1	2	1	1	2
HS	1	1	1	1	1
CL	1	1	1	1	1
PPQ	1	1	1	1	1
EC	1	1	1	1	1
TR	3	2	2	1	2
P _{assis_colab}	60	46	34	14	40
Meaning	Modest potential	Modest potential	Modest potential	Low potential	Modest potential

The CL, PPQ, and EC categories were scored with 1 point, for all tasks. Related to the CL category, the score attributed means that the cobot can do a part of the tasks of the workstation, while the worker performs the others. Related to PPQ and EC, the score means that their related issues are less than three. For the PPQ category, the issue found is related to the lack of standardization while for the EC category, is related to excessive variety of products, and/or changing of production models.

At last, related to the TR category, the results point out that all the tasks can be performed by a robot. Some of them with simple and low-cost changing to manual operation (T2-3, T5), while just one with costly and time-consuming modifications (T4). Critical assembly issues found include the assembly sequence requiring high physical dexterity, components providing resistance to insertion, and/or the assembly sequence requiring two hands for handling.

Overall, the results reflect that the main contributors to the final score of each task are related to physical and cognitive ergonomics factors, as well as technical requirements. This is in line with the EWA results. The fact that only three factors are mostly contributing to the calculation of potential, explains the level of potential attributed to most categories. This is in line with what was expected for this method.

The application of this method would benefit modern industry and automation since it will allow for a first screening of existing conditions for the implementation of assistive solutions. The major applications of robots in the industry reveal simple interactions with workers, whereas robots just work around humans. This does not take advantage of the strengths of robots, as they were developed for true collaborations with humans. The potential to provide flexible alternative solutions to the workstations allows the workers to be more efficient and productive, and reduces their exposure to repetitive and dangerous tasks, giving them spare time to deal with more cognitive challenge tasks [14].

4 Conclusions

The current study focused on the adaptation of a previous method to assess the potentiality for the conversion of a traditional workstation into an assistive collaborative workcell. The novel method considers numerous criteria (assessed throughout several guidelines) with different weights that allow computing a final score of potentiality.

The results of the application of the methodology point out, that this method not only allows for the evaluation of the potentiality for a cobot system implementation but also allows for the discovery of the main critical issues of the existing workstations. This will be a primary asset for the redesign of the existing workstation, considering the implementation of a cobot in an assistive mode.

The major limitation of this study is related to its application in only one workstation. However, this fulfilled the purpose of this pilot test, as it allowed testing and revising the application of this method. It is important to emphasize that this study is a starting point for a more comprehensive research foreseeing the validation of this method. This validation will start with the replication of this application in a major

number of workstations. Additionally, a focus group with specialists in both areas of Ergonomics and Human Factors and Robotics is also expected. A creation of a digital tool to ease the use of this methodology will be also created.

Acknowledgements Work supported by the PhD Grant SFRH/BD/151365/2021 financed by the Portuguese FCT, and with funds from state budgets, under MIT Portugal Program, FCT Project I-CATER (ref. PTDC/EEI-ROB/3488/2021), R&D Unit Project Scope UIDB/00319/2020, and DTx CoLAB under the Missão Interface of the Recovery and Resilience Plan, integrated in the notice 01/C05-i02/2022.

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Ergo4workers: Usability Testing of the Second Prototype of an App for the Ergonomic Assessment of Healthcare Professionals



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Abstract Work-related musculoskeletal disorders (WRMSD) result from continuous exposure to risk factors associated with the workplace. They affect millions of workers worldwide, including those in the healthcare sector. One of Ergonomics' concerns is fitting job demands to workers' capabilities, namely by providing risk assessment methods as tools to support the implementation of preventive strategies for WRMSD. Currently, advanced wearable technology is being used to gather objective exposure measurements in a work context. Ergo4workers (E4W) is a system that includes a smartphone app to integrate data from wearable sensors. It was developed

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following the User-Centered Design (UCD) iterative process. This approach was adopted to design a useful and usable app that assesses healthcare professionals during their daily activities, namely by providing feedback on the working postures. This paper describes the design cycle's second iteration. The second prototype was designed according to user requirements, building on an initial prototype's findings, and was tested by a potential representative user using the Cognitive Walkthrough method. Test results evidenced adequate usability, and the healthcare professional expressed satisfaction regarding the interaction with the app. Furthermore, the new findings are being used to refine the design solution, to be implemented and evaluated in a third UCD cycle iteration.

Keywords User-centered design · User experience · Cognitive walkthrough · Wearable sensors · Ergonomic risk assessment

1 Introduction

Ergonomics is a scientific discipline that mainly focuses on offering principles and methods to fit workplace conditions and job demands to workers' needs, capabilities, and limitations [10, 11]. Thus, it adopts a systems approach to ensure that humans and their work environment interact in harmony. This outcome can jointly improve the production system's overall performance and the worker's well-being [8, 11, 19]. However, many real-world working activities were not designed observing these principles, and the necessary balance between work demand and worker capabilities is not met, resulting in a situation where work-related musculoskeletal disorders (WRMSD), among other problems, can occur [6, 18].

According to the European Agency for Safety and Health at Work (EU-OSHA), musculoskeletal disorders (MSD) "cover any damage or disorder of the joints or other tissues" [9]. Even though work is not the only cause [6, 18, 25], there is a strong correlation between MSD and occupational risk factors. Thus, continuous exposure to a combination of physical, psychosocial, or individual risk factors in the workplace contributes to developing WRMSD [17, 25–27]. However, it is reported that psychosocial and individual risk factors can not, on their own, originate the development of WRMSD [3, 17, 18].

WRMSD represent a central concern, as workers from several countries face health problems that can lead to temporary or even permanent disability. Thus, besides negatively impacting the worker's quality of life, WRMSD accounts for heavy costs for organizations due to loss of productivity and absenteeism [6, 18, 26]. The physical job demand of several sectors exposes their workers to working conditions associated with a high risk for WRMSD [3, 9, 25]. Literature reports that healthcare professionals experience work-related injuries and often acute pain, mainly due to the demanding nature of their daily activities [1, 2, 7]. Periodical risk assessments are essential for reducing or eliminating exposure to risk factors [6, 9, 27]. The prevention strategies can include self-reports and observational methods

as tools to support their implementation; however, these are subjective assessments when compared to direct measurements [14]. The technological evolution, often associated with Industry 4.0, promoted the use of advanced and innovative wearable devices for collecting data on work-related physical attributes in a reliable and non-invasive way. Therefore, this technology can positively enhance occupational health and safety; therefore, contributing to overall productivity [16, 20, 21].

Considering this context, Ergo4workers (E4W) was developed as a system that includes a smartphone app that aggregates data collected from wearable sensors and provides the interface with users. The mentioned data include relevant biomechanical and physiological parameters measured by four wearable sensor systems: a motion capture system, an electromyography system, a force platform, and a smartwatch. The E4W system's aim is to provide an ergonomic assessment of daily work activities by quantifying and providing risk exposure feedback (e.g., posture and force) to users.

The E4W development cycle followed a User-Centered Design (UCD) approach. UCD consists of an iterative design methodology that focuses on explicitly understanding the needs and preferences of the users, as well as the goals they are hoping to achieve and the environment in which the system's interaction will take place [24].

Given the importance of addressing the user experience (UX) when designing interactive systems [5, 12, 23], the UCD approach requires applying usability knowledge, especially regarding effectiveness, efficiency, and satisfaction, which are the critical usability measures [12]. Usability testing is crucial for assessing the accuracy and speed with which the user completes a task or set of tasks (effectiveness and efficiency), as well as the level of acceptance and comfort they express while interacting with the system (satisfaction) [4, 13, 23, 24].

The UCD process is conducted by performing three phases iteratively: specifying user and design requirements; solution design and implementation; and evaluation. Before performing these activities, it is also fundamental to understand the context of use by specifying user, tasks, and environmental characteristics [12].

Regarding the evaluation phase, the Cognitive Walkthrough (CW) method was applied. Initially proposed by Polson and colleagues, this method analyzes the user's problem-solving process [22] and is frequently applied for the usability evaluation of interactive systems [5]. As stated in [13], involving potential users as test participants is preferable since it allows them to explore the system directly [13].

Thus, the initial stage of the E4Wapp's UCD cycle started by understanding the context of use and defining the required functionalities. The design of the first prototype involved a literature review, the design of a mock-up, and a brainstorming session. This process also involved the active participation of a representative group of potential users (i.e., healthcare professionals) composed of six occupational therapists from a Portuguese hospital. The evaluation of the app's usability was performed using the CWU method, involving seven participants in a laboratory environment. The results evidenced that some modifications had to be performed to improve the UX, for instance:

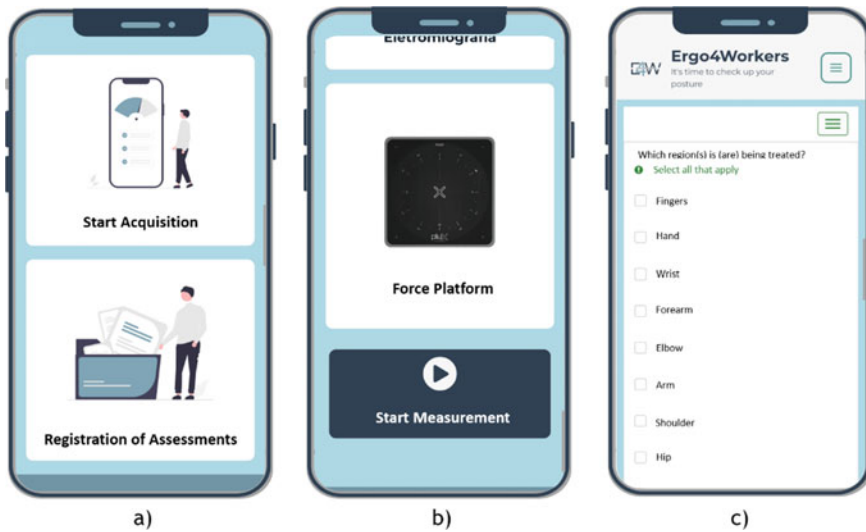


Fig. 1 Examples of interfaces of E4W's first prototype that required modifications: **a** Home page; **b** Page providing information on sensors' placement and calibration; **c** Survey to characterize the session

- On the home page, “Registration of Assessments” did not properly reflect the action it was intended for (which was consulting reports of previous ergonomic assessments performed) (Fig. 1a);
- On the page providing information on sensors' placement and calibration, participants experienced difficulties in understanding that this page only included informational content and that the next action required selecting the button “Start Measurement” at the bottom of the page (Fig. 1b);
- After submitting the survey, some participants were confused regarding the next action since they could not view the alert message to confirm the submission (at the top of the page) nor the button “Next” (at the bottom of the page) (Fig. 1c).

This paper reports the second iteration of the E4W's development cycle that addresses the improvement opportunities previously described. So, the paper describes the E4W second prototype and presents its usability evaluation results.

1.1 E4W App: Second Prototype

As mentioned, the E4W app is intended to provide access to the ergonomic risk assessments of healthcare professionals. As so, the app's main functional requirements, defined in the first iteration of the design process, included allowing real-time

data acquisition and providing access to reports on current and previous data acquisition sessions. For this specific context of use, an acquisition session corresponds to a therapy session, and users are able to introduce relevant characteristics of each session by filling in a survey.

The second prototype's implementation focused on solving the usability problems experienced by participants in the first prototype's evaluation. Hence, examples of the modifications performed included: reduced.

- The button label “Registration of Assessments” was replaced by “Consult Reports) (Fig. 2d);
- The button label “Start Measurement” was replaced with “Next”. Additionally, the layout of the page was altered. The fields presented for each wearable sensor system (in white) were reduced so that users could view the button “Next”. A more detailed description of the content displayed on this page was also added (Fig. 2e);
- The session characterization page layout was modified. The field included for filling in the survey was reduced, and a title was added so that users are aware of the aim of the survey (Fig. 2f).

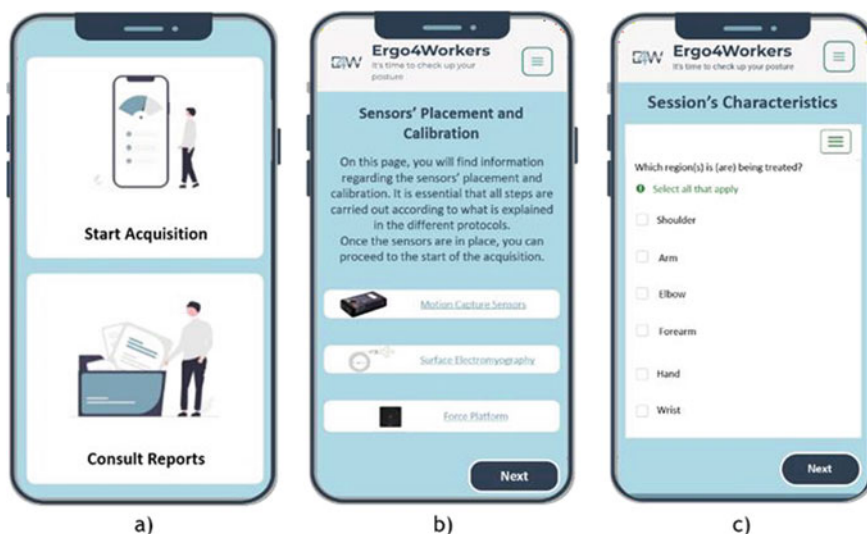


Fig. 2 Examples of modifications implemented in E4W's second prototype design: **a** Home page; **b** Page providing information on sensor's placement and calibration; **c** Survey to characterize the session

2 E4W App: Second Prototype Usability Testing

The main priority when planning a usability evaluation is to clarify the test goals, which should focus on what the researcher wants to learn regarding the users' experience [4]. The evaluation of E4W's second prototype aimed to assess whether additional usability problems were identified and if the design solution met the requirements and needs of the representative group of potential users. Considering comparability between iterations, a usability test was carried out under the same conditions as the tests of the first prototype, and it involved one occupational therapist. This participant was a 55-year-old female.

Furthermore, a CWU variant was applied to the usability evaluation involving three task scenarios. The scenarios were selected considering the most critical tasks the user must be able to perform while interacting with the app [15], which are the following:

- Scenario 1 (Sc1)—Logging in.
- Scenario 2 (Sc2)—Initialize an acquisition session with the following characteristics: (1) patient's type of condition—rheumatological; (2) treatment regions—hand, fingers, and fist; (3) workspace—high table and chair.
- Scenario 3 (Sc3)—Access the report of the previous acquisition session.

Quantitative data on the performance metrics were collected regarding the following parameters: task success; time required to perform each task (in seconds); and number of errors and actions performed. Moreover, the participant's level of satisfaction was analyzed by asking the user to express their thoughts during the test performance ("think aloud" protocol) and to propose suggestions at the end of the test [13]. Satisfaction is a critical measure since it is related to the user's expectations of the system's usability [4].

3 Results and Discussion

Performance and satisfaction metrics were successfully collected to evaluate the usability of the second prototype.

Table 1 shows the results obtained regarding the participant's performance in the usability test. Given the main goal of this evaluation, which consisted of analyzing whether the modifications implemented in the second prototype met the user requirements, it was considered that one participant among the available sample of six occupational therapists would be sufficient. However, the sample size of one participant represents a limitation of this study, given that it can compromise the results' representativity. Nonetheless, the five remaining healthcare professionals (i.e., a larger sample of participants) are aimed to be recruited for the usability testing of the prototype resulting from the next iteration of E4W's development cycle.

Table 1 Usability metrics collected in the usability test

Usability metrics	Sc1	Sc2	Sc3
Task success	S	S	S
Number of errors	0	0	0
Time required to perform each task (s)	94	80	8
Number of actions performed	3	12	2
Number of actions predicted	3	12	2

S—Success; F—Failure

For each scenario (Sc), these metrics were analyzed and compared with the values obtained in the first prototype's evaluation. To facilitate the discussion, the number of actions predicted is, as well, displayed in the table.

It was verified that all task scenarios were performed successfully, without errors and with the predicted number of actions. Furthermore, except for the first scenario, the task performance duration was inferior compared to the mean value recorded for this metric in the first prototype's test. Since no modifications were implemented in the second prototype regarding the functional requirement "allow to log in to the app", this participant might have required more time to perform Sc1 due to struggles with the smartphone's keyboard, whose characters made it difficult to type. This occurrence was also verified in the previous usability tests while participants typed in the e-mail and password to log in.

Throughout the test and at the end, the participant's expression of satisfaction was consistent with her performance. The comments included positive feedback regarding the prototype's intuitive functionalities and the fact that progress is not lost when selecting the command to return to the previous page. A positive comment was the possibility of selecting multiple options for the patient's treatment regions when filling in the survey.

As an improvement opportunity, it was mentioned that the app would benefit from displaying the treatment regions in the survey horizontally rather than vertically (which is the layout of these multiple-choice options in the second prototype). In such a manner, the healthcare professional could view multiple options simultaneously, and the time required to fill in the survey's question would be reduced. Since the users' interaction with the E4W app is meant to occur during a workday, besides improving the UX, this modification would solve a current limitation of the prototype related to the app's intrusiveness with the healthcare professionals' work activities.

4 Conclusions

The E4W app aims to gather and provide access to data measured by wearable sensors during ergonomic assessment sessions of healthcare professionals' work activities.

The paper addressed the second UCD iteration of E4W's smartphone app design, a process focused on improving the user experience. It describes how the usability problems identified by participants in the first prototype's evaluation were addressed in the implementation of a second prototype. An occupational therapist was involved in this prototype's usability testing in a real work environment. As the main goal of this test was to assess if additional usability problems needed to be addressed, this evaluation was carried out under the same conditions as the first iteration. Usability metrics, such as task success and actions performed, of three task scenarios were collected by applying the CWU method. These results were compared with the ones recorded from the previous evaluation, and the participant did not experience usability problems. Furthermore, the healthcare professional's thoughts and suggestions reflected acceptance regarding using the system.

Besides confirming the efficiency of the first prototype's usability evaluation in a laboratory environment, this iteration of the UCD process allowed concluding that this simpler design version of the app matched the needs and expectations of this group of occupational therapists. Thus, the third prototype will be implemented as a more detailed design solution for E4W's app, and its remaining functionalities will be tested in a real work environment with a larger users' group. So, it is possible to conclude that the performance of the usability evaluation described in this paper represents an important step for the successful implementation of a final prototype of E4W.

Finally, the E4W was developed with the concern of being easily adapted to other work contexts and with a different users' target population. Thus, considering the aim of the E4W system and that its design adopted a UCD approach, this system shows the potential to improve the health, safety, and productivity of workers in various occupational groups while providing a good user experience.

Acknowledgements The authors acknowledge Fundação para a Ciência e a Tecnologia (FCT-MCTES) for its financial support via the project UIDP/00667/2020 and UIDB/00667/2020 (UNIDEMI).

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Development of a Questionnaire to Understand Future Users' Preferences About Human-Centric Autonomous Car Interior



Hatice Kirkici , Ana Colim , Paula Carneiro , and Paulo Pedrosa 

Abstract Recent technological news and developments demonstrate that autonomous cars and their interior will have the potential to offer numerous advantages to passengers and, consequently, it will affect their daily routines. Therefore, it is crucial to monitor the opinion of the population on this issue. The main objective of this study was to construct a questionnaire to evaluate the preferences of Portuguese users about human-centric car interiors and apply a pilot test to understand possible corrections that should be considered. The questionnaire was constructed based on a literature review and applied to a sample of 12 volunteers. According to the pilot test results, three questions need some improvements, and the participants made several suggestions. Overall participants' evaluations of the questionnaire showed that the duration, structure, clarity of the text and relevance of the questions are adequate. The revised questionnaire will be an essential tool to collect the preferences of possible users of autonomous cars.

Keywords Human factors · Ergonomics · Smart driving · User's needs

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1 Introduction

An autonomous car is a vehicle that can drive itself from one point to another without assistance from a driver; in other words, with an autopilot system [7, 15]. The Society of Automotive Engineering (SAE) categorized six levels of autonomy in a vehicle, whereby the human driver performs part or all the driving tasks from Level 0 to Level 2, while the automated driving system performs the entire driving tasks (while engaged) from Level 3 to Level 5 [19]. The autonomous vehicle is expected to open a new opportunity for the society in terms of mobility and access to transportation in improved traveling conditions. For that, autonomous vehicles are expected to attract great demand for the technology. The prospect of comfortable travel conditions, convenience and less taxing, as well as catering for the currently excluded group of society, could change how society values time on the road [9]. Time better spent on the road on autonomous vehicles can potentially increase demand, either by taking more trips or at longer distances on autonomous vehicles. Also, would help urbanization as travel cost reductions and increased time utility. Self-driving cars would not only give older people, or those with disabilities, the opportunity to use cars but also offer them more riding comfort due to smoother acceleration and less jerk. Yet, increased demand for autonomous technology might also bring unpremeditated results: extended parking times especially for vehicles doing point-to-point services, empty runs, untenable sprawl, etc. [2].

Automotive and technology companies have an onerous task ahead, not only to ensure that autonomous vehicles operate appropriately, but also to be able to interact with humans in all driving cases that could potentially occur. Ergonomics & Human Factors, User Experience, and Design researchers have an emergent opportunity to explore, research, appropriately design, and test all possible human-vehicle interaction scenarios to contribute to the success and potentially increase the likelihood of acceptance for autonomous vehicles [6].

As autonomous vehicles prepare to take a place in our society, many novel human factors questions are emerging such as the impact of rearward facing car seats on passenger well-being. These novel problems might require novel solutions, combining fundamental theoretical knowledge with human-centric design [11]. Human-centered design is a philosophy that empowers the teams and individuals designing products, services, systems, and experiences to address the core needs of those who experience a problem [17]. Autonomous cars with the new way of driving bring the topic of new interior and safety systems. A recent study [20] presented which customer-relevant properties can be used to describe the autonomous vehicle concept. In this study, a method for the autonomous vehicle concept was developed, that was based on customer structure, customer-relevant properties, external requirements, technical characteristics, and vehicle concept. In this domain, a pilot study [16] investigated expectations for future automotive technology. According to the studies cited, there is a need for human-centric design for autonomous car users, and it is therefore critical to understand the preferences of Portuguese users for autonomous car interiors, identifying new user profiles and new demands. To

date, several studies have conducted questionnaires investigating various aspects of autonomous car technology. However, most of these questionnaires focus on only one aspect of the autonomous car and there is no questionnaire that presents a comprehensive and human-centric approach for autonomous car technology [4, 8, 14]. At this point, it is necessary to construct a questionnaire to know Portuguese users' needs, preferred activities, ergonomic aspects, and design preferences.

The current study aims the creation and testing of a questionnaire to comprehend the preferences of future users about autonomous car interiors. The questionnaire's primary goal is to collect input about ergonomics and human-centric design choices, as well as new features/functions for future autonomous car users.

2 Materials and Methods

To achieve the objectives of the current study, we created a questionnaire based on scientific literature to collect information about human needs, preferred activities, ergonomic aspects, and design preferences related to the interior of autonomous cars.

Respondents were selected ensure the sample (1) consisted of those over 18 years of age, (2) Portuguese nationality, (3) Portuguese speaker. The primary focus of this questionnaire is fully automated (completely self-driving) cars, which require no human control. To figure out future design ideas and ergonomic feature preferences, it was important to know people's knowledge about future car technology and their willingness to use it [1]. Intelligent vehicles will let the driver leave the driver's seat. Therefore, drivers and passengers will no longer need to concentrate on driving tasks, at this point, new vehicle interiors will need to be redesigned considering new technological and ergonomic aspects [21]. The questions designed to understand the expectations of future users in the context of autonomous car interior design have been created considering previous scientific studies that are based on participatory design methodologies about this topic [13, 16, 18]. In this domain, it is also important to highlight the need for design requirements appropriate to prevent possible motion sickness. Drivers who have never suffered from motion sickness while driving, when riding as passengers in autonomous cars, may be susceptible to motion sickness due to the lack of control in the vehicle, in addition to sensory conflicts. Therefore, previous studies [5, 10] focused on the causes of self-driving car sickness were used to generate relevant questions to include in our questionnaire.

2.1 Questionnaire Design

The questionnaire consisted of 20 questions Table 1 shows the details of the questionnaire.

To evaluate the Portuguese population's comfort in different autonomy levels, their opinion about different ergonomic aspects, and new cars' features, it was defined

Table 1 Question types and respective description

Question types	Description
Option closed questions	• Sociodemographic data: gender, age, level of education, residence area of the participants • Car usage type (driver, passenger, or both) • Frequency of a car usage • Familiarity with the term of “autonomous car” • The opinion about if autonomous car will let users to be more productive • If they feel carsickness when they are passengers
Multiple answer questions	• How the users learn to use the technology of their cars (e.g., friends, websites, manual etc.) • The intelligent components (with images) they would like to have in the future cars (e.g., door panel, central console) • Activities the users would like to do inside the autonomous car
Statements to classify by Likert-scales	• Those questions’ target was to gather information addressing: • Comfort level about different levels of autonomy • Usefulness of the resources or functionalities (e.g., swivel seat, foldout display mounted on the vehicle’s roof) • Importance of ergonomic aspects (e.g., console customization, adapting to the needs of those who use it), usefulness of the resources or functionalities to reduce car sickness (e.g., keep constant speed)

statements for respondents to evaluate, based on related literature [1, 13, 21]. The participants have to classify the statements using a 5-Likert scale [12], indicating their level of agreement with each particular statement. The 5-Likert scales used are labeled as follows: 1-very uncomfortable/useless/not important; 2-discomfortable/sometimes useless/little important; 3-neutral; 4-comfortable/almost always useful/sometimes important; 5-very comfortable/useful/very important.

If the options in other types of questions do not match respondents’ opinions, it was created in additional four open questions that they can freely express their further opinions about:

- other activities that they would like to do inside the car in the future.
- other important ergonomic aspects in the interior of the future car.
- other intelligent components that they would like to have inside the car of the future.
- other ways to reduce their nausea in the car.

2.2 Pilot Test Procedure

The questionnaire was constructed in Google forms, allowing participants to take it online via computer or mobile device. Instructions for the questionnaire were given to the respondents at the outset, along with a warning that their participation was entirely

optional and that their responses would be kept confidential. The participants were also informed about the questionnaire and study objectives. They were accompanied by a researcher to measure the time and answer to possible doubts. The stopwatch method was used to measure how long it took to complete the questionnaire.

After the implementation the questionnaire participants were interviewed by the researcher to complete the pilot test. For this purpose, participants were interviewed considering the following questions and/or statements:

- Which question/s accrued more doubts?
- Do you have any suggestions to change?
- The duration was adequate (1-Strongly disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly agree)
- The structure of the questionnaire was easy to follow (1-Strongly disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly agree)
- The clarity of text was easy to understand (1-Strongly disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly agree)
- The questionnaire was relevant to the research objective (1-Strongly disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly agree).

3 Results and Discussion

A total of 12 participants (6 females, 5 males, and 1 other) from Portugal were involved in a pilot test. The main points of this pilot test were to know respondents' opinions, possible suggestions, and evaluation of the constructed questionnaire.

Relatively to the mean time consumed, it was estimated a value of 7.09 ($\pm$ 0.12) minutes. Based on this result, the "answering the questionnaire takes less than 8 minutes" statement could be used in the preliminary information for future applications of the questionnaire.

The results of the interviews showed that questions 9.19 and 10 created more doubts (Fig. 1). Question 9 (*How would you rate your comfort with the following level of autonomy*) was the question that created the most doubts from participants. Participants stated that the question was not clear enough for them to evaluate their comfort level. They also suggested that the question should have stated the autonomy of the autonomous car.

Question 10 (From the following intelligent components, select the ones you would like to have inside the car of the future:) and question 19 (Please rate the following statements according to how helpful they are in reducing your nausea) were also questions with doubts.

Question 10 included images and the participants suggested changing two images (dashboard and door surround area) that were not clearly presenting the components. Question 19 created doubts in participants who did not feel any car motion sickness. In this case, they suggested to change this question to an optional question.

Considering the Question 13 (*Select the activity or activities you would like to be able to do inside a self-driving car*) had many choices and participants indicated that

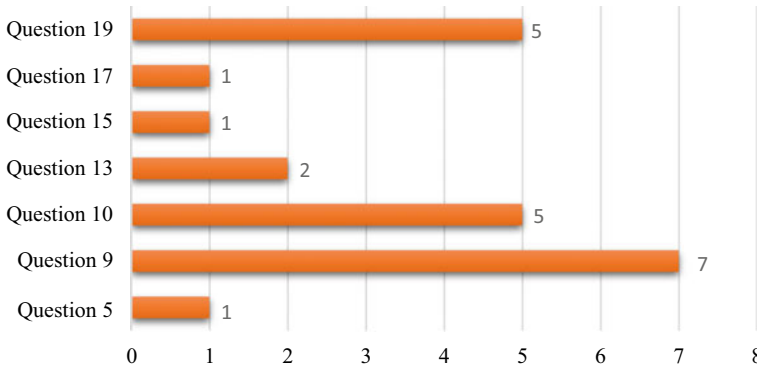


Fig. 1 Questions that created more doubts

those choices looked repeated and would be better if they simplified with groups. Question 5 (*Use of the car*) was not clear enough for one participant because of the choices (driver, passenger, or both) and it was suggested to be corrected as: *What is your frequent use of the car?*

Question 15 (Rate the usefulness of the following features or functionality inside the self-driving car) and 17 (If you consider that there are other important ergonomic aspects for the interior of the car of the future, please indicate which ones) was not clear for one participant.

In the last part of the pilot test, participants made an overall evaluation of the questionnaire (Fig. 2). Majority of the participants (83%) stated that the duration of the questionnaire was very adequate. Moreover, 59% of the participants strongly agreed with clear understanding of the text, 33% of the participants were agree and 8% of the participant answered neutral. The 58% of participants stated that structure of the questionnaire was adequate.

Finally, 50% of the participant stated questions in the questionnaire were very relevant in the scope of the research objective, 42% of them stated as adequate and 8% indicated a neutral answer.

As previous studies [3] mentioned results showed that the main issue of the questionnaire was the difficulty of imagining the technology currently not available to public. Therefore, participants stated that question 9 was difficult to answer, and the majority of the participants made suggestions on questions 9, 10, 19. Since these suggestions are considered appropriate, the future study will be aimed at improving the questionnaire in this direction and applying it to a large sample.

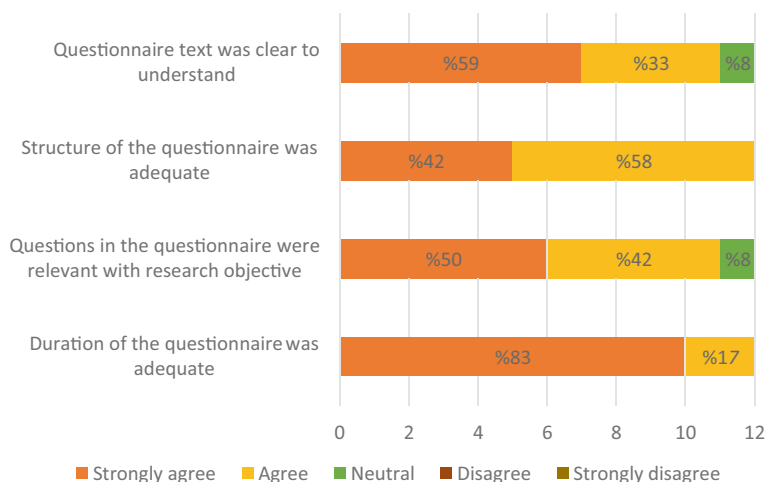


Fig. 2 Overall evaluation of the questionnaire

4 Conclusions

This study was conducted to develop one questionnaire about people's preferences for human-centric design of the autonomous car interior and perform a pilot test on it. The reason of the pilot test was to have participants' opinions for improving the constructed questionnaire. Participants made considerable recommendations about the questionnaire. The questionnaire will be improved because of this exploratory study, enabling it to be used with a large sample. Given that the questionnaire examines participants' preferences for future technology, it is fundamental in future studies to effectively explain automated and autonomous car technologies to participants.

Acknowledgements This research supported by the PhD Grant PRT/BD/152835/2021 financed by the Portuguese FCT and with funds from state budgets under MIT Portugal Program, FCT-within the R&D Units Project Scope: UIDB/00319/2020, and DTx CoLAB under the Missao Interface of the Recovery and Resilience Plan, integrated in the notice 01/C05-i02/2022.

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Occupational and Individual Factors for Musculoskeletal Pain in the Automotive Industry



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Abstract Nowadays, with the highly competitive industrial environment, new challenges are faced that increased the pressure on workers to improve productivity, with psychosocial factors playing a key role in the development of musculoskeletal pain. The aim of this study was to estimate the association of occupational factors (biomechanical and psychosocial factors) and individual factors with musculoskeletal symptoms in the shoulder, wrist/hand, and low back. A cross-sectional study was conducted involving assembly workers in an automotive industry ($n = 147$). The Copenhagen Psychosocial Questionnaire was used to characterize the psychosocial factors and the Nordic Musculoskeletal Questionnaire was used to collect musculoskeletal data. Biomechanical risk factors were extracted from ergonomics assessments using the Ergonomic Assessment Worksheet method. Odds ratios with 95% confidence intervals were calculated using logistic regression and all estimates were adjusted for sex, age, and seniority. Biomechanical factors were associated with musculoskeletal symptoms. Several psychosocial dimensions were significantly associated with the occurrence of musculoskeletal pain. Being male and over 40 years old was shown to be protective against the onset of musculoskeletal symptoms. Of the different determinants assessed, the psychosocial risk factors were those most related with self-reported musculoskeletal pain of workers on an automotive assembly line.

Keywords Biomechanical factors · Psychosocial factors · Assembly line

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1 Introduction

In today's highly competitive business environment, industrial organizations and companies are facing new challenges that demand improved productivity. Under this pressure, workplaces have no choice but to develop and maintain many competitive advantages, which can negatively impact workers health and well-being [11]. Musculoskeletal pain (MSP) is a widespread problem [3, 6], particularly in the work environments [4], and is the leading cause of disability and absenteeism [3, 23]. MSP refers to the experience of acute or chronic pain that impacts the bones, muscles, ligaments, tendons and even nerves [29]. This problem not only affects the physical and social well-being of workers, but also has a high economic burden on companies, businesses, and national healthcare systems [2]. The automotive industry is particularly affected by MSP due to the occupational exposure workers experience daily in their workplaces, thus making it one of the industries with the highest prevalence of reported musculoskeletal complaints [6].

The cause of MSP is multifactorial, with both occupational exposure and individual factors playing a major role in MSP emergence, especially when determinants such as biomechanical risk factors and psychosocial context variables are considered [7]. On this note, biomechanical risk factors are inherent in the automotive assembly line, where there is a rapid work pace, repetitive motion patterns, insufficient recovery time, manual material handling of heavy loads and forceful manual exertions, non-neutral body postures, mechanical pressure concentrations, and segmental or whole-body vibration exposure. The fundamental concept behind an assembly line is to assign each worker a repetitive task and move the product along the line to the worker who performs the task until the product is ready.

In addition to biomechanical risk factors, psychosocial constructs also play an important role in the onset of MSP [31] and are particularly relevant in the current changing labor market. Interventions to improve the working environment can help reduce physical stress [30]. For instance, despite the known detrimental effects of higher levels of exertion, physical activity is generally considered beneficial for maintaining physical function, reducing MSP, and preventing lifestyle-related non-communicable diseases [22]. To address the issue of work-related musculoskeletal disorders, there is a need to better understand the complex relationships among the large number of determinants affecting MSP and the different contexts of the automotive industry with self-reported pain in different body regions.

Therefore, this study aimed to analyse the associations between occupational risk factors, such as biomechanical, psychosocial, and individual factors with MSP in the shoulders, wrist/hand, and low back in a sample of workers in an automotive industry.

2 Materials and Methods

2.1 Study Design

This was a cross-sectional investigation conducted in an assembly line of a large automotive company during 2019 in the metropolitan area of Lisbon, Portugal.

2.2 Participants

All direct workers ($n = 1225$) from the assembly area were invited to participate in the study. The eligibility criteria included being allocated to the assembly area, not having any medical restrictions to perform the job assessed by the plant medical doctor and not being a temporary worker. The exclusion criteria were to have a clinical diagnosis of neurological and musculoskeletal chronic diseases.

All participants gave their written informed consent before their participation in the study.

2.3 Outcome Variable

2.3.1 Musculoskeletal Pain

The Standardized Nordic questionnaire adapted to the Portuguese Language [17] was used to assess the prevalence of musculoskeletal pain in different body regions during the last 12 months. Of the 10 body sites assessed we focused our analysis on the 3 sites with the most reported prevalences.

2.4 Determinant Variables

2.4.1 Biomechanical Exposure

The job rotation plan and the workstations assigned to each worker, in the previous week of data collection were provided by each Team Leader. The job rotation plan of each worker was collected to provide information on their individual daily and weekly exposure from each workstation.

The biomechanical risk factors were assessed using the European Assembly Worksheet (EAWS) by certified ergonomists who were working within the company. The EAWS method is often used and validated in the automotive industry [27]. This method uses a traffic light scheme point to classify the exposure severity level of

each workstation evaluated. EAWS is divided in four sections for the evaluation of (1) working postures and movements with low additional physical efforts, (2) action forces of the whole body or hand-finger system, (3) manual material handling (>3 kg), (4) repetitive loads of the upper limbs. The partial scores of posture, force, and manual material handling and the total score of the workstations were used to characterize the exposure.

2.4.2 Psychosocial Factors

Psychosocial factors at work were assessed using the Copenhagen Psychosocial Questionnaire (COPSOQ) adapted for the Portuguese language [28]. In this study, we used 13 scales with a total of 19 questions.

2.4.3 Individual Factors

Demographic data concerning age, sex, and seniority for all workers was collected by documental search from Human Resources Department and was provided by the company before the assessments.

Physical activity was collected through a questionnaire with the question: “Do you practice physical activity?”.

Weight and height were collected according to the standards of the International Society for the Advancement of Kinanthropometry (ISAK) [15]. Body Mass Index (BMI—weight/height²) was calculated.

2.5 Statistical Analysis

Descriptive statistics were calculated for all individual, biomechanical, and psychosocial variables to determine their distribution characteristics. Bivariate binary logistic regression analysis (Enter method) was used to estimate the association between MSP (dependent variable) and biomechanical, psychosocial, and individual factors (independent variables). Bivariate binary logistic regression analysis was performed for each region, i.e., shoulder, wrist/hand, and low back, and were adjusted for gender, sex, and seniority. Results are reported as Odds Ratio (OR) and 95% confidence intervals (CI) unless otherwise stated, using a forest plot. Variables with CI's not overlapping 1 were considered statistically significant. The model did not input missing values. Statistical analysis was performed using IBM SPSS Statistics version 28.0 (SPSS Inc., an IBM company, Chicago, IL, USA).

3 Results

A total of 147 workers replied to the questionnaire and were included in the sample. Descriptive statistics of the total sample and stratified by sex are presented in Table 1. Of the total sample, 17.7% were women and 30.6% were over 40 years old. Statistical differences between sex were found for seniority, weight, and height.

Table 2 contains the prevalence of MSP reported over the last 12 months for the shoulder, wrist/hand, and low back, as these are the body regions with higher prevalence. Women showed a higher prevalence of pain in all body regions compared to men. The wrist/hands segment had the highest prevalence in both genders.

Figure 1 depicts the associations between occupational (psychosocial and biomechanical) factors and the self-reported pain over the past 12 months for wrist/hand, shoulder, and low back regions. Regarding the biomechanical risk factors, no associations with MSP were observed. Nevertheless, significant associations between several psychosocial risk factors and MSP depending on the body region were found. The quantitative demands [OR 1.67, 95% CI 1.02–2.72], emotional demands [OR 1.48, 95% CI 1.02–2.16] and work pace [OR 1.45, 95% CI 1.00–2.10] showed higher odds for wrist/hand pain. For the shoulder region, emotional demands [OR 1.74, 95% CI 1.10–2.75] increased the odds for pain in this segment, whereas, the quality of leadership, decreased the odds [OR 0.51, 95% CI 0.286–0.92] for this body segment. With similar results, the quantitative demands [OR 2.11, 95% CI 1.22–3.65], emotional demands [OR 1.48, 95% CI 1.02–2.16] and work pace [OR 1.84, 95% CI 1.20–2.84] showed higher odds for low back pain. A protective effect was observed on the low back region from predictability [OR 0.42, 95% CI 0.23–0.77], social support [OR 0.66, 95% CI 0.44–0.99], community at work [OR 0.51, 95% CI 0.30–0.86], quality of leadership [OR 0.56, 95% CI 0.34–0.93], and job satisfaction [OR 0.49, 95% CI 0.29–0.84].

Table 1 Descriptive characteristics

	Woman (mean ± SD)	Man (mean ± SD)	Total sample (mean ± SD)
Age (years)	32.62 ± 8.94	32.27 ± 9.27	32.33 ± 9.18
Seniority (years)*	2.74 ± 5.47	6.26 ± 8.60	5.64 ± 8.23
Weight (kg)*	64.12 ± 11.78	76.99 ± 13.19	74.72 ± 13.82
Height (kg)*	1.63 ± 0.07	1.75 ± 0.07	1.73 ± 0.08
BMI (kg/m ²)	23.85 ± 4.21	25.00 ± 3.93	24.80 ± 3.99

*Differences between group values (*p* < 0.05)

Table 2 Prevalence of musculoskeletal pain in the last 12 months in the shoulder, wrist/hand, and low back

	Woman n (%)	Man n (%)	Total sample n (%)
Shoulder	8 (30.8)	19 (15.7)	27 (18.4)
Wrist/hand	9 (34.6)	33 (27.3)	42 (28.6)
Low Back	6 (23.1)	26 (21.5)	32 (21.8)

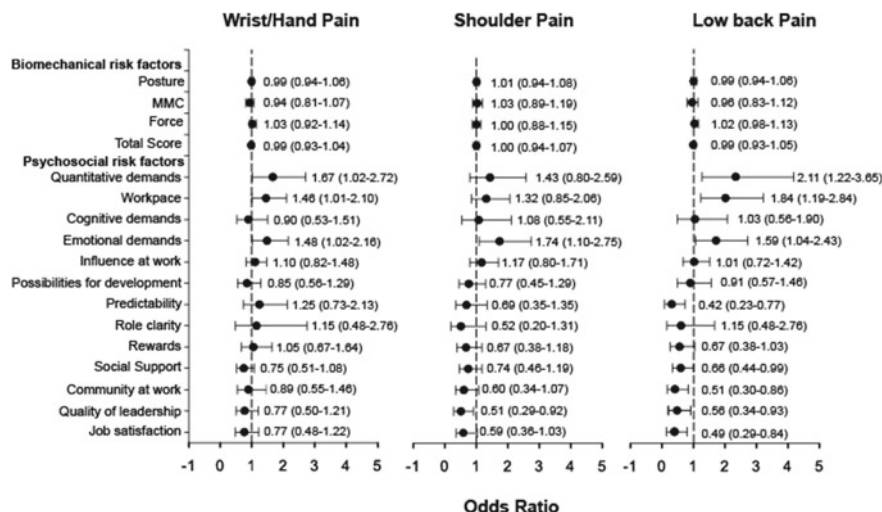


Fig. 1 Forest plot for odds ratio and 95% confidence intervals for occupational risk factors (biomechanical and psychosocial) for wrist/hand, shoulder, and low back. Odds ratios were adjusted for sex, age, and seniority. Results are presented for the total sample

Like the occupational factors, some individual risk factors were related to the occurrence of MSP, depending on the region assessed (Fig. 2). For age, being more than 40 years decreased the odds [OR 0.11, 95% CI 0.02–0.75] for shoulder pain, when compared with their peers (i.e., less than 40 years). Similarly, males showed significantly decreased odds [OR 0.26, 95% CI 0.09–0.77] for shoulder pain when compared to females. Seniority also was found to be a protective factor for workers who had been working for more than 1 year [OR 0.21, 95% CI 0.08–0.54] in the company for the wrist/hand pain. Lastly, for BMI and physical activity, no associations were found with pain in the wrist/hand, shoulder, and low back regions.

4 Discussion

The aim of the present study was to analyze the associations of occupational exposures, including biomechanical, psychosocial, and individual risk factors, with MSP in the shoulder, wrist/hand, and low back. The study identified some psychosocial constructs with an increased odds for pain in the assessed regions and others with a protective effect. However, biomechanical risk factors were not associated with MSP. Important individual factors were also identified, such as sex, where men were less likely to experience shoulder pain than women. Similarly, being over the age of 40 reduced the odds for shoulder pain compared to being under the age of 40. Importantly, the associations were region-specific to allow for future clarification of etiology, prevention, and treatment.

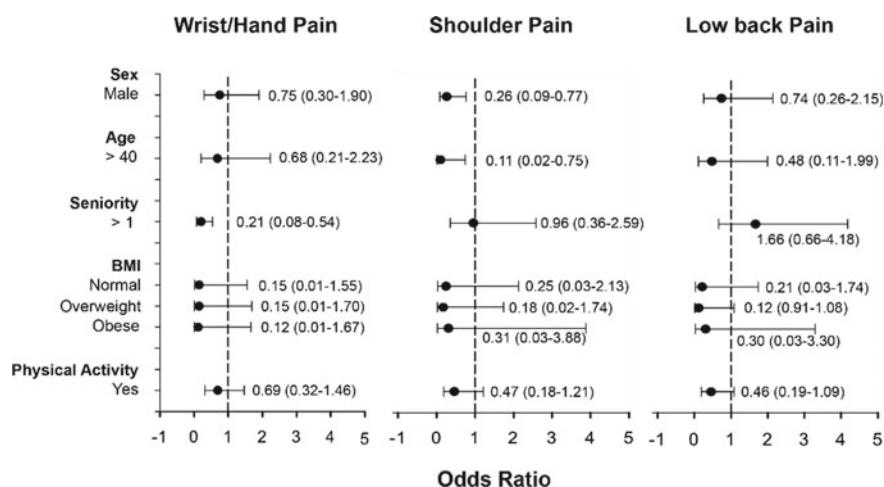


Fig. 2 Forest plot for odds ratio and 95% confidence intervals for individual risk factors for wrist/hands, shoulder, and low back. Odds ratios were adjusted for sex, age, and seniority. Results are presented for the total sample

4.1 Psychosocial Factors

The automotive industry remains one of the industries with the highest prevalence of musculoskeletal disorders, due to the type of the work performed by workers and constant exposure to various occupational risk factors. Our results complement the current literature by providing additional information on what psychosocial factors are associated with MSP. In the low back, we observed that quality of leadership, community at work, satisfaction and social support all have decreased the odds for reporting pain. Social support from colleagues and supervisors can help workers cope with work demands and stress [8]. One hypothesis may be that poor social support is a contributing factor to the onset or ex-acerbation of MSP through a stress response. Lack of support can lead to increased muscle tension, which is relieved by stress hormones that, can eventually lead to pain [13]. Quantitative and emotional demands and work pace were also associated with wrist/hand and low back pain. A systematic review in production environments found that increased MSP was associated with an increase in work pace [12]. Previous studies suggested that long working hours and physically demanding work, may increase the odds of experience high levels of stress [21], fatigue [18], anxiety and depression [25]. Thus, work control, such as the ability to make decisions and influence work processes, can help mitigate the negative impact of work demands on workers.

4.2 *Biomechanical Factors*

In contrast to the psychosocial factors, no associations were found for biomechanical risk factors such as posture, force, manual material handling and the workstations total score. Our results differ from those in the literature, where a significant body of literature, both cross-sectional and longitudinal, have identified a dose-response relationship between the exposure to biomechanical risk factors and MSP in several occupational contexts [10, 19] and in the automotive industry, mainly on the assembly line [9, 23]. In fact, in a large sample of 9,263 workers from different economic sectors, a significant association was found between biomechanical risk factors associated with distinct postural assessments for MSP in shoulder, back, hip, and knee [19]. A systematic review found that posture was associated with increased neck and low back pain in several industries, while force application was associated with wrist and shoulder pain [5]. All these segments encompass the main regions where MSP have been reported in by plant and machine operators and assemblers [6]. Furthermore, among these biomechanical risk factors, manual material handling is among one of the strongest predictors of MSP, probably due to the high internal mechanical load [23]. We can speculate that the lack of an association between biomechanical risk factors and MSP observed in our study may be due to the continuous improvement of the production line in terms of engineering, process, and product. Moreover, the automotive industry used a job rotation plan aimed to mitigate the workers' biomechanical exposure and ensure homogeneity within the team. Finally, the contexts and sample sizes of these previous investigations should also be considered as they could partly explain the differences in the results observed. For instance, [19] had included a large sample with different occupational settings, while this current study considered just the automotive industry, which is an extremely specific and highly dynamic environment [19].

4.3 *Individual Factors*

A mismatch between occupational factors and individual factors can be responsible for triggering a stress response, in which high internal biomechanical loads can lead to short-term and/or long-term discomfort, pain, or tissue damage [14]. On this note, being older than 40 years has been associated with a lower risk of shoulder pain, which may be due to the impact of the "healthy worker effect", where increasing pain may force workers to take on new tasks, which can make interpretation difficult. Some authors have shown that it is possible to compensate, in part, for pain and biomechanical risk factors by developing some strategies to protect oneself and reduce the exposure to occupational factors [1]. This rationale may also explain our results regarding the reduced odds of wrist/hand pain among workers with higher seniority. Following the same results of other studies [20], we observed that men have lower prevalence of MSP in the shoulder region. Conversely, women have higher

overall pain in the different regions, which could be attributed to psychological factors [26] Likewise, differences in muscle mass, muscle strength, and work environments designed primarily for men, could be suggested as possible explanations for these differences [24].

As far as lifestyle factors are concerned, we found no significant associations between physical activity and MSP, which is in line with some investigations [19]. Although the effects of physical activity on health-related biomarkers are well discussed in the literature, the relationship of this construct with MSP in workers of the automotive industry remains controversial [22]. The lack of consensus can be explained by differences in methodology, where data from objectively measured (e.g., accelerometry) and self-reported physical activity may account for the increased variability in outcomes. No associations were found for BMI and MSP as this association is complex, with discrepancies commonly found in the literature [16]

4.4 Limitations

This study is not without limitations. The healthy worker effect may have occurred and turned into a bias, since workers who were considered healthy tended to stay in their jobs longer. This can be related to individual factors and health. Considering the multifactorial nature of MSP, we performed an integrated analysis of risk factors of different types known to be associated with the occurrence of these conditions.

5 Conclusions

In summary, among the various determinants assessed, the psychosocial risk factors were those most related with self-reported MSP on an automotive assembly line. Nevertheless, it is important to carry out a detailed analysis of the possible factors that leads to MSP, integrating all the psychosocial dimensions that were significant in the current analysis, to better understand this occupational context. In a dynamic sector such as automotive industry, where labor standardization of leading to a more sedentary work environment, psychosocial factors seem to play a role in explaining the occurrence of MSP in workers, despite the biomechanical demands characteristic of this sector.

Acknowledgements This work was partly supported by Fundação para a Ciência e a Tecnologia (CIPER - Centro Interdisciplinar para o Estudo da Performance Humana (unit 447): UIDB/00447/2020. Ana Assunção is supported by Fundação para a Ciência e Tecnologia (SFRH/BDE/102750/2014) and Sarah Bernardes is supported by Coordination of Superior Level Staff Improvement - CAPES (011990/2013-09). The authors are grateful to all the workers who voluntarily participated in this study.

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Human-Centered Design Approach to the Development of a Graphical User-Interface for Visual Inspection Task: A Use-Case in the Aircraft Manufacturing



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Abstract The inspection process of aircraft parts is a specially demanding activity due to its strict standards and could be quite stressful for inspectors. To optimize the inspection process, support and digitize the visual inspection and improve working conditions, a portable device was developed. The present study addresses the development of a graphical user-interface (GUI) for this device. It was used need-finding techniques and ergonomics participatory approaches with the goal of addressing inspectors' needs, while respecting the task's requirements. As a result, this study presents the iterative process of developing the user interface (UI) from requirements definition to several stages of fidelity of the prototype. The usability tests carried out secured qualitative and quantitative data, from various techniques, such as video recordings, users' think-aloud, questionnaires, and notes. This combination of techniques enabled a deeper understanding of the real needs, supporting the design and improvements of the GUI, foreseeing participants' satisfaction and the inspection task's efficiency and effectiveness.

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Keywords User experience · Usability tests · Participatory approach · Inspection process

1 Introduction

Inspection tasks are defined as the act of looking at something carefully while paying special attention to flaws and critical examination. The work of an inspector is to verify that the manufactured part is defect or anomaly free and ready to be distributed to the client. Inspection, as part of the quality control of aircraft manufacturing, is a specially demanding activity due to its strict standards. In some circumstances, inspection procedures demand prolonged periods of concentration and attention to cope with very subtle and detailed defects that could lead to a catastrophic situation [20]. Thus, quality control is not only to ensure that the product is visually flawless, but also that it is safe. As a safety-critical and complex system, inspection could be quite stressful for inspectors. It requires a fast identification of defects to be mitigated early in the manufacturing process and typically needs to be performed in a certain amount of time [19].

The visual inspection of the aircraft parts of the present use case is characterized by a two-stage procedure: one characterized by Fluorescent Penetrant Inspection (FPI) and the other with a visible light inspection. The goal of the first one is the visual observation and interpretation of surface defects, while the second one is intended for the confirmation of occurrences previously signaled. Visual inspection is a highly skilled activity and, although labor intensive, it is still more accurate and precise than automated alternatives [10]. In fact, 90% of the inspection done is still human visual inspection (Johnson and Shepherd, 1993 *in* [11]). In this specific use case, human visual inspection practices continue to be more reliable [20]. Therefore, the human is considered to be the detector and the decision maker of defects detection. In this sense, inspection tasks require a significant amount of mental resources, such as attention, concentration, as well as short and long-term memory [3, 5].

In order to improve inspection quality and making the process faster and more efficient, and as part of the digitalization process of the metallic parts' inspection of an aircraft manufacturing company, a digital device was developed to assist the inspector in the task of identifying possible defects. To this end, the development of the solution began with the understanding of the context and its users using human-centered design approaches [16]. This approach is in line with the new Industry 5.0 paradigm solutions must serve people's needs and benefit them [4, 21]. Therefore, the present study addresses the design thinking approach in the development of this device to aid visual inspection. Using need-finding techniques [17] and ergonomics participatory approaches to address the needs of the inspectors, while keeping in mind the structure and constraints of the task, it was possible to design a device capable of photographing, providing the dimension of the defect and automatically generating the inspection report. Moreover, usability tests were conducted in several stages of the development of the prototype's user-interface, which enabled the integration

of user feedback into the re-design and improvement of the final prototype. The goal of this study is that this device will help inspectors throughout the inspection process, improving quality and making it more efficient and satisfying for inspectors. Therefore, this device could potentiate the reduction of non-added value tasks that the inspector needs to perform, with less tools, and consequently, with reduced time-pressure related to the inspection task.

2 Materials and Methods

2.1 Research Design

Human-centered Design (HCD) is an approach whose purpose is to develop more usable, intuitive and useful products [8, 16] as it seeks to meet the needs, realities and motivations of users. The product development process is participatory and involves continuous improvement by iteratively (1) observing, (2) generating ideas, (3) prototyping and (4) testing [16] until the solution achieves the specified user requirements [17]. During the process, needs, perceptions and insights are assessed while users interact with the product [12].

Figure 1 shows the development stages of the inspection device’s graphical user-interface (GUI) by following the above design thinking guidelines. Four stages are identified. The initial stage took place in the real-industry context to characterize the problem according to the participants needs (Needfinding). With this information, a storyboard of the inspection task was made, and requirements were established (Requirements Definition). Moreover, the Design of the GUI and Usability Testing stages were iterated several times, each time generating a prototype with a higher fidelity level, from a user-flow towards a completely functional and usable GUI.

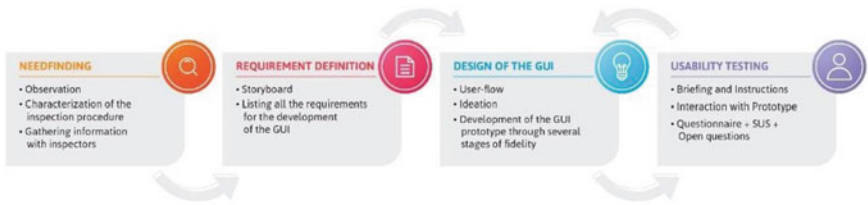


Fig. 1 Representation of the research phases

2.2 Description of the Inspection Procedure

The original inspection operation of aircraft parts via FPI is carried out by 2 inspectors simultaneously and can take a maximum of 2 hours. It is a task that requires attention and great responsibility, since critical defects can reach very small dimensions and it is a high-risk safety process. Prior to inspection, the aircraft parts undergo a sequence of surface treatments to ensure that the fluorescent penetrant dye within defects is visually detectable at naked eye. With the aid of a UV lamp, inspectors can identify the location of defects down to the size of 0.2 mm. They start doing a first screening where they mark with a pen the locations where potential defects can be recognized. Subsequently, a second screening under visible light is performed where the inspector addresses with attention all the marks indicating actual defects, and neglects those that are false-positives. A magnifying scope is sometimes used to aid the participants appraisal. Moreover, to produce the inspection report, the inspector takes measurements of the defects with a ruler, classifies them according to their category, identifies their location on the part, and collects their image through photographs. In summary, to conduct the original inspection task, the inspector would have to use several tools: a lamp equipped with UV and visible lights, magnifying scope, ruler, and a camera. The inspection device prototype supports the inspector in the process of registering the defects and creating of the final report in a digitized way. This solution promotes the accuracy and efficiency of the inspection tasks, eliminating manual operations.

2.3 Requirements Definition

Table 1 shows a list of requirements expected for the GUI, based on heuristics proposed by Nielsen [14, 15] for a good interaction design, and Gestalt rules for a useful design project [6].

2.4 Prototype and Design of the Graphical User-Interface (GUI)

The prototype developed pretends to improve the inspector's performance by providing the following technological features: (1) taking photographs of the defects under UV and visible light; (2) apply computer vision algorithms to identify, measure and classify defects; (3) produce automatic reports from the inspection sessions via a webapp. These will allow inspectors to use fewer tools during the inspection process without losing precision.

Figure 2 shows the prototype consisting of a portable device containing a camera (for capturing images), a display (for the user-interface), sensors (to aid image processing algorithms), a PC board, electronic components, and a housing. In terms of

Table 1 Graphical User-Interface (GUI) requirements

To be easy and convenient to use with a single hand	Ease of interaction	UI with functional and visual consistency
- Scaling of fonts, buttons and menus.	- Perceptible feedback from buttons for all actions.	- Use of colors / symbols and font with contrast, good readability.
- Order and placement of buttons.	- Clarity of information.	- Text blocks are grouped according to common objectives to create a grouping of information and faster understanding.
	- Use of language specific to the workplace.	- Appropriate use of colors/ typography according to tasks and device.
	- Types of menus according to the needs of the task.	- Hierarchy of information.

design, the prototype was dimensioned according to usability and ergonomic factors following previous recommendations [3], in order to create a solution acceptable for the participants.

The selected display consists of an LCD screen designed to be used with Raspberry Pi boards. This type of display tends to have a lower image resolution than smartphone displays having the same form factor. In general, within these range of products, the larger the display the better the image quality. Here, a 5-inch display was chosen since it has the best balance between size and resolution (800 × 480 px). Thus, the developed GUI was designed to fit according to this specification. The interface

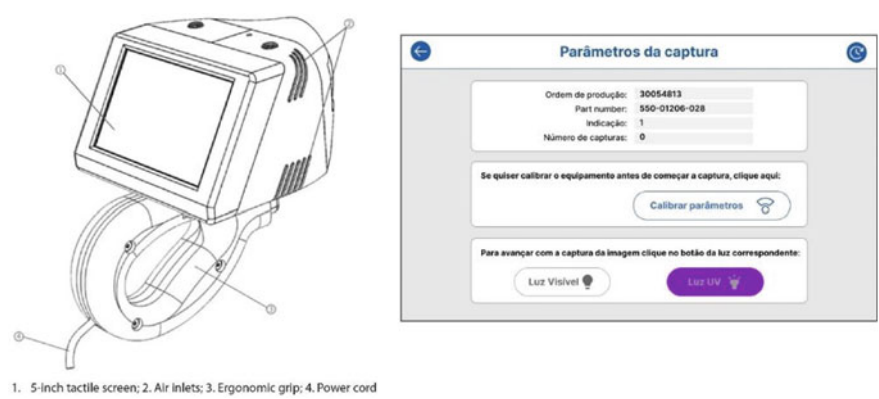


Fig. 2 Inspection device prototype (*left*), and an example of GUI window (*right*)

was designed and prototyped using Figma,¹ while the final front-end running on the prototype device was implemented using the Qt library.²

The Graphical User Interface (GUI) can be described in high level terms as “means by which people and computers communicate with each other” (Norman 1988 *in* [9]). It is responsible for displaying the visual elements and interactors and the look and feel, that provides a good user experience.

The development of the GUI followed a method of incremental development. Initially, a user flow was created to assess which functionalities were needed and the flow of screens that the application should have (can be seen in Fig. 3 in Sect. 3). A wireframe of each screen was created in a first version, the low-fidelity prototype³. This version suffered adjustments and refinements, resulting in a mid-fidelity prototype.

2.5 Participants and Usability Testing

A total sample of fifteen participants (7 females and 8 males, aged between 20 and 61 years) took part in the study, of whom some took part in more than one usability test (hereinafter denominated signated P1–P15). The sample consisted of people who were aware of the inspection task but did not know the new device. All participants signed an informed consent, respecting the principles stated in the 1964 Declaration of Helsinki. Participation in the study was voluntary and all data was analyzed and stored anonymously.

Each participant carried out the defect capture process and interacted with the prototype (more details in Sect. 3).

Usability testing is one of the many techniques that can be used to assess people’s perceptions of a product (as focused on the current study). Usability has to do with how a “product can be used by specific users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specific context of use” [7]. This technique is useful to collect user’s insights and detect the parts of an interface that most confuse people [12]. In this sense, people were instructed to carry out the defect capture process and asked them to interact with the prototype (more details below).

Overall, four usability tests were conducted. The prototype was tested on an Android smartphone (6.18 inches) in the first three usability tests, which screen had approximate dimensions to the final solution. The fourth usability test was carried out with the GUI integrated in the real device. The usability tests took place between February and July 2022 and followed the same structure. The sessions were done with the help of a facilitator and observer. Each usability test comprised three parts:

¹ Version 108.1.0 (<https://www.figma.com/>).

² Version 5.15 (<https://www.qt.io/>).

³ A low-fidelity prototype is a visual representation of a digital product that is still in the early stages of development. Therefore, it still has few graphical details, as the focus is on checking and testing functionalities rather than visual appearance.

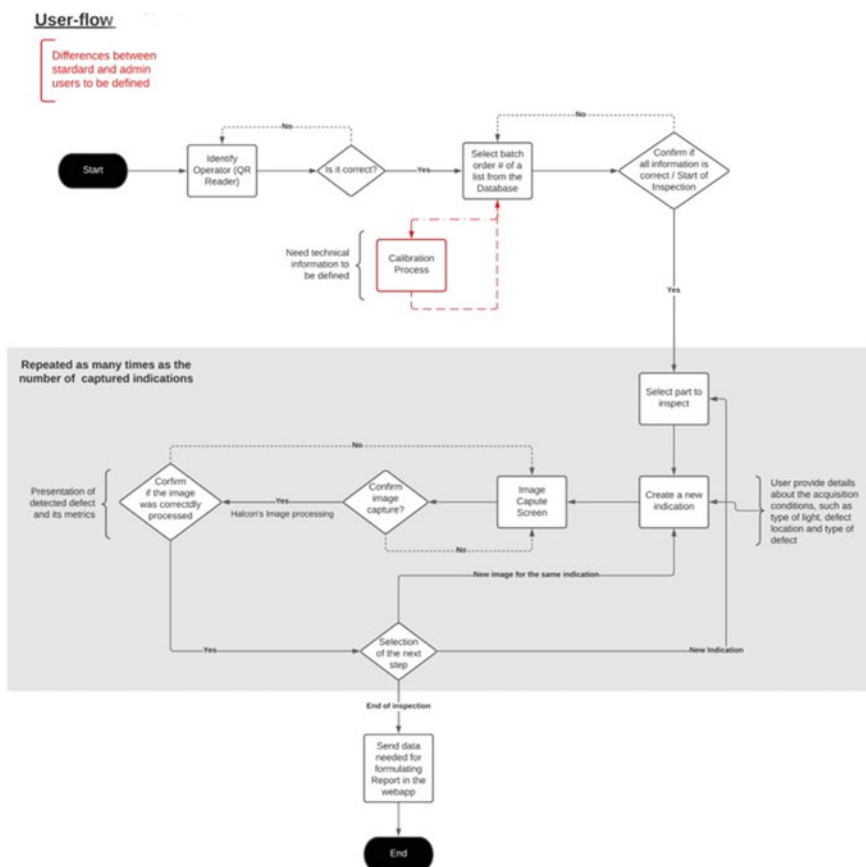


Fig. 3 User-flow chart

(1) debriefing and instructions, (2) interaction with the prototype, and (3) post-test survey. First, participants were debriefed about the workplace context, the inspection process, and instructions for testing the display interface were provided. Then the participant was asked to interact with the prototype and think aloud about what he/she was doing, while the researchers were recording it. In the post-test survey, made with Google forms, participants were asked to answer some questions, divided into three sections: (1) demographic data; (2) System Usability Scale—SUS, and (3) five open questions about their experience interacting with the interface. The main idea was to identify: (1) usability problems, (2) discover aspects to be improved and (3) user's opinions and needs about the interface. The SUS is a 10-item scale with a 5-point Likert scale for each item [2]. Then, a global score is computed, which can range from 0 to 100, with 68 indicating that the system's usability is good, as it is slightly above average [1]. The mean duration of each testing session was, approximately, 20 min each.

3 Results and Discussion

The information gathered from the needfinding and requirements definition was assembled into a user-flow to map the main interactions of the inspectors with the interface (see Fig. 3).

In the next stage, the first task was to think about the GUI and to develop the prototype to assess how the navigation could happen and how the information would be organized on the screens. After having a functional prototype with all the inspection process the tests started. The first test, with a low-fidelity prototype, was carried out to validate the navigation pattern of the application. The test occurred in February 2022 with six participants (P1 to P6, of whom 4 males and 2 females). The average SUS score was 82.9 points, which is a very positive result. Regarding the interaction, one screen caused confusion to all participants but one. Participants did not understand how to proceed in the task, which led to the need for the researcher to intervene. P6 reported that “the most negative thing is the lack of explanations” and the buttons’ placement added to the confusion. Regarding the open questions, it was said that the interface was clear but as a point of improvement, it was suggested to resize some of the buttons. It became clear that trying to simplify the presentation of information not to overload people, the interface was over simplified, which ended up confusing them. This is in line with literature [22], which states that when reducing information to a certain point, with the intention to avoid mental tension, there is the risk of oversimplifying it to the point of not helping people on tasks performance.

The prototype was updated with the suggested improvements and a second test was carried out in March 2022. Five participants (3 males; 2 females) took part in the second usability test. The average SUS result was 81 points, indicating a good usability. Additional suggestions were collected, helping the interface redesign.

The third test, with the mid-fidelity interface, was carried out in May 2022. Seven participants (4 females; 3 males) took place in this test. All participants completed the task. Only one person deviated from the expected navigation path, but soon recovered. The average score in SUS was 85.4 points, meaning the prototype is robust and a few changes need to be made. Usability problems regarding the interface were more related to the size of the buttons on certain screens. This issue was observed on screens that had a lot of content and the buttons had to be reduced, showing only icons without text. Through the answers to open questions, it was possible to identify that the participants felt that the interface was “*objective*” (P15). They also highlighted the fact that it is “*accessible*” (P14); and to “*have the colors of the actions (UV light inspection and visible light inspection) congruent with the colors of the screen edge*” (P1) as a positive point. Two participants had difficulties completing the task but soon recovered and completed it without further issues.

According to the assessment presented in the current study, some improvements to the device’s GUI were defined, namely: (1) Review the size of buttons on certain screens; (2) Put a background color on all buttons to become more visible; (3) Create a loading animation to insert on screens that take time to process information; (4) Create a calibration screen.

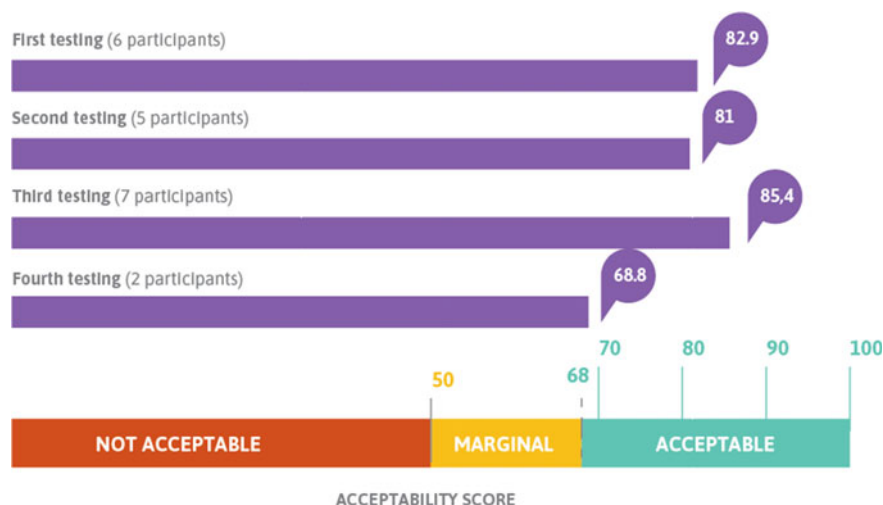


Fig. 4 Average of SUS results in the four tests performed

After reviewing these issues and according to the evaluations of the entire team, the interface was redesigned again. Its' last version was implemented on the prototype device. In July 2022, 2 participants (1 male; 1 female) tested the solution. The obtained average SUS score was 68.8 points, which is considered reasonable. Although the SUS score was not as high as in the previous tests (see Fig. 4), this result indicates that the interface is acceptable [1]. We believe that the reduced time that participants had to use the device could have influenced the SUS score. It should be noted that, in the last test, only two participants were included due to restrictions on volunteers recruitment. This is a limitation of the current study. In these type of tests, greater samples are recommended in order to obtain more robust results [13, 18]. This note will be considered for futures studies.

This last usability test was the only with the user-interface integrated in the physical device. We suspect that the SUS score might not reflect exclusively the interaction with the GUI, but also reflects the experience with the physical device. However, it is important to note that the users successfully completed the task and had no suggestions for improvement concerning the GUI. The researchers did not notice difficulties by observing the participants interacting with the device, as was the case in the other tests. The only adversity found was when pressing the trigger to take the photo. The two participants found it difficult at first, but by repeating the task they both were able to accomplish it. It was an anticipated concern from the team, but it was also expected it was a matter of practice and the right timing to click the trigger to “get the hang of it”.

Initially, the prototype had 9 screens and with the results from usability tests it ended up having 15 screens. The successive design iterations allowed the information to be displayed in an intelligible way, content organized by tasks and buttons with adequate sizes. This change will impact the way inspectors use the tool since, by fragmenting the information, it is easier to understand and process it, as demonstrated by previous studies [15, 22].

In order to have a better understanding of the impact this device has in the inspection routine the research team would, ideally, collect feedback from post-deployment field studies, as recommended to be the last step of the usability process [13]. This is also considered to be a limitation of this study and will be taken for future consideration.

4 Conclusions

The present study presented the development of a visual graphical user interface of a new digital device to optimize the inspection process of aeronautical parts. In order to improve the efficiency of the task and the inspector's performance, needs were identified, and requirements were outlined (see Sect. 2.3). The process was participatory and iterative considering the FPI procedure and the needs of the inspectors.

It is important to point out that each iteration of the design was supported by usability tests, developing a more robust and intuitive solution. The feedback from these tests together with the application of technical needs guided the design decision, reaching a solution that was in accordance with the tasks performed by workers in the inspection process. In this sense, the objective was that the interface could make the inspection process less stressful, more efficient and also more intuitive, in order to facilitate the registration of the defect by the worker.

Throughout the project's development and according to the analysis of the four usability tests, it was possible to identify that the participants were satisfied with the final interface. As a future recommendation, it is suggested that a new assessment will be carried out with more participants and after a period of use, as recommended to be the last step of the usability process.

Acknowledgements This work was supported under the base funding project of the DTx CoLAB—Collaborative Laboratory, under the Missão Interface of the Recovery and Resilience Plan (PRR), integrated in the notice 01/C05-i02/2022, which aims to deepen the effort to expand and consolidate the network of interface institutions between the academic, scientific and technological system and the Portuguese business fabric.

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Development and Implementation of a Management Model of Ergonomic Conditions Supported by Autonomous Teams



Ana Colim , Bruna Fernandes, Paula Carneiro , and Nuno Sousa

Abstract The current context of manufacturing industries is marked by challenging and complex processes. Despite Industry 4.0 advances in promoting a more comfortable way of working, work-related musculoskeletal disorders (WRMSD) continue to be a very present problem among workers. The main objective of this study was to reduce the WRMSD risk of coworkers through raising awareness and training autonomous teams in ergonomic knowledge and assessment methods, resorting to the implementation of a model for evaluating and managing the ergonomic conditions of the workplace. A critical analysis of the current process of ergonomic evaluation of work activities was carried out and several problems were identified. Key Indicator Method (KIM) was applied to assess 166 activities, so obtaining a primary overview of the company's ergonomic state. The proposals for improvement actions were focused on defining and optimizing the process of improving the ergonomic conditions of risk activities and standardizing the ways of working of ErgoTeams. With these actions, it is expected a more efficient functioning of teams throughout the company with more active participation in the identification and resolution of ergonomic needs; and improvements in working conditions with reduced risk of WRMSD.

Keywords KIM method · Manufacturing · WRMSD · Participatory ergonomics · Risk assessment

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1 Introduction

Industry 4.0 focuses on improving process efficiency and productivity [10], guiding manufacturing organizations to fast growth and progress and human-machine interaction being one of its biggest impacts [15]. With the arrival of the fourth industrial revolution, new ergonomic techniques and equipment were introduced in the manufacturing environment, aiming to improve working conditions [16]. However, despite the growing trend towards process automation, manual assembly tasks will continue to exist, so Industry 4.0 should be seen as a way to ease the burden on coworkers [14] and not a solution for the ergonomic problems manufacturing industries encounter. The ability of ergonomics to guarantee the optimization of processes and promote worker comfort enhances a competitive factor of attractiveness and productivity [5].

Musculoskeletal disorders are the main contributor to the occurrence of disabilities worldwide, affecting about 1.71 billion people globally. In Europe, despite the variety of efforts to control ergonomic issues, work-related musculoskeletal disorders (WRMSD) are the most common work-related health problem [6]. WMSD are present in both developed and developing communities [9]. However, high-income countries stand out as the most affected in terms of the number of people (441 million) [20]. According to Eurofound [7], the biggest health problem mentioned is back pain in 43% of mentions, followed by muscle pain in the neck or upper limbs (42%), and muscle pain in the hip and lower limbs (29%).

WMSD is considered an individual, organizational, and social problem since it causes constraints both to the worker and the company [3]. Thus, it becomes necessary to act in the prevention of WMSD. Observational ergonomic assessment methods are often used in industrial contexts because of the non-interference with job processes, low cost, and simplicity of use [13]. Key Indicator Methods (KIM) are a set of six qualified observational methods for risk assessment at the screening level [18]. It assumes that high scores are associated with a high frequency of musculoskeletal symptoms in exposed workers [11]. The main advantages of the KIM method [12, 18] are the easy and quick application and the possibility to assess different types of manual tasks.

A Participatory Ergonomics (PE) approach can also be effective in reducing the risk of WMSD in the workplace [19] since the active participation of workers is essential to identify WMSD risk factors, ensuring that risk assessments are adequate and the measures chosen to combat them are effective [2]. Some factors can act as barriers to the implementation of a PE program, e.g. high production pressures, not guaranteeing time for workers to move forward with ergonomic changes, lack of management commitment, insufficient financial resources, and worker frustration due to implementation delays [4].

Thus, the company, involved in the current study, aims of reducing its WRMSD risk through increased competence of its workers in ergonomics and WRMSD risk assessment methods in work activities. This objective implies the development and implementation of a model for assessing and managing the ergonomic conditions of the workplace to be used by autonomous teams. The current challenge raises

the need to rethink the assessment process of ergonomic conditions and the current contribution that the workers have to it.

2 Materials and Methods

The current project was developed in a large Portuguese site of furniture manufacturing and was based on the risk assessment of 166 activities in 23 different work areas englobing 1082 workers. Macroergonomics and microergonomics analysis were carried out and its results helped in the development of the proposed model.

2.1 Macroergonomic Analysis

In order to better understand the reality of PE in the company, it was characterized its current approach, using a Participatory Ergonomics Framework [8]. Table 1 shows the results of this analysis. It is highlighted the possibility of workers directly giving their opinion/contribution about their work, having a direct impact on the direction of the problem/topic in question; and the fact that PE is in constant permanency in the company, always trying to collect feedback from workers. There is a feeling of delay in taking action, so it is often perceived that PE is not working.

Macroergonomics is the subdiscipline of ergonomics concerned with the analysis, design, and evaluation of work systems [1]. This way, a critical analysis of the entire current process of ergonomic assessment of work activities was done to better

Table 1 Participatory ergonomics framework—from [8]

Dimension	Categories
Decision-making	Group consultation
Mix of participants	Workers-Line Management–Senior Management– Internal Specialist/Technical staff
Remit	Problem identification–Solution development–Implementation of change–Set-up/structure process–Monitor/oversee process
Role of ergonomics' specialist	Initiates and guides process—Available for consultation
Involvement	Direct representative participation
Focus	Physical design/specification of equipment/workplaces/work tasks—Designing jobs, teams, or work organization—Formulating strategies
Level of influence	Entire organization
Requirement	Voluntary
Permanence	Ongoing

understand the process and find room for improvement. It started with the collection of activities perceived as high risk by the area responsible which resulted in the identification of 166 activities that went on to microergonomic assessment, applying the KIM method. The assessment included talking to the workers of each activity and collecting data related to it. Depending on the outcome of the assessment, corrective actions were taken. These 166 evaluations made it possible to find constraints and opportunities for ergonomic improvements. Additionally, the ergonomic assessment process was carried out with the development of the ErgoTeams project. “ErgoTeams” is a concept, related to PE, adopted by the company that translates into autonomous teams responsible for the ergonomic assessment of the work activities and responsible for reducing the WMSD associated risk. The purpose of ErgoTeams is to raise ergonomic awareness and for workers to be capable of actively analyzing ergonomic aspects in the workplace, identifying situations subject to improvement, and working together to solve problems. Each one of the 23 areas of production involved represents one ErgoTeam.

2.2 Microergonomic Analysis

The company decided to establish a systematic model for ergonomic assessment common to all the factories of the company globally so it could be possible compare results. The KIM method proved to be the easiest to use and the best suited to the requirements of the factories. The microergonomic assessment of the 166 activities through the KIM method is related to a working day (8 h) [17]. In the case of the manual handling loads task under evaluation consists of several subtasks and different physical workloads, these must be evaluated separately with the respective KIM method [18]. Thus, more than one KIM method can be applied to the same activity if necessary. For each KIM method, different amounts of activities were evaluated, as shown in Table 2. Seventy-nine activities were evaluated with more than one KIM method. When assessed by more than one method, the highest classification obtained should be considered as the final value associated with a risk level of low, medium, or high.

Table 2 Quantity of activities assessed with each KIM method (n = 166 activities)

	MHO	LHC	PP	ABP	WBF	BM
N. Activities	70	97	13	37	31	19

Abbreviations: MHO—Manual Handling Operations; LHC—Lifting, Holding and Carrying; PP—Pushing and Pulling; ABP—Awkward Body Postures; WBF—Whole Body Forces; BM—Body Movement

3 Results

With the macro and micro ergonomic analysis, it was possible to state that the current process of ergonomic assessment was a time-consuming process with problems such as the lack of uniform criteria for identifying activities considered of high risk and the lack of knowledge on which KIM method to apply. Moreover, with its results it was possible to develop and structure tools aimed at solving these problems and improving the process.

3.1 *Analysis of the Company's Ergonomic Conditions*

From the 166 activities identified at the beginning (macroergonomic analysis) as high risk, the company has 66 high-risk activities (39.76%), 59 medium-risk activities (35.54%), and 41 low-risk activities (24.70%). There is a noticeable difference between the workers' perception and the results of the analyst's KIM assessment. It can also happen the opposite with high-risk activities remaining unidentified due to a misperception of the high-risk activity. Therefore, the microergonomic assessment is relevant to quantify a risk level for the activities. KIM-LHC method was the most used (57.76%). Within high-risk activities, this presence increases to 65.38%. These data shows that the risk of most of the activities is related to lifting, holding, and carrying loads. When analyzing the number of workers affected by each KIM method, it is possible to observe that the LHC method continues to be the one that has the most impact with around 43% of workers exposed to LHC problems, a value that rises to 52% when referring only to high-risk activities. KIM-MHO remains the second method most associated with workers.

It is possible to conclude that the most prevalent type of activity in the company is related to the manual outfeed of parts. This type of activity involves removing pieces from the lines and placing them elsewhere, performing a "pick up and put down" movement. Frequently, this type of activity becomes quite repetitive, promoting the musculoskeletal discomfort reported by the workers (as evidenced in [2]). The activity is often evaluated with the KIM-LHC method, when the piece has a weight greater than or equal to 3 kg, thus confirming the previously concluded statements and justifying the dominance of the method. In this case, the criteria were which type of activity affected the most workers of the company. This type of activity has a presence of 19.73%, followed by manual assembly of parts and pushing baseboards manually. These three types of activities are present in the areas of the company with the highest number of high-risk activities and have the largest number of workers. These areas should be a priority for an ergonomic intervention. The most affected body part is the arm area (62.36% of the workers).

3.2 *Process for Improving the Ergonomic Conditions of Risk Activities*

After a critical observation of 166 previous ergonomic assessment processes, it was possible to gather ideas on how to define and optimize the process of improving the ergonomic conditions of risk activities, presented in the flowchart of Fig. 1. Table 3 describes the different phases of the process. This improvement proposal is in line with the process management practice that aims to create an organized, easy-to-follow and highly efficient workflow to achieve good results.

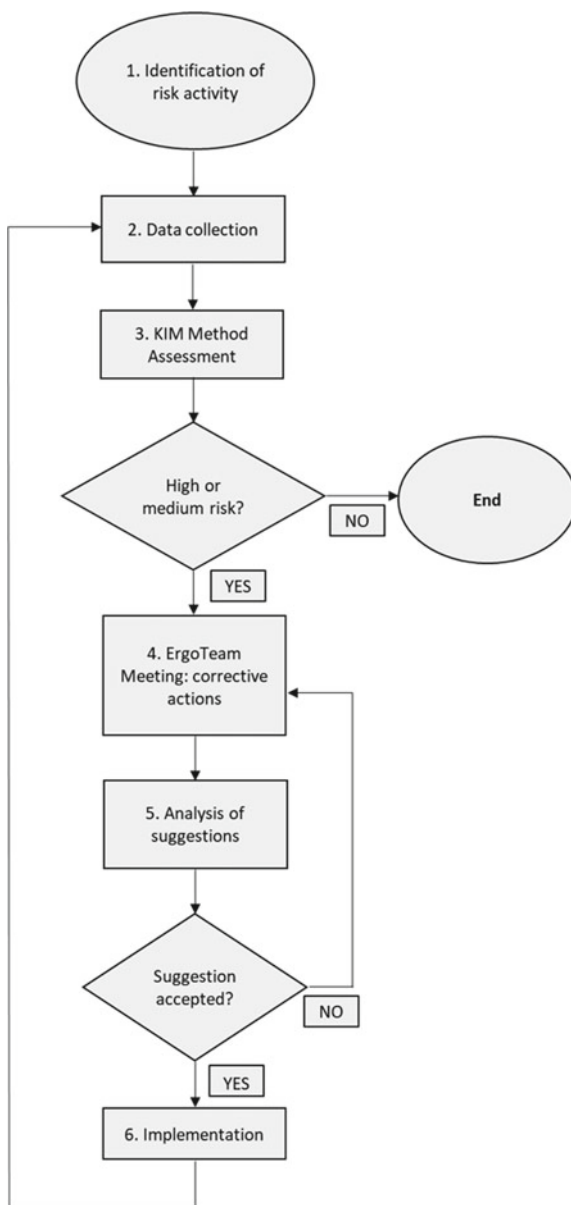
The process of improving ergonomic conditions is complex and its optimization was achieved using many tools aimed at making it simpler for those involved and solving the constraints found previously. It was developed a methodology that joins macroergonomics (Participatory Ergonomics, Checklists, Focus Groups, Semi Structured Interview, Questionnaires) and microergonomics (KIM) methods while applying established tools for problem analysis and idea generation (Flowchart and Root Cause Analysis). The developed flowchart, present in Fig. 2, intends to help in the choice of the KIM method to apply. The whole process aims to be as much active and participatory as possible. Workers have a more active participation in phase 1, 2 and 4; through giving opinions on the way and in which conditions activities are performed, helping to collect real information related to the activities and by giving inputs on corrective measures to be applied, respectively. Of the entire process, phase 2—Data Collection—proved to be the most difficult and crucial to its success.

3.3 *ErgoTeams Functioning*

All ErgoTeams should follow the previous process for improving the ergonomic conditions of risk activities, with the leader, represented by the area responsible, guiding the tasks necessary to accomplish and involving its members in the process. By standardizing the operation of ErgoTeams, all teams can have the same work methods and tools, making all information exchange and task performance simpler. Therefore, the following actions were developed:

- Standardized ErgoTeams work plan: structure and document the tasks inherent to the ErgoTeams' responsibilities and assist it, with appropriate tools, in information management;
- Communication tool between ErgoTeams;
- Responsibility matrix: correct definition of task assignment;
- Team progress-monitoring tool: due to the high volume of activity and areas of intervention;
- Analysis of the functioning of ErgoTeams through questionnaires: a mean of collecting needs for improvements.

Fig. 1 Flowchart of the process for improving the ergonomic conditions of risk activities



4 Conclusions

This project highlights the presence of risk factors for WRMSD and, consequently, the appearance of WRMSD in manufacturing industries, highlighting Ergonomics as a focus of work. In a work environment as fast paced and dynamic as manufacturing,

Table 3 Phases of the improving the ergonomic conditions of risk activities process

Phase	Main actions
Phase 1	Collection of opinions of ErgoTeam members on the activity being assessed; Creation of specific criteria for the consideration of a risk activity;
Phase 2	Guide for choosing the KIM Method to apply; Checklists with the information to be collected for each KIM method;
Phase 3	Use of KIM guidelines as guidance; Sharing of results;
Phase 4	ErgoTeam meeting methodology: Focus Groups with Workers—Root Cause Analysis with Semi-Structured Interview;
Phase 5	Discuss with topic-related people the feasibility of suggested corrective actions;

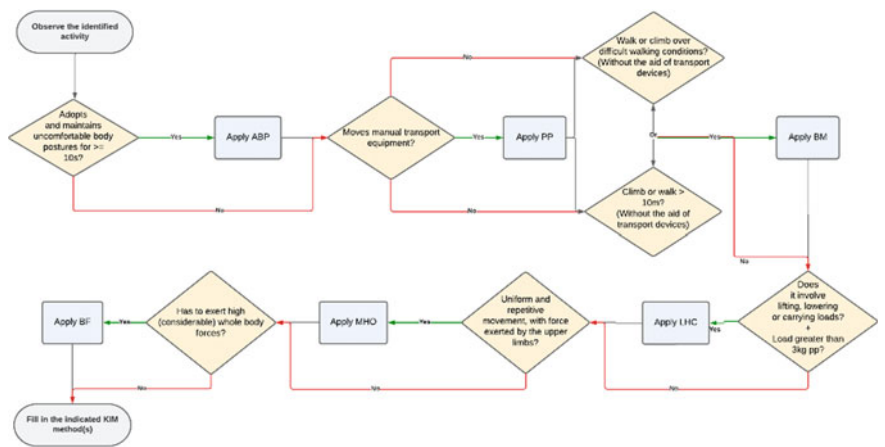


Fig. 2 Guide to choose the KIM method to apply

the implementation of a well-defined and structured process is fundamental. In this study, it was developed an assessment and management model of the ergonomic conditions of the workplace to be used by autonomous teams. This model resulted from the 166 assessments carried out that allowed finding improvements in all phases of the current process of WRMSD risk assessment and in the functioning of the ErgoTeams. It is important to emphasize that the workers' perception of what high-risk activities are does not always correspond to reality, revealing, once again, the pertinence of WRMSD risk assessments. The results taken from the analysis of the ergonomic conditions are useful to support future decision-making and to guide the company's next steps and efforts. One of the limitations encountered comes from the KIM method itself which fails to assess body areas such as the neck and is not prepared for the way certain activities are performed, thus failing to represent reality.

Through the implementation of the proposed model, it is expected an increased ergonomic awareness and motivation from the ErgoTeam members and improvement of working conditions with reduced WRMSD risk. The model presented, and its tools, it is expected to be spread and used in assessments by other companies. Considering the number of high-risk activities identified, it is clear how much effort the company will have to make to eliminate the risk workers are exposed to. Thus presenting, once again, the usefulness of the proposed model.

Acknowledgements This work has been supported by FCT—Fundação para a Ciência e Tecnologia within the R&D Units Project Scope: UIDB/00319/2020.

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Lumbar Postural Responses During Gaming Activity: A Study with Semi-Professional and Amateur Gamers



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Abstract Be a gamer is nowadays an important activity among young people. However, due to the number of hours that gamers spend seated in front of a computer, there is an increased risk of low-back pain (LBP). However, studies that address this problem for gamers are still scarce. The present study aimed to characterize gaming behaviours of amateur and semi-professional gamers and, through an experimental study, analyse the effect of those behaviours on lumbar postural responses. Firstly, questionnaires were developed and applied to the gamer community in Portugal to get information about gaming behaviours, habits and discomfort felt. Additionally, through an experimental study, lumbar flexion was assessed during a three-hour gaming session. A triaxial accelerometer system was used to this end. Results showed that gamers can play for seven days per week, training at least two to three hours per day. During a typical training session, it was observed that lumbar flexion angle varied trough time. Data showed data ROM% was 50.5% in the correct seating position, but during the session it ranged on average between 40.9 and 22.9%. These results suggest that gamers are at risk of LBP. Additional studies are needed in this field with the purpose to better understand the risk of musculoskeletal disorders that gamers are exposed.

Keywords eSports · Lumbar postures · Computer gaming · Musculoskeletal disorders · Low-back pain

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1 Introduction

Playing video games has attracted an increasing attention by scientific community and health institutions. For a variety of population, computer games have become a dominant part of their lives, defining sometimes their behaviours and social integration [9, 12, 16]. These kinds of behaviours/practices have increased after COVID-19 pandemic [13], and can result in adverse health effects. Examples of such effects are obesity, cardiovascular problems, visual problems, musculoskeletal disorders and stress [4, 9, 11, 15, 16, 19].

It is important to realize that being a gamer is not just a hobby. Nowadays, being a gamer is considered a professional job, where players are integrated in professional teams and have a contract job. However, in this kind of activities, the players are exposed to some occupational risks in the same way as in other professions. They can spend eight hours seated in front of a computer for training and even more time during competitions [10].

Studies have shown that being seated in front of a computer can be associated with an increased risk of lower-back pain (LBP) [8, 24]. Important risk factors of LBP are the long time-period spend in front of a computer without appropriate rest and the adoption of static and awkward postures [8]. Maintaining the same spinal position for a long time can lead to micro-damages of soft tissues structures, reduce joint lubrication, potentiate muscle tension, muscle strains and muscle fatigue, causing impairment of motor coordination and control, as also increasing mechanical stress on ligaments and intervertebral discs [13, 21]. This can induce low back discomfort [21], which is a stronger predictor of LBP [13].

This kind of behaviours have been also related to musculoskeletal disorders in neck, shoulders, elbows and wrists [23]. Research suggests that sitting work itself is not the major cause for developing pain [14, 18, 20], but other factors like work task may be the centre of the problem [20].

When we are addressing the problem of musculoskeletal disorders in gamers community, this is even more relevant than in other professions, since they can start playing still very young, as a teenager [12]. Additionally, spine kinematics is of particular importance to study the risk of musculoskeletal pain and injury, in particular in what regards to low back [6].

Due to the limited number of studies in this area and to find out if the job of being a gamer, i.e., practice eSport, can contribute for LBP, the purpose of this study is, in a first stage, to characterize gaming behaviours of semi-professional and non-professional gamers and, in a second stage, through an experimental study, to analyse the effect of those behaviours on normalized lumbar flexion angles during a typical gaming session.

2 Materials and Methods

2.1 Study Design

This study consisted of two parts. In the first part, a questionnaire was developed and administered to the Portuguese gaming community with the intention of characterizing their gaming behaviours and habits. In the second part an experimental study was designed to analyse lumbar postures along a typical gaming session.

The research adheres to the principles outlined in the Helsinki Declaration, and it has previously been approved by an Ethics Committee. The study's objectives and procedures were explained to all participants of the experimental study at the start. Additionally, each participant completed a digital consent form, with their personal signature.

2.2 Analysis of Gamers Community Behaviours

2.2.1 Sample

The study recruited 49 gamers from the Portuguese gaming community using social networks (Facebook and specific e-gaming communities/groups), with a focus on reaching a larger portion of the target population. Inclusion criteria required participants to play e-games either alone or in teams. Among the respondents, 79.65% were male and 20.4% were female. 4.1% of respondents identified as professional gamers, which is an important number given that professional gaming is still emerging as a viable career option in Portugal.

2.2.2 Sample

An online questionnaire was created using Google Forms to analyse the gaming habits of the Portuguese gaming community. The questionnaire included three parts. In the first part were questions to collect socio-demographic information such as age, gender, gamer activity and previous musculoskeletal disorders. Then, in the second part, questions to analyse their gaming behaviours were included, such as: "On average, how many hours do you play per week?"; "How many days do you play, on average, in a week?"; "How many time do you play without perform a break?"; "On average, during practice, how many times do you get up from your chair?"; "Do you do breaks between intervals/matches of games (queue)?". Finally, in a third part, questions to understand the discomfort felt were made. A 10 cm Visual Analogue Scale (VAS) was used to the subjects rate the perceived discomfort in different body areas, where 1 = "no discomfort" and 10 = "extreme discomfort".

This questionnaire was validated with a sample of 5 gamers that were not a part of this study for linguistic matters.

In the end of the questionnaire, participants were requested to identify if they were available to participate in the experimental study.

2.3 Experimental Procedure

2.3.1 Sample

Fourteen non-professional and amateur gamers were randomly recruited from a gaming group on the social network Facebook. Most of these individuals volunteered to participate in the study's first phase. Due to a low number of female volunteers, only male participants were included to avoid potential gender bias. This sample size was deemed sufficient when compared to similar studies in the field [3]. Inclusion criteria were: male, right hand dominant; age between 18 and 25 years old; normal Body Mass Index (BMI); absence of musculoskeletal disorders; play at least 10 h and 5 days a week. These criteria were all fulfilled by the samples. On average, gamers had 21 ($\pm 1, 4$) years old and a BMI of 22 ($\pm 2, 0$) kg/m² (normal BMI range between 18 and 25 kg/m²).

Before the experiment, it was required to participants to sign an informed consent form.

2.3.2 Room and Equipment

A room was adapted to the experiment. It was equipped with a DXRacer OH/FD99/NR Ergonomic Gaming Chair and a computer setup adjustable to each subject. The chair had adjustable arms and height, neck, and lumbar support. This is a common gaming workstation.

The room was also controlled for illuminance (139.7 ± 8.6 lux) with a digital luxmeter (Ambergo, GOSSEN, MAVOLUX 5032C). Levels of illuminance remained low, because this is a common practice among gamers. Curtains were used to control brightness on the computer screen.

Before the experiments, and after sign the informed consent, subjects were invited to seat on the workplace and then, chair, table, computer screen, mouse and keyboard were adjusted to their needs.

2.3.3 Postural Analysis

The postural response movements were analysed through a triaxial accelerometer system. Triaxial accelerometers (bioPlux, xyzPlux model, BioSignalsPlux) were fixed to the subject's skin with tape, with the +y-axis direct downward over the

L1 and S2 spinous processes [3], to observe the lumbar spine flexion/extension. This method was chosen since it is not invasive for the performance of the task of the subjects, due to the size and flexibility of the accelerometers used for data collection.

To normalized data, a calibration procedure was carried out for 10 s with the subject in the upright standing and another one with the subject in maximum lumbar flexion standing [3].

Data collection was performed during a 180 min session (3 h), in blocks of 15 min, with a frequency of 100 Hz display. Data were collected by a Bluetooth system and the signals collected from the accelerometers were obtained through the OpenSignals (r) evolution software.

2.3.4 Accelerometers Data Analysis

The accelerometers were calibrated according to the instructions given by the fabricant. Then, the values collected from the previous step were calculated to g-force according to the Eq. 1.

$$g_x = \frac{\text{signal}_x - V_{\text{MEAN}_x}}{V_{\text{MAX}_x} - V_{\text{MEAN}_x}} \quad (1)$$

In this equation, signal_x refers to the respective row of raw values acquired by bioPlux. V_{MEAN_x} refers to the difference between V_{MAX_x} and V_{MIN_x} divided by two. V_{MAX_x} stands for the xx -axis maximum values, V_{MIN_x} refers to the xx -axis minimum values. These steps were also done to the yy -axis and zz -axis.

The values obtained with the accelerometers were passed through a Butterworth 4-way filter with a 6Hz cutoff by using Acq.Knowledge 3.9.0 Software (BIOPAC Systems, Inc).

The angles in L1 and S2 were determined following the procedure described in [1]. Lumbar angles were taken as the difference between the inclination of the L1 accelerometer and S2 accelerometer. Lumbar flexion angles were then normalized and ROM% was determined according to [5].

2.4 Data Analysis

In a first stage, data from Bioplux was extracted into a Microsoft Excel software to calculate means and standard deviation.

Statistical analysis was all carried out using IBM SPSS Statistics (SPSS Inc, Chicago, USA) and statistical significance was defined at $p < 0.05$. Shapiro-Wilks test was used to verify normality. Wilcoxon test was used to compare two paired groups.

3 Results

3.1 Gaming Behaviours Analysis

Table 1 presents the results obtained in what regards to the training hours played per week. Data shows that most gamers play 1–5 h per week (24.5%) with team and a significant part of them plays between 6 or more hours per week with the team (6–10 h = 8.2%; 11–15 h = 10.2%; ≥ 16 h 6.1%). When concerns playing alone, the majority of inquired gamers reported play 1–5 h per week (34.7%) or 6–10 h per week (20.4%). However, 14.3% of gamers reported play alone for more that 16 h per week. It is important to note that subjects can play alone and with the team in the same week, increasing their gaming time. On other hand, 42.9% of gamers never practice with a team and 10.2% never practice alone.

Table 2 describes the distribution of responses about the number of days played per week. With team, 24.1% of gamers reported to play six days per week and a significant part to play only 1 or 2 days per week (1 day = 12.2%; 2 = 10.2%). Alone, 24.5% of gamers plays 7 days per week computer games and a significant part one or two days (1 day = 16.3%; 2 days = 20.4%).

The third part of the questionnaire included a question regarding musculoskeletal discomfort that subjects typically experience after a gaming session. Results about the body areas where players reported felt discomfort are described in Fig. 1. Other results were not included. It is possible to verify that discomfort levels reported were higher than 5 for almost 22% of the subjects for lower back, 20% for upper back and 28% for neck.

Table 1 Distribution of training hours played by gamers per week ($N = 49$)

	None	<1 h	1–5 h	6–10 h	11–15 h	≥ 16 h
With team (%)	42.9	8.1	24.5	8.2	10.2	6.1
Alone (%)	10.2	12.2	34.7	20.4	8.2	14.3

Table 2 Distribution of days played by gamers per week ($N = 49$)

	Number of days							
	0	1	2	3	4	5	6	7
With team (%)	46.9	12.2	10.2	8.2	4.0	6.1	24.1	8.2
Alone (%)	10.2	16.3	20.4	6.1	4.0	12.2	6.1	24.5

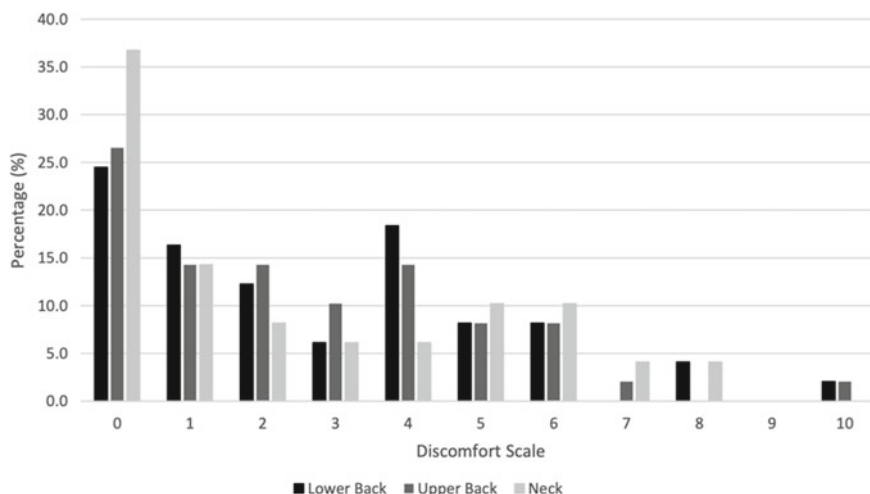


Fig. 1 Distribution of discomfort level reported at lower back, upper back, and neck ($N = 49$)

3.2 Experimental Study

Figure 2 describes the average of normalized lumbar flexion angles during the selected 6-periods of 15 min. A base line ROM% was determined for seating posture. In this study was $50.5 \pm 42.1\%$. Data shows that the lumbar spine flexion changed along the training period. On average, lumbar spine was significantly more flexed in the intervals 30–45 min ($24.7 \pm 28.5\%$), 120–135 min ($25.3 \pm 34.0\%$) and 150–165min ($22.9 \pm 48.4\%$) in comparison with the baseline lumbar flexion angle ($50.5 \pm 42.1\%$; $p < 0.05$ for all intervals). The subjects in the first hour began to flex the lumbar spine, decreasing from 50.5% ($\pm 42.1\%$) to 24.7% ($\pm 42.1\%$), in the 30–45min interval, of the lumbar angle. That decreased was in part corrected in the 60–75min ($40.9 \pm 44.3\%$), maintaining that lumbar flexion angle for 45min. After this period the lumbar flexion angle started do decrease again, reaching values of 22.9% ($\pm 48.4\%$) in the end of the training session. It is important to note that the last 15 min were removed from the sample, since some gamers had already finished the game.

4 Discussion

Results from the first part of this study showed that gaming community tend to spend more time training alone. Several gamers play alone seven days a week and with teams six days. Additionally, it was verified that when considered both the time that gamers spent training alone and with the team, data suggest that some

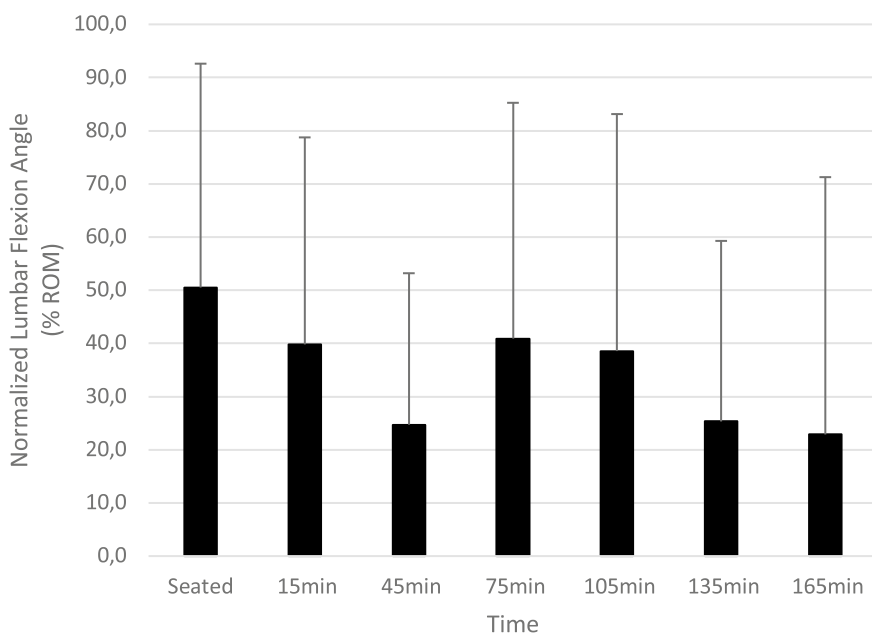


Fig. 2 Amplitude probability distribution function results for normalized Lumbar Flexion angle ($N = 16$)

gamers can spend more than 40 h per week training. Considering the time that some gamers spend practicing, and that several of them have other activities, such as be a student, this group can be at risk of musculoskeletal and visual disorders, such as other professionals that spend several hours per week in front of a computer [4, 17]. Professional gamers, due to their commitment to be the best, spend more time training than an amateur player, being that reflected in the numbers of hours that they spend in front of a computer.

Results from questionnaires also showed that they felt more discomfort in the lower back, upper back, and neck. Discomfort reported for other body regions was marginal, and because of that, the authors decided to not describe them in the results section. These discomfort feelings can be related to the time spent seated in front of the computer, without an appropriate resting period and adopting awkward postures as proved in other studies (e.g., [8]).

Because low-back discomfort was emphasized in the questionnaires, in the first part of the study, an experimental procedure was designed to analyze if these feelings can be related to the low back excessive flexion or extension. Flexion of lumbar spine is related to the rearward rotation of the pelvis that is the physical response of the body to sitting [2, 8]. The body dimensions are a huge factor when it comes to lumbar spine posture [7], however, the participants in this study had all healthy BMI's, which in theory is predicted to potentiate a more neutral lumbar spine posture.

Analysis of time-varying posture data revealed that lumbar angle does not remain consistent throughout the 3 h of gaming. In the first hour was observed a decreased of the lumbar flexion angle, that was corrected in the next 30 min, returning to the first 15 min seated lumbar angle. In the last 60 min occurred again a decrease of the lumbar angle. Data also showed that the baseline seated lumbar angle was never adopted by them during practice, suggesting an excessive lumbar flexion. These results can be related to the amount of time that the subjects are usual to play and because of the initial posture being already conditioned. The present experimental study was conducted without any breaks within the 3 h. This time period was defined since several gamers reported to play two to three hours without any breaks. Previous studies showed that breaks seem to be effective in discomfort prevention [22], which can lead to less lumbar flexion angles variations. Though these studies may prove that breaks are effective in discomfort prevention and consequent less lumbar flexion angles, the gamer reality is playing 8–10 h per day without too many breaks [10]. When taking this reality into account, where almost no breaks are performed, and gamers are seated for long time-periods, the results observed were the expected ones. Changes in lumbar flexion angles can be explained with the discomfort felt through the time, where subjects felt the need to adjust their posture.

The lumbar flexion angles variations observed in this study were obtained in a controlled and comfortable environment, to minimize the effect of other variables on lumbar posture. However, these conditions cannot be guarantee for most of the gamers. The main variable removed from this experimental study was the chair, that was provided with an adjustable lumbar support. This support provides some greater upright spine postures [13]. However, the reality for most of the gamers does not include an ergonomic gaming chair, which supposedly will reflect on their lumbar flexion angles.

5 Conclusions

The results of this study were expected and indicate that some gamers spend a considerable amount of time seated in front of a computer. When this practice is prolonged without appropriate breaks, it can have a significant impact on lumbar flexion angles. Thus, it can be concluded that lumbar flexion angles vary over time, and in some cases, the lumbar flexion is excessive.

Despite the importance of the obtained results, they have certain limitations. The number of responses obtained from the questionnaires is not representative of the entire gaming community. The conditions of the study were experimental, and different results may be obtained in the real world. Additionally, only lumbar flexion was assessed in this study due to its exploratory approach to the problem.

Musculoskeletal disorders and other disorders in gamers are a whole new area of study and needs to be more developed. This study provided a new insight to this field but needs to evolve. Further studies should verify thoracic and neck flexions.

During data collection it was possible to observe some variations in thoracic and neck postures, being important to analyze changes in these angles through time.

Acknowledgements The authors would like to thank you to the gamers that voluntarily participated in this study.

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Musculoskeletal Disorders Risk Assessment in a Radiotherapy Service



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Abstract The risk of a health worker contracting work-related illnesses is about 1.5 times greater than the risk of all other workers. For this reason, the objective of this study was to evaluate the work-related musculoskeletal disorders risks to which the clinical placement students of the Medical Imaging and Radiotherapy degree were exposed. The study was carried out in a public radiotherapy service, where 482 ergonomic evaluations were carried out, for a total number of 10 participants, using the REBA and RULA methods, using the ErgoFellow software. A semi-structured interview was also carried out. The statistical analysis of the results was performed using the IBM SPSS software. The study made it possible to understand that the ergonomic risk was mostly low in both genders and that in the workplaces, the risk was considered medium in the “Planning TC Control Room” and in the “Linear Accelerator Control Rooms”, with the activities that presented a higher level of risk were “Moving the treatment table”, “Aligning the patient along the sagittal midline”, “Placing treatment masks”, “Marking the zero cut-off points and placing the fiducial marks”, “Perform tattoos on the patient”, “View the volumes to be treated” and “Handle hardware equipment”. The variables that most contributed to the level of risk were the trunk, neck, arm, forearm and lower limbs.

Keywords Radiotherapy · Ergonomic · Work-related musculoskeletal disorders · REBA · RULA · Workplace

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1 Introduction

Over the last few years, as in the rest of Europe, we have witnessed a regular increase in the incidence of cancer in our country, at a constant rate of approximately 3% per year. On the other hand, the increase in therapeutic successes also contribute to a significant increase in the number of cancer survivors [17]. Consequently, there is an increase in demand for radiotherapy services, as radiotherapy is currently the therapy of choice for the treatment of cancer patients [1]. Radiotherapy is a medical specialty that integrates a multidisciplinary plan for the treatment of oncological disease [6] and consists of a treatment with ionizing radiation, with the objective of depositing the maximum dose of radiation in the tumor and the minimum in organs surrounding. Radiation therapy is divided into external radiation therapy and brachytherapy. With regard to external radiotherapy, beams of radiation are usually produced by a linear particle accelerator, directed at the tumor with the aim of decreasing or delaying the growth of cancer cells [21].

The knowledge and study of occupational risks, work accidents and occupational diseases are very important due to the health problems they cause in health professionals [26]. Thus, each organization must reduce and manage its risks in order to provide adequate working conditions for all employees [3]. Risk assessment is the process of identifying risks to the safety and health of workers. This implies a detailed analysis of the physical, organizational, psychological and social aspects during working time, likely to influence the safety, health and well-being of workers [4]. This is also a process that allows companies and organizations to put in place a proactive risk management policy in their workplaces. When performed well, risk assessment ensures that all relevant risks are taken into account [30]. Risk assessment serves as a basis for rational decision making about risks, allowing the assessment and classification of a risk situation as acceptable or not acceptable [24].

The need to prevent risks is the key reason why every effort is made to ensure safer environments in healthcare facilities and to ensure that work can be carried out under healthier and safer conditions. As the risk of a health professional of contracting work-related illnesses is about 1.5 times greater than the risk of all other workers [31]. Through ergonomics it is possible to make changes in the working conditions and environment, through adaptations in resources and in the work process for a better quality of life for workers. Ergonomics also prevents damage caused to workers during the performance of their duties, in order to reduce risks, without prejudice to professional performance. Thus, ergonomic risks directly influence productivity, as they cause physical and mental damage to professionals. Due to its numerous consequences, it is essential to analyze the ergonomic risks in health units, in order to identify the sectors with the greatest exposure. Ergonomics favors the health of the worker in order for them to perform their activities without putting their health at risk [27, 29]. Taking into account the whole context of accidents at work and the high incidence of them related to the work of a health professional, it is imperative that measures are taken to protect these professionals and minimize accidents at work, that is, to study all the variables that can reduce the number of accidents [26].

Ergonomic risks are essentially related to the loads that the worker bears, the positions he adopts and the physical effort he makes when assisting partially or totally dependent elderly people, causing the overload of the musculoskeletal system of these professionals [9]. Ergonomics can be defined as the scientific discipline that deals with the interactions between Man and the elements of the work system, optimizing the well-being of the worker [22].

Ergonomics studies aim to provide people with working conditions that require less demands from workers and, consequently, less wear and tear and greater productivity [8]. Therefore, it is essential to adapt the workplace, the equipment and its quality, with the objective of contributing not only to the increase in production and quality, but also to the reduction of injuries and diseases [3].

According to the European Agency for Safety and Health at Work, Musculoskeletal Disorders (MSDs) of occupational origin correspond to injuries caused or aggravated, mainly, by professional activity and its immediate effects. Most professional MSDs are cumulative injuries, resulting from repeated exposure to more or less intense exertion over a prolonged period of time [12, 5, 22]. MSDs can affect different body segments, such as the shoulders, neck, trunk, knees, wrists or hand [7]. The high physical load of the tasks performed by the worker can lead to the development of musculoskeletal disorders, especially in the trunk and upper limbs [10, 22]. Taking into account MSDs in the workplace, methods were developed to assess exposure to risk factors for musculoskeletal diseases, and some of these methods focus on these body regions [7].

The ergonomic analysis of work aims to analyze the ergonomic risks of each task and then indicate proposed measures to extinguish or reduce the existing risk, thus providing better working conditions and better performance of work tasks [11]. In this way, and given the need to understand the reality of workers present in a radiotherapy service, it was proposed, as an objective of this study, to evaluate the MSDs risks to which trainees of the degree in medical imaging and radiotherapy (MIR) were exposed.

2 Materials and Methods

The present study was carried out between October 2021 and July 2022 and data collection took place during the mornings between March and April 2022. The study was observational, analytical in nature and cross-sectional cohort type and knowledge level II (descriptive-correlational). With regard to the level of knowledge, the study was of level II. The study was carried out in a public radio-therapy service and consisted of the evaluation of ergonomic risks associated with the postures adopted by the clinical placement students of the Medical Imaging and Radiotherapy degree.

The sample was of the non-probabilistic type for convenience regarding the technique. The sample consisted of 482 ergonomic assessments for a total number of 10 participants. As inclusion criteria, all clinical placement students of the MIR degree

were considered, who were interns in the radiotherapy service, in different tasks. The total number of participants per task is shown in Table 1.

An ergonomic evaluation of the activities carried out on the clinical placement students of the Medical Imaging and Radiotherapy degree was carried out in the different tasks. For this purpose, MSDs assessment methods were adopted depending on the posture most adopted, that is, at the workstation “Planning CT Room”, “Bunker 2” and “Bunker 3” the ergonomic method Rapid Entire Body Assessment was used. (REBA).

For the workstations “Planning CT Control Room”, “Planning Dosimetry Room”, “Linear Accelerator Control Room 2” and “Linear Accelerator Control Room 3” the ergonomic Rapid Upper Limb method was used. Assessment (RULA).

The choice of risk assessment methods focused on the postures adopted by the participants relating to the method’s application scope.

In Table 2 it can be seen the levels of action according to the score obtained from the assessments.

REBA method was developed to assess unpredictable postures at work and aims to develop a postural analysis sensitive to musculoskeletal risks in a variety of tasks, divide the body into segments to be analyzed individually with reference to plans of movement and has the function to create a scoring system for muscle activity caused by static, dynamic or unstable postures [2, 11]. The RULA method was developed to investigate the exposure of individual workers to risk factors associated with upper limb disorders. It is a method developed to carry out ergonomic investigations where work-related upper limb disorders are reported. This method provides a quick assessment of neck, trunk and upper limb postures, along with muscle function and loads used [15].

A semi-structured interview was carried out to the MIR students performing the clinical placement, focusing essentially on the perceived discomfort/pain and what activities were associated with this discomfort/pain. This interview was based on the

Table 1 Number of participants per task and respective activities carried out

N	Workstation	Main activities developed
2	Planning CT room	Position patients in the correct position and mark the area to be treated with small tattoos
	Planning CT control room	Acquire and analyze patient images
4	Planning dosimetry room	Plan treatment on the Treatment Planning System and calculate dose distribution and incidence configuration of treatment beams
2	Bunker 2	Position the patient as determined in the “Planning TC Room”
	Linear throttle control room 2	Analyze scan images
2	Bunker 3	Position the patient as determined in the “Planning TC Room”
	Linear throttle control room 3	Analyze scan images

Table 2 Risk levels according to the REBA method

Method risk description		
REBA	1	Insignificant risk. No intervention is required
	2 or 3	Low risk. Intervention may be required
	4 to 7	Medium risk. Intervention needed
	8 to 10	High risk. Intervention needed as soon as possible
	11 or more	Very high risk. Intervention needed immediately
RULA	1 or 2	Acceptable posture
	3 or 4	Further investigation, change may be needed
	5 or 6	An investigation must be carried out. Changes must be introduced
	7	Further investigation, change soon

Nordic musculoskeletal questionnaire [23] and had as main objective the collection of relevant information for the analysis of the obtained results. The MSDs risk assessment was performed inside the radiotherapy service during the morning, using the ErgoFellow software version 8.0 to calculate risk score according to RULA and REBA methods. Subsequently, a more detailed analysis for activities where the average risk was greater than 50%.

The data obtained were statistically treated using the IBM SPSS Statistics software version 27. In terms of descriptive statistics, it was used absolute and relative frequency analyses, measures of central tendency (simple arithmetic mean) and measures of dispersion (standard deviation). In the inferential statistical analysis, the Chi-square test of Independence was used to understand the relationship between the levels of MSDs risks, the tasks and the activities and the T-Student test for 2 samples to understand the relationship between the levels of MSDs risk, gender, height and weight of trainees. For the estimation of statistical inference, it was taken into account a confidence level of 95% and a random error of less than or equal to 5%. That is, when the calculated significance value (p-value) is less than 5% ($p < 0.05$), it is stated that there is a statistically significant difference between the variables.

The ethical-legal procedure applied for the development of the investigation was approved by the Ethics Committee of the Polytechnic Institute of Coimbra. The informed consent was obtained from the participants before the study.

3 Results

The study sample consisted of 10 MIR clinical placement students. Of these, 40% are masculine and 60% feminine. Regarding the age of the participants, this was, on average, 22 years old. The height of the participants ranged between 1.53 and 1.86 m and weight between 51 and 103 kg.

It was intended to carry out a comparative analysis between the gender of the target population in relation to the level of risk, using the REBA method (Table 3). It was found that there is no statistically significant relationship between the gender of the sample with regard to the type of risk being assessed ($p > 0.05$). Although there are no differences, the percentage of female and male tend to be higher in activities scored with “low risk”. On the contrary, using the RULA method, it was found that there is a statistically significant relationship between the genders of the trainees with regard to the type of risk being assessed ($p < 0.05$). The female gender had a higher percentage in activities scored with “medium risk” (86.1%), while the male gender had a higher percentage in activities scored with “low risk” (75%).

A comparative analysis was performed between height, weight of participants and risk level (Table 4). When the REBA method was applied, there was no statistically significant relationship ($p > 0.05$) but on the other hand, in the activities where the RULA method was applied, there was a statistically significant relationship between height, weight of trainees and the type of risk ($p < 0.05$). In analyzing the results of Table 5, height and weight present a higher percentage in activities scored as “low risk”. Regarding the height of the participants, in activities with medium risk, the minimum height is, on average, 1.55 m and the maximum height (on average) is 1.80 m.

A relationship was made between the tasks and the types of risk, by assessment method applied. According to the results in Table 5, there was a statistically significant relationship between the tasks, with regard to the type of risk being assessed ($p < 0.05$). The “low risk” was significantly higher when the trainees carried out their activity in the “Planning CT Room” (51.5%) and in the “Bunkers” (62.2%). Regarding the level of risk that prevails, 58.6% of the assessments were scored as low risk. When carrying out an analysis, using the RULA method, a statistically significant relationship was found between the tasks with regard to the type of risk being assessed ($p < 0.05$). The “medium risk” was significantly higher when the trainees carried out their activity in the “Planning CT Command Room” (100%). Compared to “low risk”, it was significantly higher when the trainees carried out

Table 3 Relationship between gender and type of risk assessed (low or medium)

Method	Gender	Risk [N (line %)]		N	<i>p</i> -value
		Low	Medium		
REBA	Female	206 (58.0%)	149 (42.0%)	355	$\chi^2 = 0.463$
	Male	23 (63.9%)	13 (36.1%)	36	gl = 1
	Total	229	162	391	$p = 0.496$
RULA	Female	5 (13.9%)	31 (86.1%)	36	$\chi^2 = 22.750$
	Male	18 (75.0%)	6 (25.0%)	24	gl = 1
	Total	23	37	60	$p \leq 0.0001$

Test Independence Chi-square

Table 4 Relationship between height, weight and type of risk

Method	Variable	M	SD	n	Risk	p-value
REBA	Height	1.6497	0.07028	229	Low	p = 0.466
		1.6442	0.07756	162	Medium	
	Weight	69.05	13,711	229	Low	p = 0.099
		66.74	13,415	162	Medium	
RULA	Height	1.7435	0.09456	23	Low	p = 0.002
		1.6681	0.07937	37	Medium	
	Weight	76.74	16,690	23	Low	p = 0.040
		68.57	13,196	37	Medium	

Test T-Student 2 samples

Subtitle: n—sample number; M—Average; SD—Standard Deviation

Table 5 Relationship between the tasks and the type of risk assessed (low or medium)

Method	Workstation	Risk [N (line %)]		N	p-value
		Low	Medium		
REBA	Planning CT room	68 (51.5%)	64 (48.5%)	132	$\chi^2 = 4.085$
	Bunkers	161 (62.2%)	98 (37.8%)	259	gl = 1
	Total	229	162	391	p = 0.043
RULA	Planning CT	0 (0.0%)	12 (100.0%)	12	$\chi^2 = 48.190$
	Control room	18 (75.0%)	6 (25.0%)	24	gl = 2
	Planning dosimetry room	22 (91.7%)	2 (8.3%)	24	p ≤ 0.0001
	Total	23	37	60	

Test Independence Chi-square

their activity in the “Planning Dosimetry Room” (91.7%). Regarding the level of risk that prevails, 61.7% of the assessments concluded that the risk was medium.

In order to analyze which activities presented the highest level of MSDs risk, according to the results obtained in Table 6, it was possible to observe a statistically significant relationship between the various activities with regard to the type of risk being evaluated ($p < 0.05$). The “medium risk” was significantly higher when the trainees moved the treatment table (71.9%), when they aligned the patient along the sagittal midline (100%), when they put on the treatment mask (100%), when they marked the zero cut points and placed the fiducial marks (100%), when they performed the tattoos on the patient (100%) and when participants viewed volumes to be treated (100%). “Low risk” was significantly higher when trainees disinfect the treatment table and immobilization systems (100%), when they put on the appropriate immobilization systems (98.4%), when they removed the immobilization systems used (100%), when they transferred the patient to the treatment table (94.3%), when they removed the treatment masks (100 %), when they helped the patient to leave the treatment table (96.3%) and when the trainees determined

the dose to be administered (91.7%). Regarding the prevailing risk level, 58.6% of the assessments carried out using the REBA method were of low risk and 61.7% of the assessments carried out using the RULA method concluded that the risk was medium risk.

Carrying out a more detailed analysis of the activities with an average risk above 50%, using the REBA and RULA method (Table 7), it was found that the activities of “Moving the treatment table”, both in “Bunker 2” and in “Bunker 3” the variables that most contributed to the final risk level were the trunk, arm, forearm and load. When “Aligning the patient by the sagittal midline”, it was found that in the “Bunker 2” in the neck and arm the values were higher in relation to the intervals, and contributed

Table 6 Relationship between the activities carried out and the type of risk assessed (low or medium)

Activities	Risk [N (line %)]		n	p-value
	Low	Medium		
Disinfect the treatment table and immobilization systems	48 (100.0%)	0 (0.0%)	48	
Place the appropriate immobilization systems	63 (98.4%)	1 (1.6%)	64	
Remove used immobilization systems	35 (100.0%)	0 (0.0%)	35	
Moving the treatment table	18 (28.1%)	46 (71.9%)	64	$\chi^2 = 321.88$
Align the patient to the sagittal midline	0 (0.0%)	48 (100.0%)	48	$g1 = 10$
Put on treatment masks	0 (0.0%)	28 (100.0%)	28	$p \leq 0.0001$
Mark the zero cut points and place the fiducial marks	0 (0.0%)	19 (100.0%)	19	
Perform the tattoos on the patient	0 (0.0%)	17 (100.0%)	17	
Remove treatment masks	6 (100.0%)	0 (0.0%)	6	
Assist the patient off the treatment table	26 (96.3%)	1 (3.7%)	27	
View the volumes to be treated	0 (0.0%)	12 (100.0%)	12	$\chi^2 = 48.190$
Determine the dose to administer	22 (91.7%)	2 (8.3%)	24	$g1 = 2$
Handle hardware equipment	1 (4.2%)	23 (95.8%)	24	$p \leq 0.0001$
Total	252	199	451	

Test Independence Chi-square

to the increase in the final risk level while in the “Planning CT Room”, was the neck, trunk and arm, the variables that influenced the final risk level. Regarding “Putting on treatment masks”, in both “Bunker 2” and “Bunker 3” and in the “CT Planning Room”, the final risk level was higher due to the higher values in the neck, trunk, arm. When “Marking the zero cut-off points and placing the fiducial marks” and “Performing the tattoos on the patient”, in the “Planning CT Room”, the variables that contributed to the final risk level were the neck, trunk, arm and forearm. “Visualizing the volumes to be treated”, in the “Planning CT Control Room”, the variables that contributed to the increase in the final risk level were the forearm and lower limbs. Regarding “Handling hardware equipment”, in the “Linear Accelerator Control Room 2” and “Linear Accelerator Control Room 3”, it was found that in the forearm the values were higher in relation to the interval and contributed to the increase in the ultimate risk level.

According to the results obtained, it was found that the MSDs risk was mostly low in both genders. Regarding the tasks, the risk was considered medium in the “Planning CT Control Room” (100%) and in the “Linear Accelerator Command Rooms” (95.8%), with the activities that presented a higher level of risk were “Move the treatment table” (71.9%), “Align the patient along the sagittal midline” (100%), “Put on treatment masks” (100%), “Mark the zero cut points and place the marks fiducial” (100%), “Perform tattoos on the patient” (100%), “View volumes to be treated” (100%) and “Handle hardware equipment” (95.8%), with mostly a level of higher risk in the trunk, neck, arm, forearm and lower limbs.

Table 7 Score of activities with an average risk of more than 50%

Activities	Workstation	Method	Score ^a
Moving the treatment table	Bunker 2	REBA	5
	Bunker 3	REBA	5
Align the patient to the sagittal mid-line	Bunker 2	REBA	5
	Planning CT room	REBA	5
Put on treatment masks	Bunker 2	REBA	5
	Bunker 3	REBA	5
	Planning CT room	REBA	5
Mark the zero cut points and place the fiducial marks	Planning CT room	REBA	6
Perform the tattoos on the patient	Planning CT room	REBA	6
View the volumes to be treated	Planning CT control room	RULA	6
Handle hardware equipment	Linear Throttle Control Room 2	RULA	5
	Linear Throttle Control Room 3	RULA	5

^aREBA range [1–13]; RULA range: [1–7]

4 Discussion

Risk assessment is the basis for preventing occupational accidents and illnesses. This must be carefully carried out and adapted to the reality of each company, ensuring that all relevant risks are identified and that the respective prevention measures are indicated [16].

When comparing the genders of the target population with the type of risk, it was found that the activities scored with medium risk are carried out mostly by the female gender. There is indeed a significant difference in prevalence between genders [25] females are more susceptible to RSI/WMSDs (Repetitive Strain Injury/Work-Related Musculoskeletal Disorders), based on the assumption that female and male genders are exposed to the same workload [18]. One of the reasons given would be related to the segregation, by gender, of the labor market, in which men and women worked in different sectors and consequently different activities. Currently, the greatest justification has been focused on occupational risk factors, such as exposure to physically heavy and demanding factors, such as manual handling of loads. Exposures relevant to the occurrence of musculoskeletal disorders include physical workload [13].

With regard to the height of the participants, in activities with medium risk, the minimum height is, on average, 1.55 m and the maximum height (on average) 1.80 m. according to [32], this fact reveals that anthropometric measurements are the main causes of ergonomic risks [32]. In fact, the workstations must be adjusted, namely in the placement of equipment adjustable to the height of the professionals and furniture suitable for the activities carried out. It was evident, through observation *in loco*, that the shorter participants, faced with the need to develop their activities, demonstrated a rise of the shoulders. On the other hand, taller trainees developed spinal flexion with a higher level of severity. Reflecting further with regard to height and gender, it is the female participants who are at higher risk since they are, on average, shorter from the point of view of height.

In the “Planning CT room” and in the “Bunkers” the percentage was higher in the ergonomic evaluations classified as “low risk” while in the “Planning CT control room” and in the “Linear accelerator control rooms” the percentage was higher in ergonomic assessments classified as “medium risk”. These results make visible the exposure of professionals to ergonomic factors such as inappropriate postures and repetitive gestures [8] mentions that these professional exposures can result in injuries or fatigue for workers either in the short or long term. Lima [14] mentions that injuries can be influenced both by the height and depth of the seat, referring that individuals who are shorter tend to move their legs more, possibly due to the fact that the seat of the chair is height comparing to their height. However, the authors also state that these individuals become less restless and more active after stretching. Therefore, it is important to implement corrective and/or preventive measures for trainees in order to reduce the levels of risk encountered, namely through raising awareness about adopting correct postures, adjusting equipment, adapting the control desk to the worker, implementing supports for feet and suitable ergonomic chairs and awareness raising for carrying out labor gymnastics.

According to the results, when applying the ergonomic method, the activities of “Moving the treatment table”, “Aligning the patient along the sagittal midline”, “Putting on the treatment mask”, “Marking the zero and placing the fiducial marks”, “Performing the tattoos on the patient”, “Viewing the volumes to be treated” and “Handling the hardware equipment” were the ones that had a higher level of exposure to risk. This level of risk is due to the existence of a lateral flexion of the trunk when “Moving the treatment table”; lateral flexion of the trunk, elevation of the shoulders and flexion of the neck to “Align the patient along the sagittal midline”, to “Mark the zero cut-off points and place the fiducial marks”, “Perform the tattoos on the patient” and “View the volumes to be treated”; of a trunk flexion when “Putting on the treatment mask” and a lateral trunk flexion when “Handling the hardware equipment” and the lack of adequate equipment in this same activity. According to the study carried out by [23] the tasks that influenced the onset of musculoskeletal symptoms were fully associated with postures that involved twisting and rotating the trunk and handling heavy loads. According to [20], 95% of the activities are performed standing up, 26% of which require flexion and rotation of the trunk, causing pain in the trunk due to static and/or repetitive movements of workers in a short period of time. These tasks, according to [5], require readjustments of the activity, namely, the reduction of repetitive actions and the application of procedures that require less effort and/or flexion of the trunk. In order to reduce the levels of risk found, it is important to adopt corrective and/or preventive measures for interns, namely through the correct use of equipment in activities such as “Moving the treatment table”; from adopting correct postures to “Aligning the patient along the sagittal midline”, “Marking the zero cutoff points and placing the fiducial marks”, “Performing tattoos on the patient”, “Visualizing the volumes to be treated” and “Handling the hardware equipment” and making adjustments to the equipment when “Putting on the treatment mask”, allowing the worker to adopt more natural postures, without bending the trunk,

In the analysis of the responses collected through the semi-structured interview, the main discomforts mentioned by the population were trunk pain and eye strain.

In view of the detailed analysis of the activities where the risk was higher, the variables that most contributed to the final risk level were the trunk, arm, forearm, neck, load and lower limbs [21] mentions that due to exposure to ergonomic factors, it becomes visible that professionals sometimes adopt inappropriate postures in the exercise of their activity. In turn, [19, 28], compares complaints of dorsolumbar discomfort with different work activities and states that there is a relationship between trunk flexions and complaints of discomfort, but that, above all, there is a great influence of physical activities in the pathological context of each symptom. Salvador [27] mentions that patient mobilization may increase the probability of IAM, due to the patient’s weight and the effort required to perform tasks.

5 Conclusions

By carrying out a risk assessment, we are able to identify the factors that influence the level of MSDs risk and to implement corrective/preventive measures. The results of the study show that in the radiotherapy service, the activities rated with medium risk are mostly performed by the feminine gender, as well as by the population with shorter and taller stature. The workstations that presented a higher level of risk were the “Planning TC control room” and the “Linear accelerator control rooms and the activities that presented a higher level of risk were when “Moving the treatment table”, “Align the patient along the sagittal midline”, “Put on treatment masks”, “Mark the zero cut points and place the fiducial marks”, “Perform the tattoos on the patient”, “View the volumes to be treated” and “Handle the hardware equipment”, which presented a higher risk level at the level of the trunk, neck, arm, forearm and lower limbs. The verified risk originated from inadequate postures in carrying out the activities, unadjusted equipment and the existence of inappropriate material for carrying out the activities. It is therefore important to implement corrective measures and/or preventive measures for trainees in order to reduce the risk levels encountered and prevent injuries in the short and long term, namely through awareness-raising for the adoption of correct postures, equipment adjustments, adaptation of the control table to the worker, the implementation of supports for feet and appropriate ergonomic chairs and awareness-raising for carrying out labor gymnastics.

Regarding the limitations of the present study, we found that the activities carried out by the interns showed great postural changes, which makes it more difficult to assess the posture in each activity performed, since the interns were only two weeks in each task post. work, and therefore it became difficult for them to perceive the risk to which they were exposed, as well as the pain/discomfort that could result from carrying out their activities and that if the sample were larger we would have a greater representation. It is recognized that a larger sample would have more robust results.

For the continuity of this investigation, it is suggested, the implementation of a new evaluation of the MSDs risk in workers with more years of service and in that sense apply the Nordic musculoskeletal questionnaire to understand which symptoms the workers already present and the accomplishment of a new evaluation. after raising workers’ awareness with the results of these studies to understand changes in behavior.

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Deep-Sea Port Crane Operators' Muscle Fatigue on Low Back and Shoulder: A Primary Exploration for Occupational Health and Safety Purposes



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Abstract Global trade heavily relies on ocean logistics shipping. Deep-sea port crane operators are one of the frontline workers who work around the clock to achieve this goal. This study aimed to investigate muscle fatigue development using muscle strength test as a primary tool in occupational health and safety purposes. Twenty-six of them participated in the study. Only low back and shoulder (right) were tested for the maximum voluntary contraction before and after the routine 4 h work session. Results significantly revealed the occurrence of muscle fatigues development ($p < 0.05$) which indicated through the decrease of maximum voluntary contraction after the work session: 108.3 ± 38.3 declining to 95.4 ± 40.1 kg for the low back ($p = 0.000$) and $59.9 \pm$ declining to 51.9 ± 12.3 kg for the right shoulder ($p = 0.001$). Shoulder (right) in this study showed higher differential percentage of the maximum voluntary contraction with the value of 14.7 over 11.9% from the low back. This might have been due to the muscle loading transfer, that shifted from the low back to the shoulder, since the low back might have already been in musculoskeletal problem. This simple assessment tool, as a primary exploration, proved to be practical in an implementation on the occupational safety and health intervention.

Keywords Awkward working posture · Container transshipment · Muscle strength test

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1 Introduction

Muscle fatigue can be described as exercise-induced decrease in the ability to produce force or a decrease in maximal force or power production in response to contractile activity [22]. Muscle fatigue is a phenomenon that normally experienced in routine life among human-beings. It is even much more prevalent in workers who have to perform their tasks repeatedly throughout the day and five to six days a week. According to recent reports, in Asia-Pacific, about 12–45% of its general population is found being in this trouble [12]. And if considering in the global scale, about 14–22% of its regular population suffers from fatigue [23].

Work-related musculoskeletal disorders (WMSDs) are the leading cause of work-related health problems in the occupational health and safety sector. It remarks the health problem that involves the development on muscle fatigue, chronic pain, suffering and finally disability of the musculoskeletal system including: muscles, nerves, blood vessels, ligaments and tendons [16].

In the United State alone, one-third of all workers compensation cost is from WMSDs and the direct costs of WMSDs is calculated at around \$20 billion a year, by which five times more is estimated for the amount of an indirect financial burden [7]. Correspondingly, all across Europe WMSDs affect millions of workers and cost employers billions of euros [8].

There are various kinds of agents that lead to WMSDs. Physical and biomechanical factors which mainly contribute to muscle fatigue seem to play a major role in causing WMSDs development. This is also alongside with the organizational and psychosocial factors, and individual factors [8].

Deep-sea port crane operators are among those that suffer from this WMSDs [5]. The occurrence of muscle fatigue which largely found in this occupation is mainly from its specific task and unique working environment. The port crane operators have to work in the small cabin suspended above the ground at around 30–40 m. height. Besides, they have to deal with over loaded maritime shipping, reportedly around 80% of the overall volume achieved by them globally [21].

Controlling WMSDs situation by mean of muscle fatigue development in work conditions could help increase workers well-being and happiness. But it seems that preventing any occurrence of muscle fatigue is far and even impossible from working reality. To minimize this problem, muscle fatigue contributors must be focused and put them in to control via occupational health and safety programs or intervention projects. Following the management model cycle known as PDCA or Plan Do Check Act cycle, one important part of those problem solving program is its achievement evaluation or check in PDCA [18]. Generally, there are two kinds of those consisting of qualitative and quantitative assessment. And due to a lack of researches using the quantitative one which provide more reliable results in these real employees, this study aimed to investigate muscle fatigue applying physical fitness test using a simple and practical qualitative assessment tool as a primary exploration on low back and shoulder (right) in port crane operators for occupational health and safety purposes.

2 Materials and Methods

2.1 Subjects

An a priori power analysis was conducted using G*Power version 3.1.9.7 [10] to determine the minimum sample size required to test the study hypothesis. Results indicated the required sample size to achieve 80% power for detecting effect size = 0.6 and at a significance criterion of $\alpha = 0.05$, was $n = 24$. Thus, the obtained sample size of 26 in this study is adequate to test the hypothesis.

Twenty-six participants in this study were recruited voluntarily from containers crane operators working in the deep seaport being studied. Only male workers were considered. Those included in this study must have experience in this job for at least 1 year and had no historic medical record for the musculoskeletal disorder, diagnosed by the doctors. And more importantly, all agreed to join the research project after being explained all data collection protocol and signing the informed consent.

2.2 Instrument

Back dynamometer was applied for the physical fitness test which aimed for the assessment of the fatigue indications on low back and right shoulder. It is a product from Lafayette instrument company model no. 32526, serial no. 1-800-428-7545. For muscles strength measurement, the back dynamometer was used in cooperation as an experimental set with the stool and spring balance.

2.3 Research Protocol

An experimental study was set for the exploration on muscle fatigues development among port crane operators before and after their routine work session. All of them were explained for the research objectives then asked for the voluntary sign on informed of consent. A direct interview for the questionnaires was completed via the assistance of the research team. The physical fitness tests on muscle strength before and after the routine work session were conducted step by step following the experimental protocols. It started with the low back muscle strength test via the performing of the back dynamometer, pulling for 3 times. This is for measuring for the highest maximum voluntary contraction (MVC) [19]. To obtain the focused value precisely, all participants were trained to maintain their legs straight, only the upper limb that did the pulling as demonstrated in Fig. 1 (right-hand side). After the MVC test, they were allowed to take a rest for 10 min before the start of the shoulder (Upper trapezius) strength measurement. Also, to find the MVC, it was done 3 times of the pulling attempts on the spring balance, utilized from the back dynamometer.

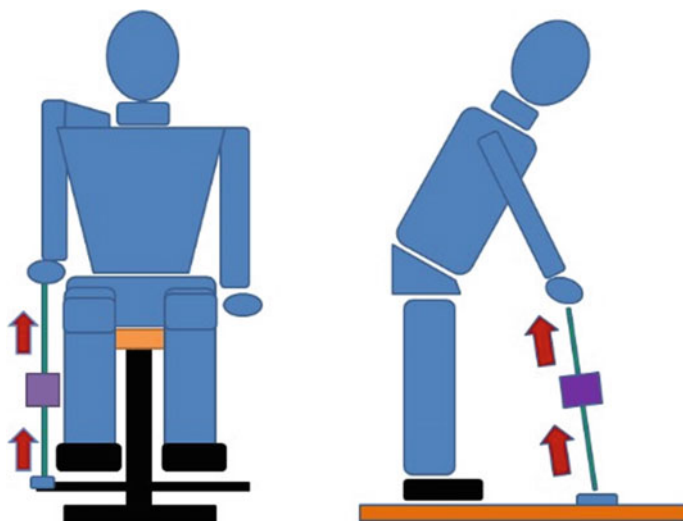


Fig. 1 Physical fitness tests for muscle strength on right shoulder (left-hand side) and low back (right-hand side) before and after the routine working session

In this process, they were insisted firmly to maintain their trunk straight and raised only the right shoulder up as shown in Fig. 1 (left-hand side).

2.4 Research Ethics

Prior to the data collection, all the study protocol and collecting tools were reviewed and approved by the Institutional Review Board committee of Burapha University, Thailand (IRB No. Sci 025/2560). Informed of consents were agreed and signed by each subject. And they were given a full right to decline or withdraw out of the research project at any time.

2.5 Statistical Analysis

The SPSS/PC version 22 software was utilized in the data statistical analysis. Demographic features of this study were explained through mean and standard deviation. The statistics analysis for the comparison on the developing muscle fatigue, before and after the routine work session, utilized statistics depending on its normality distribution of the data. The paired t-test will be used for the samples that showed normality and Wilcoxon signed rank test will be used for the non-normal distribution. All was set for the significant level at $p < 0.05$.

3 Results

The participants of this study consisted of male 26 deep-sea port crane operators. Their age and Body Mass Index (BMI) ranged between 28.3 and 58.3 years (mean age: 42.5 ± 6.7 years) and 17.9–43.9 (mean BMI: 26.3 ± 5.7) respectively. All had worked 24–96 h/week (mean: 51 ± 13.4) and 80.8% of them were right-handed.

Following the data collection, all related information to be studied was then checked for its normality using Shapiro-Wilk test, since the sample size was small ($n = 26$). For the low back fatigue test, it showed the evidence of normality (Before: $W = 0.964$, $p = 0.466$), (After: $W = 0.952$, $p = 0.253$) so that the paired t-test was selected. The Wilcoxon signed rank test was chosen for the shoulder (upper trapezius) due to the non-normal distribution obtained from the test (Before: $W = 0.902$, $p = 0.017$), (After: $W = 0.910$, $p = 0.026$). The statistical analysis yielded results which can be classified following the muscles being investigated as detailed below.

3.1 Low Back Fatigue Test

Results of low back fatigue, obtaining via the physical fitness test, showed that an averaged MVC of the before routine work session was at 108.3 ± 38.3 kg, with 185 and 35 kg for the maximum and minimum value respectively. Concurrently, the averaged MVC of the after a routine work session was at 95.4 ± 40.1 kg, with 205 and 1 kg for the maximum and minimum value respectively. All can be graphically shown in Fig. 2. After the statistical analysis with paired t-test, it clearly demonstrated a significant decrease in MVC ($p = 0.000$) on the low back after a routine work session as explained in detail in Table 1.

3.2 Shoulder (Upper Trapezius) Fatigue Test

Results from shoulder (upper trapezius) physical fitness test, on the right shoulder, showed the averaged MVC of the before routine work session was at 59.9 ± 14.6 kg, with 105 and 40 kg for the maximum and minimum value respectively. Meanwhile, the averaged MVC of the after a routine work session was at 51.9 ± 12.3 kg, with 80 and 35 kg for the maximum and minimum value respectively. All can be graphically shown in Fig. 3. After the statistical analysis with Wilcoxon signed-rank test, it also demonstrated a significant decrease in MVC ($p = 0.001$), on the right shoulder, after the routine work session as explained in detail in Table 1.

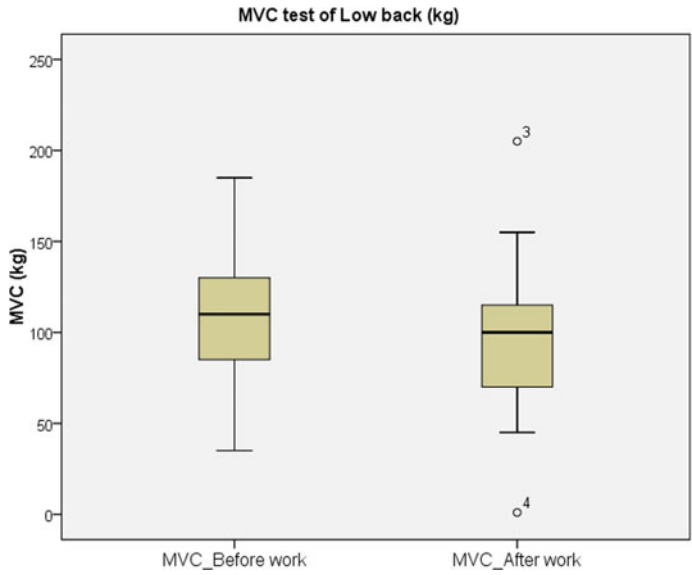


Fig. 2 Mean, maximum and minimum values of MVC on low back for the before and after a routine work session

Table 1 Muscle fatigue test statistics analysis [Before and After] (n = 26 for both analyses)

Physiological fatigue test	Statistic-analysis	Statistic-test	Effect size	Sig (p-value)
Low back MVC	Paired-samples t-test	t = 4.44	0.87	p = 0.000 ^a
Shoulder MVC	Wilcoxon signed-rank test	z = -3.358	0.66	p = 0.001 ^a

^aSignificant at p < 0.05

3.3 Differential Percentage of MVC Between Before and After a Routine Work Session

The comparison between before and after the routine work session showed that the averaged MVC of both muscles declined by 12.9 kg for low back and 8.8 kg for the right shoulder. And if considering in term of differential percentage, the decrease on MVC after the routine work session was at 11.9 and 14.7% for low back and the right shoulder respectively, as demonstrated in Fig. 4.

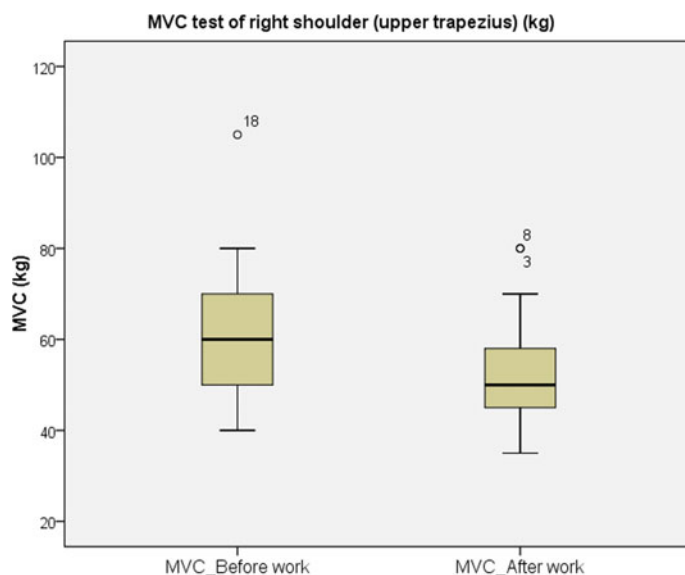


Fig. 3 Mean, maximum and minimum values of MVC on right shoulder (Upper trapezius) for the before and after a routine work session

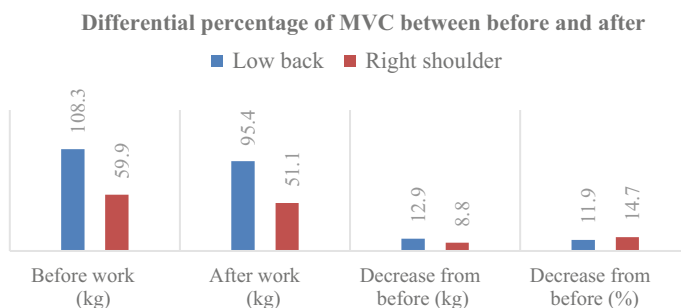


Fig. 4 Averaged MVC before and after work session and its differential percentage of the low back and right shoulder

4 Discussion

Port crane operators, working in Thailand's deep-sea port, clearly seemed to suffer from muscle fatigue, developing during their routine work. The physical fitness tests revealed statistically significant decreases in muscle strength after their daily work session on both muscles, noticeably for the low back with its significant value at $p = 0.000$. This is in line with other researches, conducting also on port crane operators, but using a qualitative assessment tool such as Nordic Musculoskeletal Questionnaire (NMQ).

Those include Azmi et al. (2019) which did the research surveying the prevalence of musculoskeletal (MSK) problem using Nordic Musculoskeletal Questionnaire (NMQ) among quay crane operators in Malaysia's seaport [14]. And Nourollahi-Darabad et al. (2018) that conducted the research using the same assessment tool (NMQ) but in Rubber Tired Gantry (RTG) crane operators, in Iran [15]. All had come with the finding suggesting that port crane operators were experiencing problems on WMSDs by which the lower back was the most problematic body part.

In this study, the occurrence of MVC declination after the work session could be explained as an impairment on exert force, power production in response to contractile activity which precisely indicates the sign of muscle fatigue [6, 11, 22]. This physical demonstration or known as peripheral fatigue is a consequence from the insufficient oxygen and nutritive substances that are being supplied through blood circulation during the muscle fatigue phenomenon [2]. And another muscle fatigue related phenomenon is known as the central fatigue. This will function in reducing the neural drive rate from the brain to the muscle [1, 11, 22]

The significant development on muscle fatigue found in this occupation could have been a consequence from its severe awkward working posture. To complete the job, the container crane operators have to perform the task in static and non-neutral sitting postures. This is done through the leaning of their upper limb forward, as much as 60–70°, to gain the loading and unloading view down below, through the cabin's glass floor [17].

As previously mentioned, working in the small cabin from the height of about 30–40 m. above the ground surface [5] requires a very precise control. Besides, they also have to work for a relatively long session which is about 4–6 h each [9, 13]. And due to a small space of working environment, workers are likely to have no chance to change their working posture in order to reduce any developing muscle fatigue. Worse than that, the cabin when it is in operation, it has to travel with acceleration and deceleration, forward and backward passing the boom junctions, and this in turn generate a large amount of vibration [17]. All these combined, it could eventually generate a lot of stress both physically (muscle fatigue) and mentally [3].

Regarding the limited amount of in-service port cranes, together with the specific skills required for qualification to be the operators, this directly leads to the limited number of crane operators employed each port. And according to the report from Thailand port authorities, up to 90% of imports and exports of Thailand's trading were made via ports cargo shipments [20]. By this, it seemed that this small group of people was working at high work demand. Furthermore, by the time of this study, there were no others supporting technologies or any kinds of autonomous controls to aid the workers. Working with these conditions could be one of the keys element that contributes to muscle fatigue [8].

Considering the differential percentage of the MVC found in this study, low back likely presented as the most problematic body part, but the higher value of the differential percentage belonged to the shoulder (right). This might have been explained as a consequence from the effects of muscle loading transfer, that shifted from the low back to the shoulder, since the low back might have already or previously been in musculoskeletal problem [4].

Although, there are other investigating tools for muscle fatigue that provides higher degree in precise measurement such as electromyography or shortly EMG. This muscle strength test, using simple equipment such as dynamometer testing set with stool and spring balance, seemed to provide enough quantitative evidence, and suitable for the evaluation of the achievement on the occupational health and safety programs.

5 Conclusion

This study revealed once again that musculoskeletal problem particularly on upper limb, in which low back and right shoulder were investigated, requires a huge attention. Deep-sea port crane operators are among those that suffering from muscle fatigue and urgently need consideration on sustainable problem-solving programs. All the MSK problem related contributors such as prolong awkward working posture, occurring vibration in the cabin, work and mental stress must be exclusively handled with more innovation. It would be about the time to speed up the utilization of emerging technology such as remote or autonomous control or even artificial intelligence in solving this kind of persistent problem. Despite clinical tools such as EMG investigation could provide more precision, physical fitness test proved to be simple and practical enough for the primary exploration, particularly for the occupational health and safety purposes.

Acknowledgements This article was produced from the research project supported by the Faculty of Public Health, Burapha University, Thailand. The research team would like to thank all the participants for excellent cooperations throughout the study.

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Risk Factors for Lower Limb Work-Related Musculoskeletal Disorders



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Abstract Lower limb work-related musculoskeletal disorders have multifactorial etiology, primarily caused by prolonged exposure to physical risk factors, including awkward postures, repetitions, and forceful exertions. These disorders can significantly affect worker's health and work performance. However, the literature regarding the risk factors of the lower limb work-related musculoskeletal disorders is generally under-represented. This study aims to identify the relative importance of the risk factors that lead to the development of each lower limb work-related musculoskeletal disorders. The research method was based on a questionnaire and interviews with ten health experts, namely: two orthopedists, two occupational doctors, four physiotherapists and two physiotherapists/osteopaths. The application of the questionnaire highlighted the difficulty in objectively characterizing the importance degree of the risk factors. Nevertheless, the interviews were quite relevant to complement the information regarding the most common risk factors contributing to the development of lower limb work-related musculoskeletal disorders. Overall, the expert's feedback indicates that workers exposed to prolonged standing work involving static postures

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are substantially more likely to develop lower limb work-related musculoskeletal disorders. The information gathered will be used in developing an assessment model to predict the possibility of developing lower limb work-related musculoskeletal disorders.

Keywords Ergonomic risk analysis · Prolonged standing · Occupational disorders · Lower extremity

1 Introduction

Lower limb work-related musculoskeletal disorders (WRMSD) cover a broad range of inflammatory and degenerative conditions that affect muscles, tendons, ligaments, joints, peripheral nerves, and related blood vessels of the lower extremities [38].

The statistics related to lower limb WRMSD prevalence vary by country and occupation [4]. This is due to several factors, such as differences in work practices, including differences in the use of tools and machinery, the frequency and duration of work, the variations in work tasks and postures, and the availability of protective equipment and ergonomic interventions.

According to the United States Department of Labor, lower limb WRMSD accounted for 17% of the total WRMSD, in 2020. The knees were the third body region most affected by WRMSD, after the back and the shoulder. The incidence of knee WRMSD was approximately 29700 in 2020, accounting for 10% of the WRMSD [47].

In Great Britain, a labor force survey conducted between 2021 and 2022 revealed that 99000 workers suffer from a lower limb WRMSD. This represents 21% of the total workers who reported being affected by WRMSD [21]. In the European Union (EU), according to a European Working Conditions Survey, in 2021, 35% of workers in the EU-28 reported lower limb musculoskeletal disorders complaints in the previous 12 months [15]. The same report highlighted that the occupations with the highest rate of lower limb musculoskeletal disorders were agricultural occupations (18.4%), followed by elementary workers (10.7%), services and sales workers (7.8%), and craft workers (7.6%) [15].

Concerning the main WRMSD affecting the lower limbs, it is noteworthy that epidemiological research or risk assessments regarding lower limbs are generally under-represented, limiting the understanding of the prevalence of lower limb WRMSD. Also, the absence of substantial longitudinal data limits their use to generate statistics about the suspected risk factors [11, 18]. The literature reported a relationship between work-related risk factors and the development of lower limb WRMSD seems to be limited to hip osteoarthritis, knee osteoarthritis, knee meniscal disorders and knee bursitis [4, 5, 9, 12, 14, 29, 36]. However, in addition to these WRMSD, the list of professional disorders approved by Regulatory Decree No 6/2001, the International Classification of Diseases (M00-M99, among other reports, refers the following established lower limb WRMSD: Achilles tendinitis,

inflammation of sacroiliac joint; infrapatellar tendinitis; ischial bursitis; patellar bursitis; piriformis syndrome; prepatellar tendinitis; tibial periostitis; trochanteric; and trochanteric bursitis [16, 17, 22, 40, 41, 45]. The development of lower limb WRMSD are generally related to continuous exposure to awkward postures, forceful exertions and task repetitiveness, which includes tasks requiring a cyclical use of the same tissue while performing an activity repeatedly or tasks involving a repetitive muscular effort without movement [4, 9, 12, 27, 30, 48, 52, 53]. However, some studies also reported the contribution of vibration, cold and direct pressure on the joint to the development of lower limb WRMSD [4, 29, 53]. In addition, individual factors can have a synergetic effect on the development of these disorders. The most reported individual risk factors for the development of lower limb WRMSD, include aging, female sex, overweight and obesity, previous injuries and sport activities [1, 9, 27, 43].

However, a common gap in identifying the risk factors that contribute to the development of lower limb WRMSD is in quantifying or qualifying the significance of each risk factor in the development of the disorder, since the risk factors do not contribute equally to develop WRMSD [46].

This study aims to identify the relative importance of the physical and individual risk factors that lead to the development of the abovementioned lower limb WRMSD, through data collected from experts.

2 Materials and Methods

To collect the data regarding the importance degree of each risk factor to the development of the lower limb WRMSD identified in the introduction section, the authors applied a questionnaire and conducted interviews with the experts.

The methodology employed in the present study consisted of the following stages: (1) development of the questionnaire; (2) preparation of the interviews; (3) application of the questionnaire and the interviews; (4) data analysis.

2.1 *Development of the Questionnaire*

The questionnaire was developed based on the lower limb WRMSD and the physical and individual risk factors identified in the introduction section.

The questionnaire comprises two tables: the first one aims to establish a relationship between the lower limb WRMSD and the physical risk factors; and the second table establishes a link between the lower limb WRMSD and the individual risk factors.

The following physical risk factors were taken into consideration:

- Posture: looks at each lower limb joint to assess whether the development of the lower limb WRMSD is related to the joint deviation [24].
- Repetition: which applies to the contribution of cyclical use of the same tissue while performing an activity repeatedly or a repetitive muscular effort during static postures, to the development of the lower limb WRMSD.
- Force: which considers the contribution of forceful exertions due to external loads to the development of the lower limb WRMSD.
- Vibration: involving the contribution of vibration tools to the development of the lower limb WRMSD [34, 33, 44].
- Direct pressure: refers to the contribution of extrinsic contact stress to the development of the lower limb WRMSD.
- Cold: refers to the influence of low temperature in the development of the lower limb WRMSD.

Also, the following individual risk factors were taken into consideration:

- Age: refers to the contribution of aging to the development of lower limb WRSD. Since aging significantly affects muscle strength, bone density, or tendon and ligament properties [23, 51]
- Gender: contribution of gender in the development of lower limb WRMSD. Some studies among the general population and various occupations have reported that women are more likely than males to develop WRMSD [10].
- Body mass index (BMI): refers to the contribution of higher BMI to potentiate the development of lower limb WRMD. This is because being overweight or obese may act as a permissive factor in musculoskeletal disorders by interacting with and potentiating the effects of other risk factors, such as skeletal misalignment [13].
- Previous injuries: refers to the contribution of previous lesions to increase the risk of developing lower limb WRMSD in the same area [9]. This may be due to factors such as altered biomechanics, reduced muscle strength or flexibility, and changes in joint alignment. Additionally, individuals who have experienced a previous injury may be more likely to engage in compensatory movements or postures, which can also increase the risk of developing a WRMSD.
- Leisure-time activities: refers to the contribution of certain leisure-time activities that cause biomechanical overstrain of the lower limbs.
- Sport activities: evaluate the role of sports in the development of the lower limb WRMSD, due to the repeated and high-impact sports activities.

To assess the importance degree of each risk factor to the development of each lower limb WRMSD, the following parameters are used: null; low; medium; high; extreme [31].

Additionally, the questionnaire provides a section to justify the given rate, by specifying the attributes that could be used to evaluate the risk factor's severity. For instance, when considering the posture risk factor, the attributes are the specific joint

possible movements (e.g., flexion/extension, adduction/abduction). When considering the repetition risk factor, the attributes are static postures or frequent movements of the specific joint. Also, it is possible to complement the questionnaire with additional risk factors if they were crucial to the development of the WRMSD. To validate the questionnaire, a pre-test was conducted with one orthopedic doctor and one physiotherapist with experience in occupational health. The pre-test allowed to validate the lower limb WRMSD and the risk factors included in the questionnaire.

2.2 Preparation of the Interview

The individual face-to-face interviews were prepared to complement the answers to the questionnaire. So, the interviews were prepared to cover the study's goals and the topics of the questionnaires, but without an objective classification. The interviews collect descriptive data in the subject's language and provide access to the interviewee's thoughts and perceptions, allowing the researcher to develop an idea about how subjects understand certain aspects [26]

The open interviews include the following trigger questions to coarsely guide them: "Which are the most common occupational activities or body postures that can cause discomfort of the lower limbs, and in the future, can lead to repetitive lower limb WRMSD?" and "Which are the possible physical and individual risk factors associated with the development of lower limb WRMSD?". The first question related to the lower limb discomfort in terms of postures and activities can be defined as having pain, soreness, stiffness, numbness, or tingling due to physiological factors related to the body's internal biomechanics and muscle fatigue capacities.

2.3 Application of the Questionnaire and the Interviews

The questionnaire and the interviews were applied to ten health experts, namely: two orthopedists, two occupational doctors, four physiotherapists and two physiotherapists/osteopaths. The reason behind choosing these health professionals was that they have extensive knowledge in the field of WRMSD and work directly with individuals who suffer from these conditions. Therefore, they are familiar with the occupational tasks and risk factors that may be linked to the development of lower limb WRMSD.

In the beginning of each of the individual face-to-face sessions, a briefing about the study's goals was properly done to the expert. The experts were then asked to respond to the questionnaire before being interviewed. The sessions were conducted between October and December 2022.

The experts were also assured about the possibility of not responding to the questions about which they were unsure.

2.4 Data Analysis

The data provided by the questionnaire were analyzed by calculating a weighted average of the rating given by each expert. The purpose of weighting the averages is to give greater importance to the rating given by the expert whose main area of expertise is that in which the factor falls [31].

The interviews were analyzed through a content analysis method in order to provide a thorough analysis of the data. In content analysis, the content of the interview is analyzed, and data coding is created at the same period [50].

The interviews were transcribed and coded according to the following coding frame, which was developed based on the research question and relevant literature:

- Static body postures: this category included any mentions of static body postures, such as sitting or standing for long periods of time.
- Dynamic activities: this category included any mentions of dynamic activities, such as squatting, kneeling, or walking.
- Physical risk factors: this category included any mentions of physical risk factors.
- Individual risk factors: this category included any mentions of individual risk factors, such as age, gender, or health status.

During the coding process, the first researcher was responsible for the data analysis based on the codes. The whole process of categorization was carefully followed by the other authors.

3 Results

3.1 Questionnaire's Results

This subsection presents the results of the pre-test and the answers given by the experts who completed the questionnaire regarding the risk factors. The questionnaire allowed greater coverage of the knowledge necessary to assess the risk factors. Namely, it allowed obtaining quantitative data on the importance of each risk factor for developing lower limb WRMSD, which is not reported in the literature.

Regarding the pre-test, the two experts advised for the exclusion of hip and knee osteoarthritis since these disorders take a long time to develop, and their multifactorial nature makes it very difficult to rate the contribution of each risk factor in the development of these disorders. Therefore, the questionnaire was adapted, and it excludes these disorders.

Out of the ten professionals who participated, only four felt sufficiently confident to complete the questionnaire despite their extensive experience. The remaining professionals believed that they lacked the sensitivity to accurately classify the importance of each risk factor to the development of each lower limb WRMSD.

Table 1 presents the weighted averages of the results regarding the contribution of the physical risk factors for the development of each lower limb WRMSD. The mean was determined by assigning a weight of 0.3 to the two physiotherapists/osteopaths with experience in WRMSD and 0.2 to two physiotherapists.

A significant outcome of the questionnaires suggests that a core of physical risk factors consistently emerged as having “Extreme” or “High” importance in most disorders. These risk factors are repetition and awkward joint posture. In addition, forceful exertions were classified as having a “High” or “Medium” importance in most of the disorders.

Posture was classified as having “Extreme” importance for the development of 45% of the lower limb WRMSD and as having “High” importance in 45% of the disorders, making a total of 90%. Repetition was classified as having “Extreme” importance for the development of 64% of the lower limb WRMSD and as having “High” importance in 36% of the disorders, making a total of 100%. Force was classified as having “High” importance for the development of 36% of the lower limb WRMSD and as having “Medium” importance in 36% of the disorders, making a total of 72%.

Instead, vibration was classified as “Null” or “Low” in 82% of the disorders, direct pressure was classified as “Null” in 63% of the disorders, and cold was classified as “Null” or “Low” in 73% of the disorders.

Additionally, the results reported that for the development of hip WRMSD, awkward postures of the hip joint and repetition were classified as having an “Extreme” or “High” importance for the development of all the hip WRMSD considered. In addition, forceful exertions in the hip joint were classified as having a “High” or “Medium” importance for the development of all the considered disorders. The other risk factors (vibration, direct pressure and cold) were mostly ranked as having a “Low” or “Null” importance. The answers given by the experts allowed for highlighting that the most important attribute to consider for assessing the severity of the posture risk factor is coxofemoral flexion/extension, and for the repetition risk factor is important to assess the adoption of prolonged static sitting or standing postures, as well as repetitive coxofemoral flexion/extension motions.

Regarding the knee joint, the results reported that the most critical physical risk factor for the development of knee WRMSD was repetition, which was rated as having an “Extreme” impact in all the knee WRMSD. Also, the adoption of awkward postures of the knee joint was rated as having an “Extreme” or “High” importance in 75% of the disorders and in 25% of the cases as having a “Medium” importance. Forceful exertions affecting the knee joint were rated in 50% of the disorders as having a “High” contribution. The vibration, and cold risk factors were mostly ranked as having a “Low” or “Null” impact. The experts emphasized that severe knee flexion for the posture risk factor and repetitive knee motions for the repetition risk factor should both be taken into consideration when determining the severity of the risk factor.

Concerning the ankle joint, the experts reported that in addition to posture and repetition, forceful exertions in the Achilles tendon are a highly important risk factor for the development of Achilles tendinitis.

Table 1 Physical risk factors contributing to the development of lower limb WRMSD

Lower limb WRMSD	Attributes obtained through the questionnaire	Weighted average of the importance rate given by experts					
		Posture	Repetition	Force	Vibration	Direct pressure	Cold
Achilles tendinitis	Plantar flexion/extension while squatting; Repetitive ankle motions; Forceful exertions while squatting	Extreme	Extreme	High	Low	Null	Null
Inflammation of sacroiliac joint	Coxofemoral flexion/extension; Prolonged static upright postures on unlevel surfaces; Forceful exertions; Direct pressure in coxofemoral while sitting	Extreme	Extreme	High	Low	High	Medium
Infrapatellar tendinitis	Knee flexion/extension; Repetitive knee motion	Medium	Extreme	Null	Null	Null	Null
Ischial bursitis	Coxofemoral flexion/extension (while seated); Repetitive hip motion; Forceful exertions	High	High	Medium	Low	Null	Low
Meniscal tears	Knee rotation; Repetitive knee motion; Forceful exertions while rotating	Extreme	Extreme	High	Null	Null	Null
Patellar bursitis	Knee flexion/extension; Repetitive knee motion; Forceful exertions; Direct knee pressure while kneeling	High	Extreme	High	Medium	High	Low
Piriformis syndrome	Coxofemoral adduction/abduction; Prolonged static upright postures; Forceful exertions	Extreme	High	Medium	Low	Null	Null
Prepatellar tendinitis	Knee flexion/extension; Repetitive knee motions; Direct knee pressure	High	Extreme	Null	Low	Medium	High

(continued)

Table 1 (continued)

Lower limb WRMSD	Attributes obtained through the questionnaire	Weighted average of the importance rate given by experts						
		Posture	Repetition	Force	Vibration	Direct pressure	Cold	
Tibial periostitis	Ankle flexion/extension; Repetitive ankle motions; Direct knee pressure	High	High	Null	Medium	Extreme	Null	
Trochanteric (muscle)	Coxofemoral flexion/extension; Repetitive knee motion; Forceful exertions while rotating	Extreme	Extreme	Medium	Null	Null	Medium	
Trochanteric bursitis	Coxofemoral flexion/extension (while squatting); Repetitive hip motion; Forceful exertions while rotating	High	High	Medium	Low	Null	Low	

Table 2 presents the weighted averages of the results regarding the contribution of the individual risk factors for the development of each lower limb WRMSD. Only the two physiotherapists/osteopaths felt comfortable to rate the importance degree of individual risk factors for the development of each considered WRMSD.

The questionnaire results reported that the individual risk factors with more relevance for the development of all lower limb WRMSD were: high BMI, which was rated as “Extreme” or “High” importance to the development of 64% of the disorders and “Medium” importance to 36% of the disorders; previous injuries, which was rated as “Extreme” or “High” importance to the development of 36% of the disorders and “Medium” importance to 45% of the disorders; and sport activities of high impact in lower limb joints, which was rated as “High” importance to the development of 18% of the disorders and “Medium” importance to 45% of the disorders.

Table 2 Individual risk factors contributing to the development of lower limb WRMSD

Lower limb WRMSD	Weighted average of the importance rate given by experts					
	Age	Gender	High BMI	Previous injuries	Leisure-time activities	Sport activities
Achilles tendinitis	Low	Low	Medium	Low	Null	Low
Inflammation of sacroiliac joint	Low	Low	Extreme	Medium	Medium	Medium
Infrapatellar tendinitis	Null	Null	Medium	High	Low	High
Ischial bursitis	High	Null	Extreme	Medium	Medium	Medium
Meniscal tears	High	Null	Extreme	Extreme	Null	Medium
Patellar bursitis	Low	Low	High	High	Low	Low
Piriformis syndrome	Low	Null	Extreme	Medium	High	Null
Prepatellar tendinitis	Null	Null	Medium	High	Low	High
Tibial periostitis	Null	Null	Medium	Null	Null	Null
Trochanteric (muscle)	Extreme	Medium	Extreme	Medium	Medium	Medium
Trochanteric bursitis	High	Null	Extreme	Medium	Medium	Medium

3.2 *Content Analysis of the Interviews*

This section presents the outcomes of each coding category, based on the answers of the ten experts: (1) static body postures, (2) dynamic activities, (3) physical risk factors, and (4) individual risk factors.

According to their experience with patients with lower limb WRMSD, the specialists agreed about the extreme importance of avoiding prolonged static standing postures, with the risk rising as additional loads are added. Moreover, eight experts pointed out that it is particularly important to avoid static postures, which may also lead to the development of venous disorders. Also, one expert highlighted the risk associated with long standing duration in occupations such as police officers, hotel industry, waiters, and physiotherapists.

Regarding dynamic activities, three experts mentioned the contribution of frequent and prolonged kneeling on hard surfaces to the development of knee WRMSD due to direct joint pressure. One expert highlighted the relationship between the repeated use of pedals and the development of ankle WRMSD, giving the metallurgical and sewing occupations as an example. In respect to repeated squatting activities, an activity that is frequently discussed in the literature, two experts emphasized the low incidence of WRMSD due to prolonged exposure to this activity. The experts justified the low incidence due to the dissemination in the industry of lift tables and other equipment that reduce the frequency of squatting activities.

Concerning the lower limb risk factors, the experts who did not answer the questionnaire, indicate difficulty rating the degree of importance of each risk factor to the development of each lower limb WRMSD due to the multifactorial nature of these disorders. Additionally, one expert mentioned that the lower limbs are usually more related to acute traumatic disorders than to prolonged exposure to risk factors. Nonetheless, the experts mentioned the importance of the following risk factors in the development of lower limb WRMSD:

- Time spending in one position: more time means an increased risk of developing lower limb WRMSD, especially in the upright position;
- Working posture: greater risk when movements approach the joint's limit range of motion;
- External loads: lead to increased muscle effort on the lower limbs.

As for the contribution of individual risk factors, most experts emphasized that higher BMI could potentiate the development of lower limb WRMD. Being overweight or obese would likely raise stress in soft tissue and weight-bearing joints (back and lower extremities). Additionally, aging was also noted as a significant individual risk factor. However, several experts mentioned that the rate of aging remains highly individual since risk factors such as genetics, lifestyle, or past injuries can influence functional aspects. Despite that, when asked to give a range of ages where the risk is more hazardous, the experts agreed with an age above 50. In addition, one expert justifies that for ages below 30 years old, the development of lower limb WRMSD is highly influenced by genetics. Another risk factor referred several times

was the presence of rheumatic disorders or past injuries, which strongly influence the development of lower limb WRMSD.

For the relevance of gender risk factor as co-founder, four experts mentioned that women have higher risk of developing lower limb WRMSD due to the anthropometric differences between genders, which promote that women have less tolerance to biomechanical loads and the hormonal fluctuations that occur in the menstrual cycle.

Moreover, one expert identified that strength training could improve an individual's strength, flexibility, and endurance, which can enhance postural control, and the ability to resist muscle fatigue, all of which can help to lower the risk of developing WRMSD. Nevertheless, it was mentioned that sports activities of high impact and increase the load on lower limbs should be avoided.

4 Discussion

This study aimed to identify the relative importance of the physical and individual risk factors that lead to the development of lower limb WRMSD. It was based on the application of a questionnaire and an interview.

The information retrieved from the questionnaires reported that repetition and awkward joint posture consistently emerged as having “Extreme” or “High” importance for the development of lower limb WRMSD. Also, the importance of forceful exertions was rated as “High” or “Medium” in the majority of the WRMSD. Although it was not found other studies evaluating the relative importance of the risk factors for the development of lower limb WRMSD, the same physical risk factors were reported in several studies as a significant risk for the development of lower limb WRMSD [6, 7, 9, 30, 53]. For instance, several tasks have been shown to contribute to the perception of repetitive WRMSD symptoms in the hips, including frequent kneeling and working with the back bent or twisted, prolonged standing and repetitive bending postures [7, 46]. Regarding the knee WRMSD, the study of Le Manac’h and colleagues reported that knee bursitis was highly reported in the construction sector and in skilled crafts blue-collar workers, due to prolonged exposure to heavy workloads and to frequent and/or sustained kneeling [29]. Concerning the ankle WRMSD, the study of Bugajska and colleagues and the study of Thetkathuek and Meepradit, reported an association between physical demands and holding lower limbs in awkward positions [8, 46].

However, it is relevant to highlight that previous research has identified a gap in the literature regarding high-quality studies, such as prospective cohort studies and quantitative exposure-effect studies, that establish a clear relationship between risk factors and the development of lower limb WRMSD [11, 18, 52]. These will minimize potential bias in examining the relationship between risk factors and lower limb WRMSD.

Overall, the expert feedback also highlighted the importance of avoiding prolonged static standing positions to prevent the development of lower limb

WRMSD. These results align with previous studies indicating that repetitive exposure to prolonged standing increases the likelihood of experiencing lower limb pain and muscular fatigue [19, 20, 27, 35, 42]. The studies reported the importance of the duration of standing, working posture, muscle effort, and holding time conditions for the development of lower limb WRMSD. In addition, there are also standards and ergonomic tools, such as ISO 11226: 2000 and OWAS, that highlight the risk associated with exposure to prolonged standing and lack of variation in movement in the upright position [25, 28, 39]. Regarding the individual risk factors, the questionnaires underlined the high contribution of high BMI and previous injuries in the development of lower limb WRMSD. Also, the expert's feedback highlights the contribution of aging. Several studies showed consensus with this finding [1–3, 32, 38]. In addition, Wearing and colleagues identified that high BMI may act as a permissive factor in musculoskeletal disorders by interacting with and potentiating the effects of other risk factors, such as skeletal misalignment [49]. Also, according to cross-sectional studies of the muscles in the lower limbs, strength typically reduces by 10% each decade, starting around the age of 40–50, with signs of accelerated losses in extremely old age [23].

Concerning the limitations of this study, they include difficult access to participants and low participation. The authors suggest that in future studies, more questionnaires related to the contribution of the risk factors in the development of lower limb WRMSD should be used, and the results should be compared with the results of the present study.

5 Conclusions

This paper presents the development and application of a questionnaire and interviews for experts to validate the contribution of risk factors in developing lower limb WRMSD. The researchers parted from a need to define the importance of each risk factor for the development of lower limb WRMSD and to identify the attributes that can be used to quantify and assess the risk factor's severity.

The study's findings revealed a core of physical risk factors that promote lower limb WRMSD, including repetition, awkward joint posture, and forceful exertions. Regarding the individual risk factors, it was highlighted the contribution of higher BMI, age, and previous lesions. The expert feedback highlighted the importance of avoiding prolonged static standing positions to prevent the development of lower limb WRMSD.

In the near future, the authors will use the information collected to develop an ergonomic assessment model to predict the possibility of developing lower limb WRMSD, based on a Fuzzy Multiple Attribute Decision Making model. The lower limb ergonomic assessment model is an extension of the ERGO-X system. The ERGO-X system identifies, assesses, and controls risk factors that can contribute to the development of upper-limb WRMSD [37].

Overall, this study provides valuable insights for researchers and practitioners to develop effective strategies to prevent and manage lower limb WRMSD in the workplace.

Acknowledgements The authors acknowledge Fundação para a Ciência e a Tecnologia (FCT/IP) for its financial support through the grant UIDB/00667/2020 (UNIDEMI).

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Evaluation of the Physical Activity Intensity in Primary School Children During the Lockdown



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Abstract The COVID-19 pandemic led governments to impose measures to reduce virus transmissibility, leading to the home office, and children were sent home to take online classes. These restrictions affected children's movement time and interrupting sports activities. This study aimed to assess the levels of children's physical activity (PA) during confinement. Children used an accelerometer in their non-dominant wrist to measure levels of PA and separated by sedentary-to-light or moderate-to-vigorous intensities, for four consecutive days (two days during the week and two during the weekend). Results showed that children spent only one hour in moderate-to-vigorous physical activities per day, but it is not consecutively. In addition, we also analyze the consecutive time of PA, which provides further information regarding children's activity patterns. Besides, children spend most of their time at sedentary levels, being more active during the weekend days. Regarding the environment, there are significant differences between having outdoor space and living in a house or apartment. Children have increased their sedentary levels by spending more time in sedentary activities. Our findings provide further evidence that COVID-19 affected PA levels in children. This behavior can affect long-term mental and physical health if subjected to long-term assessment.

Keywords Exercise · Accelerometry · Pandemic · Children · Physical activity

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1 Introduction

Due to the emergence of COVID-19 in 2020, the World Health Organization (WHO) needed to implement public health measures, which had the intention to reduce the virus transmission risk to decrease the total number of severe cases and deaths. One of the main regulations was the lockdown, which consequently decreased the number of steps walked daily by 25% [1]. Since the outbreak of the COVID-19 pandemic, children became confined to their homes, causing severe movement restrictions, with the closing of schools, squares, parks, and outdoor spaces [2]. The new children's routine increased the use of technologies, and an overall growth in screen time (i.e., the use of television, tablet, mobile phone, video games, and computers), which has increased by 80% [3, 4]. Additionally, there were also changes in hours of physical activity (PA) and sleep, in which 78.5% decreased the number of weekly hours of PA and 38% of the individuals had a delay in getting to sleep and changed their sleep patterns [4].

High levels of PA and low time devoted to sedentary behaviors are both healthy and necessary for children and adolescents [4]. Thus, the lockdown brought several consequences to families' routines, such as prolonged stress, increased body mass index, and increased sedentary behaviors [5, 6]. Since the COVID-19 pandemic changed our way of living, it is important to understand how different environments (especially home and school) can be used as spaces to prevent sedentary lifestyles, trying to improve PA levels.

Some investigations showed that during the lockdown unhealthy lifestyles have affected people's health status, increasing obesity levels and cardiovascular risk, which can lead to other associated diseases [5, 6]. The literature also shows that the multiple environments that schoolchildren engaged in are essential to developing a wide range of Fundamental Motor Skills (FMS), improving self-perception of motor competence, motor development, and motor learning [7, 8]. Despite that, during the confinement, sports activities ended, forcing children to spend 80% of their time in sedentary movement [9]. Besides, Physical Education (online classes) became one of the few activities performed during the lockdown. Despite that, those classes showed low levels of intensity, few spaces to move, and a high dropout rate among children [10]. According to [11], over the years children spend more time in sedentary activities, due to demotivation and lack of interest, and do not practice extracurricular activities. Additionally, children with overweight or pre-obese levels showed a decrease in their physical condition during the COVID-19 outbreak [12]. Then, it is important to assess if the recommended amount of time (60 min per day) for moderate-to-vigorous physical activity (MVPA) for children is accomplished [13].

One of the main ways to directly measure the levels of PA in children is using accelerometers [2, 14–17]. A substantial number of studies used accelerometry to collect data on children's physical levels during school [17], in outdoor parks [15], and in sports activities [14], but few tried to use in their own homes [16]. Thus, as far as we know no other study has assessed the level of PA at home using accelerometry

during the COVID-19 outbreak. The limited amount of research in the literature used surveys to assess this matter [2]. Therefore, the aims of this study are twofold, first this investigation aims to assess the levels of children's PA during the confinement period and, in second, analyze if the recommended daily levels of PA were accomplished. We believe that quantifying the levels of PA in children's homes during lockdown could provide further information regarding the levels of sedentary time and children's health in the future.

2 Materials and Methods

2.1 Participants

This study followed a cross-sectional study design. Forty-two Portuguese children participate in the present research in 2021 February and March. The sample was intentionally selected among the primary school students, with a mean age of 8.02 ± 1.22 years old, weight of 30.30 ± 7.48 kg, and height of 1.32 ± 0.11 m. For Ethnicity, 90% of children were Caucasian, 4,0% were African and 6,0% were Asiatic.

For inclusion criteria, were included only healthy boys and girls between the ages of 6 and 10. Children who did not use the accelerometer properly, or who did not use the equipment every day ($n = 4$ days) were excluded from the study. In fact, due to data loss ($n = 2$) or equipment misuse ($n = 4$), six children were excluded from the final phase of the study. Likewise, children with special needs or health problems were also not included.

Participants were recruited in Portugal's central region, all in urban areas. Oral assent was obtained from the participants and written consent from their parents/guardians, before beginning the experiment. None of the participants had any developmental difficulties or medical restrictions to perform the activities. Ethical approval for the investigation was granted by the University Ethics Committee (Protocol: CEIP/3/2020), and the study protocol followed all Helsinki Declaration guidelines.

2.2 Procedure

Children were separated into three groups to facilitate data collection. Each group was composed of sixteen children, which received the accelerometer devices and their parents received further information about the use of the accelerometer. Participants had to use the accelerometers for two days during the week and two during the weekend (Thursday to Sunday). After four days, the equipment was returned, and then a questionnaire was sent to all parents [9]. Parents were asked to answer

regarding the previous Friday, verifying if their perception corresponded to the data and knowing the type of environment that which the child was confined.

To ensure the quality of the data collection only sixteen accelerometers were used at the same time, in which children needed to wear the equipment on the non-dominant wrist for four days (two weekdays and two weekend days) [15]. Children only could remove the accelerometer during sleep or when in the shower.

2.3 Instruments and Data Processing

The Actigraph accelerometer, model wGT3X-BT (Pensacola, FL, USA) was used to measure children's PA levels during the lockdown. Data Processing was performed using the Actilife program in applying cut-off values for intensity and bouts (considered as ten consecutive minutes of MVPA, with 2 min spike [18]. The download of the data was done in intervals of 5 s, using the cut-off values (counts/minute): sedentary < 305, light 306–817, moderate 818–1968, vigorous > 1969. The data were grouped into sedentary-to-light intensity (SEDLI) comprising cut-off values of < 817 and MVPA, considering all values over 818 [15]. The MVPA was defined as at least ten consecutive minutes, allowing for a 1–2 min interruption [19]. This first data processing was used to transform the “count” value which is the accelerometer unit into information in time and % of the time for a better understanding and biological sense of the data.

The InBody, model 270 (USA, Cerritos, CA-USA) and a stadiometer (SECA 213, Bacelar and Irmão Lda, Portugal) were used to collect data regarding body mass index (BMI) levels and stature, respectively. The BMI was calculated by: $BMI = \text{body mass (in kilogram)} / \text{Height}^2 \text{ (in meters)}$ (Garrow and Webster 1985). The same researcher with experience in anthropometric data collection performed the assessments. Stature was recorded during inspiration using the stadiometer. All participants were asked to stand erect on the stadiometer with bare feet. The horizontal bar of the stadiometer was placed on the vertex of the subject and the readings were recorded. Thus, the survey developed by Pombo et al. [2], was used to ascertain the conditions of the dwellings where the children are (apartment or villa, garden, or balcony), socioeconomic status, and family situation (number of siblings).

2.4 Statistical Analysis

Statistical analysis was done using the software IBM SPSS Statistics version 27.0, where normality and homogeneity of variances were verified by the Shapiro–Wilk test and Levene's test, respectively. Then the intensity recorded by the accelerometers was described by the mean and standard deviation for each day of use according to the years of schooling. A paired t-test was applied to compare week and weekend days. T-tests for independent samples were used to comparisons between, gender,

BMI, outside space, house type, and siblings. The ANOVA one-way was used to compare years of schooling. For follow-up analyses, we used Tukey’s post hoc test.

3 Results

Figure 1 shows the daily levels of moderate to vigorous physical activity on week-days and weekend days, respectively. Children spent 85% in sedentary behaviors and 15% in more vigorous movements. Regarding the comparison between week-days and weekend days, significant differences were observed for sedentary-to-light intensity (SEDLI) ($p = 0.018$) and moderate-to-vigorous intensity (MVPA) ($p = 0.001$). Thus, during weekend days children were more active compared to weekdays. Additionally, comparisons among years of schooling and physical activity levels showed no differences.

In the comparison between healthy and unhealthy BMI, gender, having or not having a garden, living in a house or apartment, there are differences in having or not having an outdoor space (balcony or garden), where children who do not have an outdoor space spend more time in MVPA intensity ($p = 0.011$). And between having a house or apartment, they show that children living in apartments also spent more time in MVPA intensity ($p = 0.019$) (Table 1).

Figure 2 shows the percentage of children reaching 10 min of consecutive MVPA activity (bouts) during weekdays and weekends, respectively. The results showed that most of the children (70% on Weekdays, and 83% on Weekend days), do not perform even ten consecutive minutes of physical activity. Additionally, none of the children reached the 6 periods of 10 min of consecutive physical activity (6 bouts).

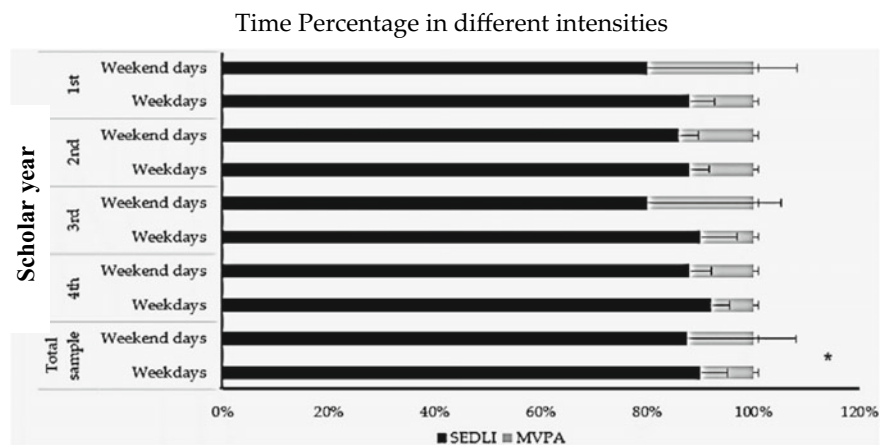


Fig. 1 Wear-time (normalized by waking time) spent in each level of intensity, divided into weekdays and weekends, for each scholar year

Table 1 Time spent (HH:MM) on weekdays and on the weekend according to the environment

Variables		Weekdays				Weekend days			
		SEDLI		MVPA		SEDLI		MVPA	
		Mean (SD)	p	Mean (SD)	p	Mean (SD)	p	Mean (SD)	p
BMI	Healthy	11:52 (2:12)	0.94	1:17 (0:36)	0.601	10:57 (1:36)	0.724	1:31 (0:31)	0.637
	Unhealthy	11:54 (1:11)		1:12 (0:30)		10:45 (2:04)		1:26 (0:33)	
Gender	Male	12:00 (1:34)	0.52	1:19 (0:38)	0.337	10:46 (1:50)	0.963	1:32 (0:30)	0.411
	Female	11:38 (2:03)		1:09 (0:26)		10:48 (1:54)		1:24 (0:33)	
Outside space	Yes	11:57 (1:50)	0.408	1:07 (0:28)	0.011*	10:51 (1:46)	0.901	1:26 (0:31)	0.498
	No	11:39 (2:04)		2:27 (0:37)		10:59 (1:56)		1:52 (0:23)	
House Type	House	11:56 (1:54)	0.590	1:11 (0:28)	0.368	11:06 (1:45)	0.019*	1:30 (0:30)	0.535
	Apartment	11:36 (1:33)		1:23 (0:43)		9:56 (1:51)		1:23 (0:36)	
Siblings	Yes	12:08 (1:27)	0.348	1:10 (0:37)	0.401	10:47 (1:38)	0.982	1:26 (0:33)	0.701
	No	11:36 (2:02)		1:19 (0:30)		10:47 (2:02)		1:30 (0:30)	

ILegend: The data is presented in hours and minutes; BMI—Body mass index; SEDLI_W—sedentary and light intensity in weekdays; MVPA_W—moderate to vigorous intensity in weekdays; SEDLI_WE—sedentary and light intensity in weekend days; MVPA_WE—moderate to vigorous intensity in weekend days; * $p < 0.05$; all values are present in mean values (SD) and hours and minutes

4 Discussion

The present investigation assessed children's PA during the lockdown. It was also observed if the recommended daily levels of PA were accomplished, and examine the types of activity they usually do, regarding the age of schooling. The findings showed that children, independently of the day, spent more time in SEDLI activities comparing MVPA. Similar results were found in the literature [2].

Flôres et al. [9] showed that during the lockdown, Portuguese children reported less than half of the total time of PA compared to previous data. The authors' results also showed that there were no differences in PA in any of the school years. Moreover, the average time in PA was extremely low (only 15% in MVPA). Figure 1 shows that children spend 85% of their walking time in sedentary-to-light intensities, contrasting

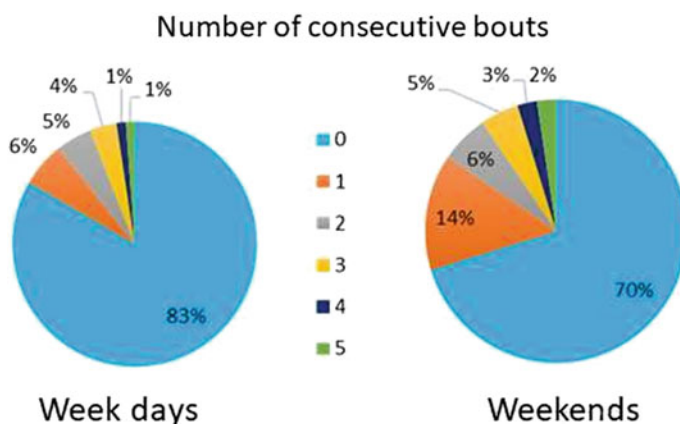


Fig. 2 Number of 10 min consecutive MVPA (bouts) on Weekdays and Weekend days

with the WHO guidelines, which argue that children need at least 60 min a day, of moderate to vigorous-intensity PA [20]. Besides, results show that children spent more than one hour in MVPA the WHO recommendations also state that this intensity should be performed for at least ten consecutive minutes, to cause adaptations in the children's health.

Through bout analysis (1 bout implies having a MVPA for at least ten continuous minutes with a limit of two tolerance spikes) demonstrated that children did not spend the time in MVPA continuously, because the time in moderate to vigorous intensity seems to be only the accumulated during the day (Fig. 2a, b). This shows the importance of evaluating the physical activity of children by bouts and not just the total MVPA, because it may seem that they meet the daily recommendations, but in fact, they do not. Similar research suggests that physical activity accumulated over shorter periods is related to cardiometabolic risk factors [21].

On a normal day, school-aged children have several different PA opportunities to move, such as walking to school, engaging in physical education classes, playing during recess time, and participating in sports clubs [2, 8]. All these normal activities are forbidden during the lockdown, which hampers the daily levels of PA. In confinement, and during online classes, children tend to spend prolonged periods sitting down doing school activities. Thus, it was possible to observe that the children were more active on the weekend days (Fig. 2b), which can be explained by the fact that parents have more time available and can spend more time playing with the children. Also, the children do not have school on the weekends, which may be another factor explaining the increase in PA these days. Previous findings also showed that during weekdays children spend most of their free time on screen time, watching TV or playing video games, and using smartphones [3, 22].

Our findings also showed that there were significant differences between having outdoor spaces for MVPA on weekdays (Table 1). Children and their families that do not have outdoor spaces spent more time in MPVA, opposing what was expected

and the literature results [2]. One of the main reasons for these surprising results may be that parents are trying to improve indoor spaces for children to move around by having active video games (i.e., exergames), and other devices that can provide opportunities to move children around. These are extremely attractive and common to be played by younger children, they are a source of physical activity that elevates motor skills [23].

Some investigations argue that the lockdown results in decreased levels of physical activity increased body mass index, and sedentary behaviors [6, 7]. Additionally, other researchers found an increase in hours in front of the screen [4]. Thus, all these changes resulted in huge changes in children's health and wellbeing, harming their mental health [24], prolonged stress [5], and increased levels of sedentary lifestyles and weight [5].

Finally, [24] showed that PA can be an interesting way to improve fitness levels in children, preventing sedentary behaviors.

The present study has some limitations. First, few parents allowed their children to participate in the investigation, which can hamper the generalization of the results. Secondly, the reach other families were difficult since the government limitations imposed in Portugal. Finally, the return to school made it impossible to continue gathering information regarding the children's confinement.

Despite the limitations, this study was capable to present interesting results. First, we showed that 6-to-10-year-old schoolchildren were negatively influenced by the restrictions and home confinement. Also, it was found that is a general issue and there were no differences in school years. A horrifying result is that children spent more time in SEDLI compared to MVPA, which can decrease fitness levels. Future studies might address the consequences of the excessive sedentary time during lockdown in the development of the children from this generation.

5 Conclusions

The findings of the present investigation provide further evidence that COVID-19 affected PA levels of Portuguese schoolchildren. Our results showed that the daily recommended levels of PA, were not fully accomplished. Thus, better context conditions at home could be important to healthy lifestyles development and provide a SEDLI decrease. Spending more time at MVPA should be one of the parent goals and other family members. Thus, these results can help highlight the current reality by encouraging increased PA, such as exergames, and decreased sedentary time in front of the screen.

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Circadian and Biological Rhythms in Shift Workers—A Firefighter's Study



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Abstract Shift Work contribute to dysregulation of the typical sleep and awake periods that cause circadian distortions, increasing the risk of cardiovascular mortality and morbidity and developing metabolic diseases. Firefighting is a career that demands much of individuals and has a great impact on their health, making it a high-risk job. **Objectives:** This study aims to characterize shift workers' blood pressure profiles in an attempt to understand the repercussions of shift work on the circadian blood pressure rhythm in a sample of professional firefighters. **Materials and methods:** Participants were classified based on their dipping status: dipper drop of 10–20%; non-dipper 0–10%; invert-dipper when there is a rise in BP; extreme-dipper superior to 20%. **Results:** Abnormal dipping was found in 55.6% of the participants, and there was a marked difference in gender in percentage where dipping is concerned, with 66.7% of women having abnormal dipping against 50% of the men. It was proved that men had a slower heart rate than women ($p\text{-value} = 0.029$) and that dippers had a higher 24 h DBP compared with those of abnormal dipping ($p\text{-value} = 0.049$). **Conclusions:** Shift work is a high-risk module of labor, and its consequences require a more thorough examination. Abnormal dipping prevailed in firefighters, and the differences between genders need to be better characterized in future studies.

Keywords Shift workers · Circadian rhythm · Firefighters · Blood pressure dipping

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1 Introduction

As the world became industrialized, the need to ensure 24 h services increased significantly and a new work format appeared—shift work which entails work hours different from the traditional diurnal period, including night shifts [4, 7, 11]. This type of labor disrupts the normal awake-sleep pattern [7], interfering with the human body's biologic and circadian rhythm and equilibrium [4].

Circadian rhythms are 24 h cycles present in physiologic and behavioral functions generated by molecular clocks that coordinate the internal organism to the external world [6], controlled by the suprachiasmatic nucleus, also called the circadian pacemaker [16].

Therefore, shift workers are more susceptible to circadian misalignment, especially on night shifts [3], due to sleep deprivation and the dysregulation of sleep and awake periods [12]. Consequently, shift workers are more likely to develop certain pathologies, such as hypertension, obesity, hypercholesterolemia, acute myocardial infarction, stroke, diabetes, and coronary disease, caused partially by the disruption of the circadian rhythm [12, 13], but also provoked by the higher prevalence of smoking and inadequate diet, which constitute risk factors that may be related to the work characteristics [13]. Employees in this regimen have an increase in cardiovascular mortality and morbidity [11].

A normal blood pressure's (BP) circadian rhythm entails an early morning surge, lower levels at the end of the day, and a decrease in the transition between sleep and awake, with an expected systolic blood pressure (SBP) drop of 10 to 20% and a less significant drop of diastolic blood pressure (DBP) [1, 17]. This variation in blood pressure can be analyzed with an Ambulatory Blood Pressure Monitoring (ABPM), a 24 h exam that is used not only to diagnose hypertension, particularly white coat hypertension and masked hypertension [14], but also the efficacy of the antihypertensive medication and to characterize the circadian blood pressure profiles [1]. The ABPM also allows to measure pulse pressure (PP), defined as the difference between SBP and DBP [19]. ABPM allows a healthcare provider to assess your blood pressure during your routine activities in daily life, whether working, sleeping, or doing chores.

Blood pressure profiles are established according to the SBP drop between the awake and asleep periods. As such, we classify as a dipper when the drop ranges from 10 to 20%; an extreme dipper when the decrease is more significant and exceeds the 20%; an invert-dipper when instead of diminishing, the BP rises; non-dipper when the drop is less than 10% [14].

The natural dip in BP that occurs every 24 hours appears to play an important role in the risk of cardiovascular diseases (CVD) [15]. The profile non-dipper has been associated with a higher risk of cardiovascular events [5], and is considered a consistent marker of clinical and subclinical mortality and morbidity in both normotensives and hypertensives [9]. Shift workers have higher BP, even during sleep, when compared with diurnal workers, which causes a higher BP in the 24 h [15]. Various

studies have been conducted to investigate the repercussions of shift work, but the level of influence that shift work has on the normal BP dipping is still poor [15].

Firefighters are an important work class tasked with protecting and helping the population by engaging in multiple activities, partaking in urgent, emergency and essential services [20]. This study aims to characterize the shift workers' blood pressure profiles, in an attempt to understand the repercussions of shift work on the normal pattern of blood pressure, in a sample composed of professional firefighters.

2 Materials and Methods

2.1 Participants

The participants for this study were collected from different volunteer firehouses after obtaining permission from the respective chiefs. The sample was composed by 30 professional firefighters that submitted to the ABPM screening. The sample was constituted by convenience, and the sample size was studied to have statistical significance. Firefighters who worked night shifts, aged between 18 and 67, from both genders were considered eligible. On the other hand, participants who didn't fulfill these conditions were excluded. From the sample that met the admission criteria, 1 subject gave up on the day of the exam, and 2 didn't achieve the minimum measures required. In the end, 27 firefighters successfully concluded this study.

2.2 Study Design

All participants had to answer a questionnaire to collect socio-demographic information that included basic data as age, gender, height and weight- to calculate the body mass index (BMI), lifestyles- smoking and caffeine consumption- and clinical particularities such as family history or personal diagnose of hypertension, and current medication. Before starting the exam, all participants had to indicate what shift they were working on the day of the examination (night shift or diurnal and night shift), what function they would carry (be it either on the ambulance or on the fire truck), how long they had this job and to estimate the number of night shifts per week.

2.2.1 Abmp

The ambulatory blood pressure was measured with a noninvasive, automated oscillometer device (ABPM 4). An appropriate cuff in size was placed on the participant's

left arm (since all participants were right dominant), and BP was registered automatically every 20 min during the wake period and every 30 min during sleep. The awake and sleep periods were established according to the subject's usual bedtime and rise hours. The ABPM was set on a day the participant worked the night shift.

A basal BP measure was taken on the laboratory to guarantee viable results and to test the equipment. Participants were asked to keep their left arm extended and be still whenever a reading was being taken.

The participants were then classified according to the percentage of drop in SBP in the transition from awake to sleep. Dippers were defined as a 10–20% decrease in SBP, non-dippers when the drop was less significant, between 0 and 10%, invert-dippers when instead of a decline, there's a rise in SBP, and extreme dippers when the decrease was prominent, superior to 20%. To be considered viable the ABPM required a minimum of 70% valid measures.

2.3 Statistical Analysis

This study's database was compiled and transposed to the application IBM SPSS Statistics 24.0 for statistical analysis. All data were descriptively analyzed and described as the mean $\pm$ standard deviation (SD) for continuous variables and as a percentage of the total (%) for categorical variables and respective 95% confidence intervals (95%CI). The Shapiro-Wilk test was applied to investigate the variables' distribution in terms of normality, and Levene's test was used to assess the equality of variances. The student's t-test was applied to compare continuous variables between two independent groups when distribution was normal, otherwise, the U Mann-Whitney test was used. Fisher's Exact test, whenever appropriate, was used to observe the association between categorical variables. Significance was fixed at a value of $p < 0.05$ for a confidence interval of 95%.

3 Results

This study counted with a sample of 27 professional firefighters, 18 men (66.7%) and 9 women (33.3%). The sample was questioned and characterized based on age, weight, height and BMI, years on the job and number of night shifts per week (Table 1), and also, smoking and caffeine habits and family history of hypertension (HTN).

In terms of the variables chosen to characterize this population (Table 1), we found that the mean "age" was 39.56 ± 9.79 years, "weight" 83.81 ± 12.22 Kg, "height" 1.72 ± 0.09 m, "BMI" 28.59 ± 4.50 Kg/m², "time on the job" 8.77 ± 8.77 years and night shift per week 2.44 ± 1.15 .

It was found that there were statistically significant differences (p -value < 0.05) between men and women in terms of "age" (p -value = 0.032), where men ($41.94 \pm$

Table 1 Characterization of the study's population

	Total n = 27	Men n = 18; $\bar{x} \pm s$ (95%CI)	Women n = 9; $\bar{x} \pm s$ (95%CI)	p-value
Age (years)	39.56 $\pm$ 9.79	41.94 $\pm$ 10.62	34.78 $\pm$ 5.74	0.032
Weight (Kg)	83.81 $\pm$ 12.22	84.11 $\pm$ 10.17	83.22 $\pm$ 16.28	0.898
Height (m)	1.72 $\pm$ 0.09	1.74 $\pm$ 0.09	1.65 $\pm$ 0.50	0.004
BMI (Kg/m ²)	28.59 $\pm$ 4.50	27.64 $\pm$ 3.75	30.50 $\pm$ 5.46	0.122
Time on the job (Years)	8.77 $\pm$ 8.77	9.69 $\pm$ 9.75	6.94 $\pm$ 6.49	0.641
Night Shift/ week	2.44 $\pm$ 1.15	2.33 $\pm$ 1.14	2.67 $\pm$ 1.22	0.489

10.62 years) were older than women (34.78 $\pm$ 5.74 years), and “height” (p-value = 0.004), where it was determined that men (1.74 $\pm$ 0.09 m) were taller than women (1.65 $\pm$ 0.50 m).

However, the remaining variables showed no statistically significant difference between the two genders. Still, men showed higher mean values in terms of “weight” (p-value = 0.898): men (84.11 $\pm$ 10.17 kg), women (83.22 $\pm$ 16.28 kg), and “time spent on the job” (p-value = 0.641): men (9.69 $\pm$ 9.75 years;), women (6.94 $\pm$ 6.49 years).

Women revealed higher values in terms of “BMI” (p-value = 0.122): men (27.64 $\pm$ 3.75 Kg/m²), women (30.50 $\pm$ 5.46 Kg/m²); and “number of night shifts per week” (p-value = 0.489): men = 2.33 $\pm$ 1.14; women = 2.67 $\pm$ 1.22, though none statistically significant.

According to smoking habits, it was discovered that 17 participants (63%) were non-smokers, while 10 individuals (37%) were active smokers, 7 (38.9%) were men, and only 3 (33.3%) were women. Since the percentages were similar, no statistical differences were found between the two groups (p-value = 1.00).

When looking at caffeine ingestion, the numbers considerably rose with only 3 participants (11.1%) that didn't have this habit and 24 participants (88.9%) who drank coffee daily. Of these 24, 18 were men (100%), and 6 were female (66.7%), with a significant difference (p-value = 0.029), stating that men drank more coffee than women. The daily coffee consumption's mean was 4.11 $\pm$ 2.61. In terms of the number of coffees consumed daily, 14.8% drank 1 or fewer coffees, 55.6% drank between 2 and 4 coffees, 18.5% drank between 5 and 7 coffees, and 11.1% drank between 8 and 10 coffees per day.

Finally, 16 individuals reported having a family history of hypertension, where 6 women (66.7%) responded affirmatively against 10 men (55.6%), though it wasn't enough to be statistically significant (p-value = 0.692).

According to the results of the ABPM (Table 2), the sample's mean for “24 h SBP” was 125.89 $\pm$ 11.26 mmHg, “24 h DBP” 75.48 $\pm$ 7.55 mmHg, “Diurnal SBP” 128.96 $\pm$ 11.56 mmHg, “Diurnal DBP” 78.19 $\pm$ 8.17 mmHg, “Nocturnal SBP”

119.59 $\pm$ 13.97 mmHg, “Nocturnal DBP” 69.74 $\pm$ 8.58 mmHg, “PP” 50.56 $\pm$ 7.90 mmHg and “heart rate” (HR) 75.52 $\pm$ 9.50 bpm.

Some variables’ means were slightly higher for women when compared with men: “24 h SBP” (128.11 $\pm$ 12.46 mmHg versus 124.78 $\pm$ 10.81 mmHg), “Diurnal SBP” (129.33 $\pm$ 13.23 mmHg versus 128.78 $\pm$ 11.04 mmHg), “Nocturnal SBP” (125.89 $\pm$ 15.34 mmHg versus 116.44 $\pm$ 12.50 mmHg), “Nocturnal DBP” (71.00 $\pm$ 11.94 mmHg versus 69.11 $\pm$ 6.66 mmHg) and “PP” (53.67 $\pm$ 7.91 mmHg versus 49.00 $\pm$ 7.63 mmHg), but they didn’t produce statistically significant differences (p-value = 0.471; p-value = 0.757, p-value = 0.104, p-value = 0.938, p-value = 0.151, respectively).

In contrast, some variables proved to be higher on men than women: “24 h DBP” (76.00 $\pm$ 6.85 mmHg versus 74.44 $\pm$ 9.15 mmHg) and “diurnal DBP” (79.17 $\pm$ 7.76 mmHg versus 76.22 $\pm$ 9.08 mmHg), though this too didn’t provoke significant changes (p-value= 0.623; p-value= 0.110, respectively).

From this data, we highlight the HR (p-value = 0.039), which proved that women (80.78 $\pm$ 8.03 bpm) had a higher HR than men (72.89 $\pm$ 9.27).

The ABPM performed on the participants revealed that 3 of them had hypertension (11.1%), 1 woman (11.1%) in HT stage I, and 2 men (11.1%) in which 1 was in stage I and the other on stage II.

In terms of dipping (Figure 1), it was found that 12 individuals were dippers 44.4% (95%CI 26.9%–63%); 11 were non-dippers 40.7% (95%CI 23.7%–59.5%) and 4 were invert-dippers 14.8% (95%CI 4.9%–31.1%). Since the percentage of invert- dippers is relatively small, non-dippers and invert-dippers were combined and formed the variable abnormal dipping. Therefore, 44.4% (95%CI 26.9%–63%) of the individuals had a normal dipping profile and 55.6% (95%CI 37.0%–73.1%) pre- sented an abnormal dipping (Fig. 2).

Table 2 ABPM results regarding “BP”, “PP” and “HR”

	Total n = 27; $\bar{x}$	Men n = 18; $\bar{x}$ + s (95%CI)	Women n = 9; $\bar{x}$; s (95%CI)	p-value
24-h SBP (mmHg)	125.89 $\pm$ 11.26	124.78 $\pm$ 10.46	128.11 $\pm$ 12.46	0.471
24-h DBP (mmHg)	75.48 $\pm$ 7.55	76.00 $\pm$ 6.85	74.44 $\pm$ 9.15	0.623
Diurnal SBP (mmHg)	128.96 $\pm$ 11.56	128.78 $\pm$ 11.04	129.33 $\pm$ 13.23	0.757
Diurnal DBP (mmHg)	78.19 $\pm$ 8.17	79.17 $\pm$ 7.76	76.22 $\pm$ 9.08	0.110
Nocturnal SBP (mmHg)	119.59 $\pm$ 13.97	116.44 $\pm$ 12.50	125.89 $\pm$ 15.34	0.104
Nocturnal DBP (mmHg)	69.74 $\pm$ 8.58	69.11 $\pm$ 6.66	71.00 $\pm$ 11.94	0.938

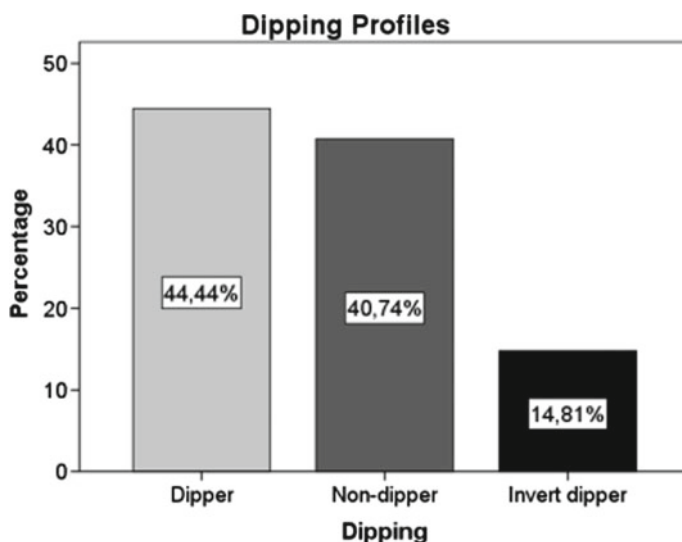


Fig. 1 Graphic of proportion of dipping profiles

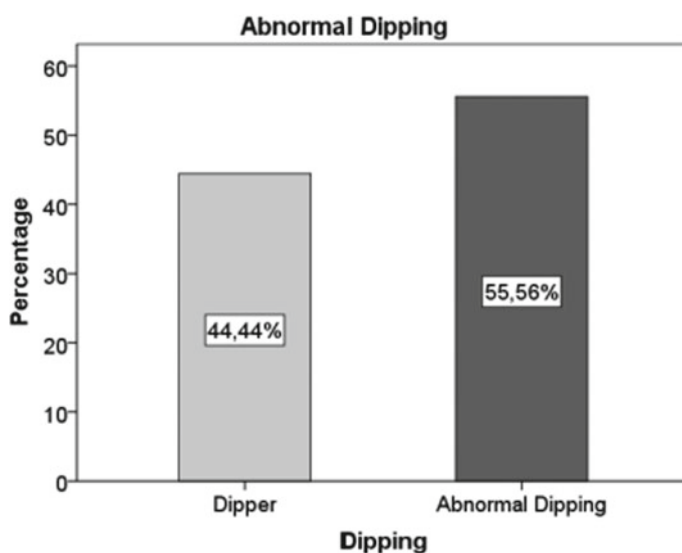


Fig. 2 Graphic of proportion of abnormal dipping

When we compare dipping profiles to gender (Fig. 3), 6 women, 66.7% (95%CI 34.5%–90.5%) presented abnormal dipping, against 9 men, 50% (95%CI 28.1%–71.9%), although there were no statistically significant differences.

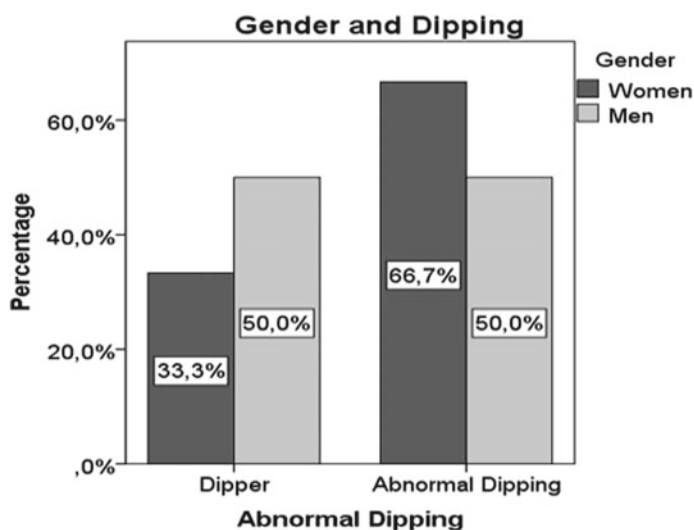


Fig. 3 Graphic of proportion of abnormal dipping according to gender

The variable abnormal dipping was used to understand if there was any association between an abnormal dipping profile and the individual's characteristics (Table 3). Considering the variable "24 h DBP" (p-value = 0.049), there were statistically significant differences between dipping profiles, where dippers (77.75 ± 7.10 mmHg) proved to have higher values than those with abnormal dipping (73.67 ± 7.64).

Abnormal dipping profiles revealed higher mean values than dippers for the following variables: "night shifts per week" (2.60 ± 1.18 versus 2.25 ± 1.14) and "time spent on the job" (9.27 ± 7.79 versus 8.15 ± 10.19), but neither were statistically significant (p-value = 0.434; p-value = 0.749, respectively).

Table 3 BP dipping profiles and population's characteristics

	Total n = 27; $\bar{x}$	Dippers n = 12; $\bar{x} \pm s$ (95%CI)	Abnormal dipping n = 15; $\bar{x} \pm s$ (95%CI)	p-value
Night shifts per week	2.44 ± 1.15	2.25 ± 1.14	2.60 ± 1.18	0.434
24-h SBP (mmHg)	125.89 ± 11.26	127.08 ± 12.10	124.93 ± 10.87	0.631
24-h DBP (mmHg)	75.48 ± 7.55	77.75 ± 7.10	73.67 ± 7.64	0.049
Time on the job (Years)	8.77 ± 8.77	8.15 ± 10.19	9.27 ± 7.79	0.749

In opposition, in terms of “24 h SBP” (p -value = 0.631), dippers showed a slightly higher mean value (127.08 ± 12.10 mmHg versus 124.93 ± 10.87), which didn't prove to be statistically significant.

4 Discussion

Shift work may cause a disruption in the normal circadian rhythm and sleep patterns, provoking grave consequences on the employees' health, and is frequently associated with several risk factors of cardiovascular disease, CVD [11, 18].

Exposure to shift work, especially nocturnal, alters the normal diurnal pattern of BP, with BP maintaining a high value even during sleep [15]. Some shift workers' groups might present a blunted BP dipping between awake and sleep during night shift and during rest following shift work [14].

The main finding of this study might be the gender difference regarding dipping status, with 66.7% of women presenting an abnormal dipping against only 50% of the men. Despite data being insufficient to declare statistical significance, the difference between percentages is enough to warrant new projects based on this doubt. Female firefighters are a minority in this profession [20], with women gaining numbers in recent years. This might play a significant role in variables as women respond to physical and physiological demands of firefighting differently than men [20]. Some studies have explored the difference between genders in firefighters in terms of performance and have concluded that women respond differently than men to occupational performance [20].

Even though there are several studies that focus on analyzing the association between BP and shift workers, and even the recovery after shift, we found very few articles that described dipping status and none that compared dipping status with gender or other variables such as the ones studied by the ABPM, with most studies focusing on the differences between shift workers and a control group of diurnal employees.

One of the most important findings of this study is that abnormal dipping prevailed over the dipping pattern, with non-dippers and invert-dippers constituting 55.6% of the population and dippers 44.4%.

These results support Yamasaki et al., that showed that evening and night shifts workers were more likely to be non-dippers than diurnal employees, with 79% of individuals working the night shift classified as non-dippers, with night-shift workers being 6.1 times more likely of being classified as non-dippers than diurnal workers (p -value < 0.001) [21]. This discrepancy may be caused by the impairment of the quality of sleep provoked by shift work [21].

Yamasaki et al., also affirm that individuals that show a normal nocturnal BP fall (dippers) become non-dippers when working at night [21].

Kitada et al., make this evidence stronger by stating that the majority of their study's population presented a non-dipping status [8]. As did Lo Sh et al, by discovering that changes in BP profiles between dipper and non-dipper in rotating shifts were common, with a 69% of cases in the population [10].

This stands in line with the findings of Nascimento Jov et al, with a majority of shift workers presenting a non-dipping profile, and this study adds that the high values of BP during sleep suggest that shift workers are exposed a greater cardiovascular risk [13].

No statistically significant difference regarding BP were observed when compared with gender and neither on 24 h SBP with abnormal dipping. Men drank more coffee than women (p -value = 0.029) and they have a lower heart rate when compared with women (p -value = 0.039), and that dippers had a higher 24 h DBP when compared with those with abnormal dipping. (p -value = 0.049). In contrast Fialho et al., who found no statistically significant differences that could classify the participants as non-dippers [2]. Patterson et al., in a systematic review, state that the blunted BP dipping may be restricted to certain groups of shift workers or conditions and that the attenuation may diminish after a short period of time [15].

The present study had some limitations, such as a small sample of women, which may explain the difficulty of finding statistical significant differences based on gender, given the low representation of women.

Another limitation is that we solely analyzed the dipping profiles on the day of a night shift and, as such, we can't determine if the abnormal dipping derives from the night shift or if, in fact, this was the participants' basal profiles.

Further investigation in this area is needed to characterize and explore the changes that a shift worker's body goes through, both during shift and the following recovery period. In this perspective, it's important to note that, according to this study's results, it is essential that future projects explore the difference between genders where abnormal dipping is concerned.

Another fragility of this research is not considering the workplace-related factors, such as the physical and psychosocial risk factors (e.g., work intensity; different shift patterns; ...), in the analysis. Additionally, the data analysis contrasted by gender dimension seemed interesting, but we don't studied if firefighters from different gender have different functions and different working conditions, variables that could influence the results.

Finally, we would like to highlight the need for more investigation on firefighters, given their crucial work in society, and the consequences that such effort may cause on their health.

5 Conclusions

Shift work is a type of labor that entails many health risks, including changes in the circadian rhythm of BP. The abnormal dipping prevailed in the studied firefighter's and a difference between genders made itself known, which needs to be explored in a larger population for better characterization.

It is essential that we continue to study the consequences of shift work in all its aspects to protect firefighters and implement strategies related to health promotion to protect firefighters considering that they are a risky group attending shift work and the circadian rhythm of BP. The reorganization of the working schedule could be a strategy to be addressed and tested in future works.

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Characterisation of the Portuguese Footwear Industry Relative to Occupational Health and Saefety



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Abstract The footwear industry, part of the traditional manufacturing sector, plays a prominent role in Portugal. Understanding some occupational health and safety (OHS) characteristics is essential to implement and consolidating prevention. Thus, this study searched for relevant information about the OHS characterisation of the Portuguese footwear industry. Eighty-five companies replied to the questionnaire. Topics such as dimension, OHS services, certification, training, OHS mandatory annual consultation, near-miss management (NMS), and workplace exercise program were analysed. Most companies were SMEs, not possessing internal OHS services. Few respondents had a certification, and only one was certified by ISO 45001. The majority of the companies referred to performing training and OHS consultation. Some respondents referred to implementing NMS. Thus, it is essential to understand the quality and quantity of the existing previously stated by the respondents regarding training, consultation and NMS to ensure their effectiveness. Although it is an industry still characterised by repetitive operations and maintained postures, no company referred to performing workplace exercise programs, and few considered adopting them. OHS issues are still not regarded as top company priorities within this sector.

Keywords Traditional manufacturing · Prevention · Certification · Training · Near-miss

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1 Introduction

Within the manufacturing sector, some industries are involved in the processing and production of goods that have existed for a long time without much disruption or change and are commonly called “traditional manufacturing industries” [26]. In this kind of manufacturing industry, most of the following characteristics still hold: “long-established” as traditional implies history; “labour-intensive” with low-skilled workers, repetitive operations, and manual work; “great innovation potential” [27]. Manufacture of food products and beverages, textiles and textile products, leather and leather products, ceramics and other non-metallic mineral products, mechanical/metallurgy or primary metals and metalworking and manufacturing, and automotive (motor vehicles or other components) can be considered as traditional manufacturing industries [27].

European Textile, Clothing, Leather, and Footwear industries are significant players in the European Union’s economy and cultural heritage, encompassing 200,000 companies, generating over 200 billion Euros turnover, and employing nearly 2 million people in 2019 [10]. The footwear sector is a diverse industry covering various materials and products. In 2012, this sector generated 24 billion Euros in turnover and 6.2 billion Euros in added value, directly employing more than a quarter of a million people [9].

The “Porter Report”,¹ among other things, determined the necessity of identifying what was unique in Portugal instead of imitating other countries’ strategies. It defined the Portuguese strategic clusters [28]. Michael Porter assumed a selection of six clusters based on representativity and the importance of action over analysis: footwear was one of those. The trajectory of the footwear sector, following this Porter Report, has been very positive. Portuguese footwear is designated as “The sexiest industry in Europe” and, more and more, is an example of competitiveness, reinventing itself, innovating and increasing exports. As referred to by the former Portuguese minister of economy, Manuel Caldeira Cabral, “It was an industry that by innovating transformed a traditional sector in a sector with future” [6].

Thus, the Portuguese footwear industry is a successful case in the Portuguese economy. In 2019, Portugal was the 15th biggest world exporter of leather footwear in terms of the value of exports. Italy, France and Portugal accounted for 21% of global leather footwear exports that year [11]. According to the [5], 56.44% of

¹ In 1992, the Portuguese Government, with the involvement of various industrial organizations, asked the “Monitor Company”—a company led by Michael Porter, professor at Harvard Business School to conduct a study with the aim of “Building the competitive advantages of Portugal” [14, 28].

Portuguese footwear companies are micro-enterprises,² 31.87% are small enterprises, and 11.21% are medium. Only 0.48% are big enterprises. Almost half of the total employees in this sector (45.47%) work in medium enterprises, and 34.19% work in small enterprises. More than 1500 Portuguese companies operate in the footwear, components, and leather goods sectors, employing 40,000 people. In 2021, the Portuguese footwear industry, highly concentrated in the country's northern region, exported footwear worth 1676 million euros to 162 countries on five continents, and exports grew 29% over the past decade [3].

The growth in this sector can be more sustainable if it considers working conditions, as poor health and safety create costs for organisations. Well-planned and systematically carried out occupational safety and health measures deliver economic returns, which are 3–10 times greater than the monetary investment [1]. Thus, good occupational safety and health is a good business [8] and can add competitiveness to any sector. Some indicators can characterise organisations' OHS, such as the following:

- Type of OHS services: every company must have organised OHS services that can be internal, external or common services.
 - Existence of any certification: OHS practices tend to have better rates if a company is certified than those of a non-certified company. Nevertheless, the standard cannot guarantee the fulfilment of its requirements [12].
 - Training: the quality of safety training is considered a key factor for a strong safety culture [7]. Training is mandatory by the European Union Law (Directive 89/391/EEC Consolidated 1989).
 - Mandatory annual workforce consultation: employers must consult their employees or their employees' representatives on health and safety matters (Directive 89/391/EEC Consolidated 1989).
 - Near-miss Reporting: a near-miss (NM) is "an opportunity to improve environmental, health and safety practice based on a condition or an incident with potential for a more serious consequence" [25]. It is a proactive safety indicator [17]. Reporting NM requires changing the company's culture, as workers must understand they are the ultimate risk managers [16].
- Musculoskeletal injuries are common in the footwear industry due to maintained/forced postures (standing or sitting) and repetitive movements [29]. Thus, adequate near-miss management can and must identify events that can degenerate in future musculoskeletal injuries. One of the recommended workers' coping strategies for performing their activities effectively without harming their health is the implementation of workplace exercise programs,

² A microenterprise is defined as an enterprise which employs fewer than 10 persons and whose annual turnover and/or annual balance sheet total does not exceed EUR 2 million. A small enterprise employs fewer than 50 persons and whose annual turnover and/or annual balance sheet total does not exceed EUR 10 million. A medium-sized enterprises is from 50 to fewer than 250 persons and which have an annual turnover not exceeding EUR 50 million, and/or an annual balance sheet total not exceeding EUR 43 million (Commission Recommendation 2003/361/EC, 2003).

as it is necessary to create muscle-strengthening activities and breaks for stretching [18].

As there is not much research on this traditional sector, specifically related to safety at work, this study aims to add relevant information about this subject, leading to a more comprehensive OHS characterisation. This characterisation includes the type of OHS services, certification, training, worker's consultation, near-miss management and workplace exercise programs to identify gaps regarding OHS management in the Portuguese footwear industry.

2 Materials and Methods

There has been a significant development in the Portuguese footwear industry recently. However, there is no general perception of the relevance of Health and Safety at work in this sector. Thus, some dimensions intrinsically connected to this subject are presented in this field study.

This study was carried out using a survey by questionnaire, characterised by posing questions to the company's representatives, allowing for subsequent quantitative treatment. This tool lets researchers gather much information cheaply, regardless of the significant non-response usually associated with surveys.

Data Collection Process The questionnaire survey is organised into two sections, as evidenced in Table 1. Depending on the nature of the question and the data available, questions were asked of a quantitative nature, i.e. structured questions that specify a set of alternative responses and the response format.

The questionnaire was designed with multiple-choice questions where respondents opt for one of the alternatives or a certain allowed number of options and dichotomous questions that present only two types of answers: yes/no.

Table 1 Sections and topics of the questionnaire

Sections	Main topics of the questionnaire
Characterisation of the enterprise	District
	Dimension
Characterisation of the OHS area	OHS type of services
	OHS certification or others
	Existence of OHS training and other training
	Existence of OHS workers' consultation
	Existence of near-miss management
	Existence of a workplace exercise program

Sample and Data Collection Technique The survey applied in this study was a questionnaire adapted from Pedrosa et al. [21].³ A list of the Portuguese Footwear, Components, Leather Goods Manufacturers' Association [3] with a total of 208 footwear companies associates was used initially. The questionnaire was disseminated firstly via email, mainly intending to contact the quality or the health and safety officer if existent. Afterwards, a second attempt was made at those who did not respond initially through other vias. Firstly, by phone and, in some cases (2 companies), even in person. From that original list, 74 companies replied to the placed questions. In addition to those 74 companies on the original APICCAPS list, 11 more companies agreed to be part of the research, totalling 85 responses, a more significant figure (all these means aimed to obtain the highest possible number of responses).

3 Results and Discussion

Approximately 36% of the original 208 enterprises belonging to the APICCAPS list and eleven companies more joined the project. In total, 85 companies. The relatively high adhesion rate may be because the questionnaire was disseminated through different vias. Firstly, an email was sent to all companies (41% of the responses were achieved through this via). Subsequently, in the cases of non-response, several phone calls reinforced the previous figures (57% of the total responses were achieved by phone) and even two contacts in person (2% of the total responses). In a similar study, but in the broader sector of the manufacturing industry, some of these same authors obtained an adhesion rate of 20%, where the contact was only by email. One of the research implications of that previous study was that a personal contact rather than an email contact could guarantee better and more significant results, even if it would be challenging to implement [21].

Table 2 presents the results of each of the posed questions.

The respondent companies were mainly from the districts of Aveiro (46%), Porto (36%) and Braga (11%). Two companies were from Leiria (2%), two from Lisboa (2%), another two from Viana do Castelo (2%) and one from Guarda (1%). This sample is representative of the actual distribution of the Portuguese footwear industry highly concentrated in the northern region. More than 90% of those companies can be found in a circle of 50 km from the city of Porto [3].

The respondents' functions in the company were diverse. Some were of the top management (36%); quality or health and safety officers (12%); human resources officers (5%), and administrative officers (39%). These numbers can be more easily perceived as only about 5% of the respondents were big companies. Therefore, and according to European legislation, most organisations that responded to this study are not required to have internal OHS services. Indeed, a formal OHS internal structure

³ This questionnaire included both OHS and environmental topics and was applied to all Portuguese certified companies to assess the impact of certification on those topics.

Table 2 Main results of the questionnaire

Companies' district		Aveiro (46%) Porto (36%) Braga (11%) Leiria (2%) Lisboa (2%) Viana do Castelo (2%) Guarda (1%)
Company dimension		Big companies (5%) Medium companies (61%) Small companies (27%) Micro companies (7%)
Companies' OHS services		Internal OHS services (4%) External OHS services (94%) Common OHS services (0%) None (2%)
Certification	Certified company?	Certified companies (19%) Non-certified companies (80%) Did not answer (1%)
	Types of Normative Certification in the certified companies	Companies certified by ISO 9001 (64%) Companies certified by ISO 14001 (57%) Company certified by ISO 45001 (7%)
Training	The company trained workers?	Yes (87%) No (11%) Did not answer (2%)
	Any of the training was about OHS?	Yes (76%) No (12%) Did not answer (12%)
Did the company consult workers about health and safety conditions?		Yes (82%) No (13%) Did not answer (5%)
Does the company manage near-misses?		Yes (34%) No (61%) Did not answer (5%)
Workplace exercise program	Is there any Workplace exercise program?	Yes (0%) No (42%) Did not answer (58%)
	Would the company be receptive to one?	Yes (2%) No (20%) Maybe, the company would be receptive (14%) Did not answer (64%)

does not exist in 96% of the respondents, with 94% of these referring to having external services and 2% of the companies with no kind of service, not following the legal requirements. Thus, collecting reliable data may become challenging, and there may be some bias in some of the collected data. Most interviewees are either top management or administrative, maybe due to a lack of medium management (simplified structured organisations due to the small size of the companies since 7% were micro-enterprises and 27% were small enterprises).

Regarding certification, only 19% of the respondents had at least one normative certificate. These companies' major concerns are quality (64% of these 14 companies with at least one certification were certified by ISO 9001) and environment (57% were certified by ISO 14001). Just one of the respondents was certified by ISO 45001 (7% of this total certified companies). As referred by Pedrosa et al. [21], a low number of OHS certifications may be due to a few per cent of the companies in the survey being big companies (5%), typically companies with higher resources than SMEs. According to the already OHS-certified companies, the main reasons for their certification are the assurance of better OHS conditions followed by legal compliance and decreased workplace accidents [21]. Thus, the traditional manufacturing sector, particularly footwear companies, should invest more in OHS certification. Nevertheless, some organisations still act reactively, looking for certification only as a customer and a market requirement [19].

Training is mandatory according to European legislation. About 87% of the respondents' companies refer to the existence of training. Of those, 76% mentioned that the training was related to OHS. Nevertheless, some ended by saying that only a few workers were trained. Workers must be involved in improving their workplace. Thus, they must be adequately trained. Only well-trained employees can participate in decision-making as knowledge is crucial to anticipate risk and improving worker's autonomy [22, 23]. Thus, in future studies, a more discriminating, but also more challenging to obtain, indicator should be posed: the number of training hours per worker.

Annual OHS workers' consultation is mandatory according to European legislation. Workers, or their representatives, should be consulted regarding the working conditions and the working environment for the safety and health of workers (Directive 89/391/EEC Consolidated 1989). About 82% of the respondents' companies refer to having consulted workers. It would be interesting, in future studies, to confer the number of workers that effectively responded to the consultation.

Near-miss Management Systems (NMSs) are mandatory in the Major Accident Hazard (MAH) legislation [13, 30]. However, in other sectors, such as the manufacturing industry, employers are not currently required to report near-misses [4, 20]. Nevertheless, it is essential to manage near-misses efficiently, as they constitute a proactive strategy for improving risk prevention and preventing accidents [2, 13]. As referred to in requisite 10.2, "the organisation shall establish, implement and maintain a process(es), including reporting, investigating and taking action, to determine and manage incidents and non-conformities" (ISO Standard No. 45001, 2018). In this study in the traditional manufacturing industry, about 34% of respondents referred to reporting near-misses. In another study in the manufacturing industry [21], a lower

figure of 20% of respondents referred to reporting near-misses. In addition, evidence of published work attesting to the existence of near-miss management in the traditional manufacturing industry could not be found, which may indicate in this study, some bias in understanding this specific topic. Near-miss management is a proactive and fundamental indicator to help improve work conditions. Companies must introduce proper and adequate near-miss management so that it is actually implemented and not just a pledge.

These last dimensions: certification, training, workers' consultation and nearmiss management, are general topics that can help OHS characterising any industry. Nevertheless, many other specific items can be used to complement this analysis linked to the particular issues of each sector. For example, one of the issues more recurrent in this industry is the one related to ergonomics. In the footwear industry, there are maintained/forced postures (standing or sitting) and repetitive movements, so musculoskeletal injuries are common [29]. Thus, adequate near-miss management can and must identify events that can degenerate into future musculoskeletal disorders (MSDs). Therefore, fundamental proactive actions can be put in place to prevent them, such as improving the ergonomic conditions of the workstations. The leadership must embrace the workers' suggestions (through the worker's consultation and other instruments), be receptive to proactive ergonomics changes, privileging workers' well-being, and ensure that the MSDs are eliminated or substantially reduced [24]. One of the recommended workers' coping strategies for performing their activities effectively without harming their health is the implementation of workplace exercise programs, as it is necessary to create muscle-strengthening activities and breaks for stretching [18]. There is also stress linked to work overload, long shifts, etc. Thus, providing a good work environment can bring many benefits as decreasing absenteeism and workplace turnover [29]. Granzotto et al. [15] stated that workplace exercise programs improved motivation, reduced stress, etc. Thus, the existence of workplace exercise programs was one of the specific dimensions also asked in this study's questionnaire. It can be considered linked to near-miss management as it is a proactive indicator that can prevent one of the most frequent consequences to the worker's health in this industry: musculoskeletal injuries. Only 42% of the companies responded to the posed question about whether there was a workplace exercise program in the company, and none of the responses was affirmative. When asked what the company's reaction would be if challenged to adopt any workplace exercise program, 64% of the total companies did not reply; 14% said that maybe the company would be receptive, 20% said no, and two companies responded yes. In an industry still characterised by many repetitive operations, it would be worth trying to change the leadership mindset and introduce such programs. Considering it is a labour-intensive industry where every production minute counts, these programs should be well-planned and adapted to the workstation. Maybe a preparatory-to-work type of workplace exercise program of about 5–10 min before the work shift would be a good choice to start on and break through the initial scepticism that may exist.

4 Conclusions

Understanding the state of the art of Occupational Health and Safety within the footwear sector, as in any industry, is essential. Nevertheless, this present study has some limitations. It could not comprise all the dimensions characterising occupational health and safety as organisations are not motivated to reply to extensive questionnaires. Most companies under the survey were part of APICCAPS list (its associates). Thus, this list may not reflect the sector reality entirely, a sector with more than 1500 companies. These associates will likely have more visibility and, consequently, better OHS indicators than the other footwear companies.

Safety and health at work cannot be the weakest link in such a labour-intensive sector. Thus, it is recommended that more studies on this subject are carried out, ideally within all companies of this study. Nevertheless, as it will be challenging, this more discriminative study could be done within two or more companies to compare with this present study and consolidate a more reliable OHS characterisation of this sector.

Acknowledgements The Doctoral Program in Occupational Safety and Health of the University of Porto supported this work.

Without the responses of the various companies to the survey, it would be impossible to disclose this study.

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Occupational and Environmental Health

Modelling Physical Fatigue Through Physiological Monitoring Within High-Risk Professions



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Abstract Physical fatigue is not only a tiredness condition but can also be a symptom of various diseases or a precursor of workplace accidents and incidents. High-risk professions like firefighters and military personnel are more frequently exposed to it and its consequences. To contribute to current research efforts towards physical fatigue quantification approaches for these professionals, the current work aimed to test a previously developed machine learning algorithm based on physiological monitoring on a dataset of soldiers engaged in an incremental running protocol.

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Personal characteristics and signals from heart rate, breathing rate and core temperature were recorded from participants and used to extract 20 features. These were used as inputs to an XGBoosted algorithm to classify four levels of physical fatigue: low, moderate, heavy and severe. Outcomes showed an overall accuracy of 85% and accuracies of 100 and 92% for detecting the low and heavy levels. Also, the importance of individualised monitoring and the need for more than one physiological indicator to accurately characterise the subject physical fatigue status were demonstrated. Overall, the results confirm the model's contribution to current fatigue detection methods. Future studies will be oriented to test its validity within a bigger sample while assessing more occupational activities.

Keywords Physical exertion · Firefighters · Military · Machine learning

1 Introduction

Physical fatigue is a prevalent issue among occupational groups, mainly caused by increased physical work demands, adverse environmental conditions, inadequate rest breaks and stress [34, 35]. It is manifested as a decline in energy and power, as well as the ability to complete tasks optimally [13]. Individuals and organisations that do not timely manage it are at high risk of causing injuries and errors that can lead to harmful and lasting consequences [22, 36]. Since this condition significantly increases the risk of adverse health issues, recent studies have determined it to be a predictor for these outcomes rather than just a tiredness symptom [22]. While physical fatigue can be experienced at some point by any individual and be surpassed with some rest, given the nature of their occupational activities, some professions are more prone to it and its lasting consequences [34].

Among these high-risk job occupations are firefighters and the military. These workers put their lives on the line daily to protect society while dealing with adverse environments, great stress loads, physical demands and insufficient rest-break periods [26, 37]. Such circumstances expose them, potentially more than other working groups, to the risk of physical fatigue development that could later impact their preparedness, overall health condition and well-being [10, 24]. Given the fundamental importance of these factors for their operations, proactive physical exertion led fatigue monitoring and management have become of utmost relevance for these professions [10, 33]. Various methods have been explored to accurately assess their physical demands, including questionnaires [27, 38] and physical exertion-induced changes in physiological measures [4, 10, 23].

With innovations in wearable sensor technology, multiple physiological datasets can be continuously and noninvasively assessed. However, the success of these systems lies in their ability to provide important actionable information from those assessments [14]. Hence, current research is oriented towards developing physical fatigue quantification approaches that translate physiological signals into physical fatigue indicators based on traditional programming techniques, statistical indices

Table 1 Participants anthropometrics [9]

Assigned code	Age (years)	Weight (kg)	Height (cm)	BMI (Kg m ⁻²)	Body fat (%)
M01	22	75.8	177.2	24.1	6.8
M02	22	71.5	170.8	24.5	13.7
M03	24	69.6	177.9	22.0	8.9
M04	21	70.1	173.6	23.3	6.1
M05	23	103.5	172.5	34.8	23.7

or machine learning approaches [3, 18]. However, more investigation is needed to fully explore the potential of these sensors and provide generalisable methods for assessing physical fatigue among high-risk professionals. To contribute to current research efforts, we developed a decision-based algorithm for physical exertion detection and tested it within a soldiers sample [9]. Later, we improved our initial approach by modelling a machine learning classifier with data from a firefighters sample [8]. As a next step, the current study aims to test the machine learning model within the initial soldiers sample to determine if our model could also be used among other workers groups and compare its results with those obtained by our initial approach.

2 Materials and Methods

2.1 Participants

Data from five male subjects from the Portuguese Army enrolled in a Commando training course were used for testing the model [9]. They were aged 22.4 ± 1.14 years and weighed 78.1 ± 14.41 kg (Table 1 contains their main anthropometric characteristics). Volunteers gave their informed written consent before investigative procedures and were briefed on the purpose, potential risks and benefits for participating. Also, they went through a medical examination (as a standard requirement to take part in the course) and did not present cardiac, vascular, pulmonary, gastrointestinal or any allergic diseases and were not prescribed any regular medication.

2.2 Experimental Design

Subjects were assessed while performing an incremental running protocol on a treadmill (T2100 treadmill; GE, Boston, MA, USA) until perceived exhaustion. Initially, they completed a 5 min warm-up run at low velocity (8 km/h) inside a climatic chamber (FITOCLIMA 25,000 EC20; Aralab, Portugal; Guedes et al. [16]). After running (5 min at 4 km/h), they performed a progressive and continuous test to

exhaustion at an initial velocity of 10 km/h, with load increments of 1 km/h every 2 min [9]. During the trials, breath-by-breath respiratory gas exchange was assessed using a portable telemetric gas analyser (Cosmed K4b2; Cosmed, Italy) placed near the body centre of mass [12, 32]. Heart rate was recorded every 5 s using a Polar sensor that telemetrically transmitted the data to the K4b2 equipment. For measuring core temperature, ingestible thermometer pills from Vital Sense were used (Vital Sense, Phillips Respironics, PA; Bongers et al. [7]). Ratings of perceived exertion were reported verbally using the modified Borg Scale, with subjects rating their level of physical exertion on a scale from 0 (none) to 10 (maximal exertion) during and immediately after the incremental test [12].

2.3 *Physical Fatigue Classification Model*

Recordings from heart rate, breathing rate and core temperature, synchronised using a 1 min frequency, were used as the primary variables for estimating physical fatigue. Various features from each variable and personal characteristics were extracted, with six corresponding to personal variables (age, weight, height, fat mass, fat-free mass and body mass index), six to heart rate (baseline, mean, minimum maximum, the age-predicted maximum heart rate— $220 - \text{age}$ —and the percentage of the age-predicted maximum heart rate) and eight to breathing rate and core temperature (maximum, minimum, mean and baseline from each). The levels registered with the modified Borg scale were simplified to a four-level scale (i.e., low, moderate, heavy and severe) and used as labels for each set of features [5, 8].

Previously, several supervised machine learning classifiers were tested and evidenced that the XGBoosted algorithm led to the best results [8]. This algorithm is a scalable tree-boosting method resulting from several consequent decision trees in which trees are created using the prediction errors or residuals of the previous tree model, therefore, targeting those samples with higher uncertainty. Although it has similar parameters to those of other tree-based models, it encompasses specific hyperparameters designed to reduce the risk of overfitting and pre-diction variability while increasing accuracy [1, 21]. In the current study, we used this classifier with 500 estimators, a maximum depth of five estimators and a learning rate of 0.1 as main hyperparameters. The reasons for feature selection and hyperparameters tuning are not described here, as they are detailed in our previous study [8] and can be consulted in various machine learning resources [21].

The methodology employed for physical fatigue modelling is illustrated in Fig. 1, describing the training and testing main stages. Our dataset comprised 1 min sets of 20 features from 23 male individuals, of which 18 were firefighters monitored during the trials reported in [8] and five were the soldiers described in Table 1. Data from the first group (corresponding to 78% of our dataset) was used to train our machine learning classifier and the latter was used to test the model. To evaluate the performance of our model on these five individuals, we calculated the accuracy or percentage of correctly predicted observations from the total amount of tested observations.

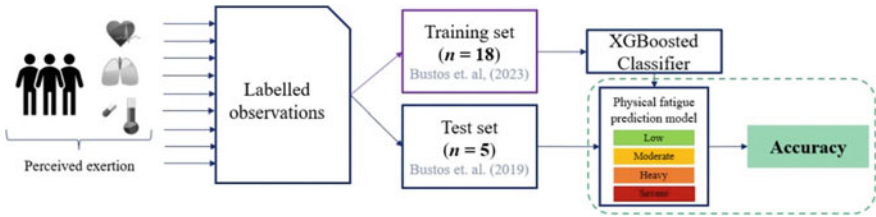


Fig. 1 Methodology employed for implementing the physical fatigue classification model

Each participant’s data corresponds to more than one point in our dataset and may be autocorrelated. Hence, to avoid overfitting our model, we used the leave p -participants method instead of the commonly used randomised 10- fold cross-validation method [30]. We trained the model with the data from the 18 participants and then tested it in our five-soldier sample separately and without randomising the observations [30].

3 Results and Discussion

Features extracted from heart rate, breathing rate and core temperature signals were used as inputs to classify four physical fatigue levels. Table 2 provides an overview of the responses recorded through each variable, showing the physiological alterations during the trials. Outcomes revealed periods in which heart rate, breathing rate and core temperature values reached 190 bpm, 60 breaths/min and 38.7 °C (respectively). Since these responses are in line with what is evidenced in literature during military field events [25, 26, 28], they show the appropriateness of the applied running protocol to retrieve representative physiological responses to use our model in future real-life practices. Given the interindividual variability of participants responses, the relevance of personal data and individualised monitoring for accurate physical fatigue estimations were demonstrated. Also, the intra-subject monitored differences indicate the need to assess more than one physiological indicator to make correct predictions (e.g., participant M03 had the lowest increase in heart rate but had the most evident alterations in core temperature). Consistently, previous studies have confirmed that multivariable fatigue assessments yield better results than those focused on just one indicator [4, 6, 17].

The overall accuracy of using the XGBoosted classifier within the five participants was 84.62%. The confusion matrix displayed in Fig. 2 contains the results obtained for classifying each of the four physical fatigue levels, being observed variations from 50 to 100% among the categories, with the best predictions registered in the low and heavy intensities. The model describes a high accuracy in three levels ($\geq 80\%$) but fails to reliably predict the moderate level half of the time. The reason behind this may be attributed to the fact that the observations collected for this category were $<10\%$. Indeed, it is well known that for machine learning models, a larger dataset could lead to greater performance accuracy and vice versa [21]. In our dataset, 20%

Table 2 Summary of physiological responses at baseline and during the incremental running protocol for each participant and for the total sample

Physiological variable	M01	M02	M03	M04	M05	All
Baseline heart rate (bpm)	77	65	72	102	92	82
Mean heart rate (bpm)	173	173	134	166	144	157
Maximum heart rate (bpm)	190	188	179	190	181	190
Minimum heart rate (bpm)	141	145	67	115	98	67
Baseline breathing rate (breaths/min)	16	20	21	18	38	23
Mean breathing rate (breaths/min)	38	49	39	41	48	42
Maximum breathing rate (breaths/min)	44	58	52	55	60	60
Minimum breathing rate (breaths/min)	30	39	23	23	32	23
Baseline core temperature (°C)	37.4	37.5	37.7	37.3	37.8	37.5
Mean core temperature (°C)	38.0	37.8	38.4	38.1	38.2	38.1
Maximum core temperature (°C)	38.4	38.0	38.7	38.4	38.2	38.7
Minimum core temperature (°C)	37.6	37.6	38.0	37.7	38.1	37.6

of observations belonged to the low category, 8% to the moderate, 41% to the heavy and 31% to the severe levels.

Although there is room for improvement, the overall accuracy evidenced a satisfactory performance (compared to similar machine learning models; Aguirre et al. [2], Aryal et al. [5], Jebelli et al. [20]) and the contribution of our study to fatigue

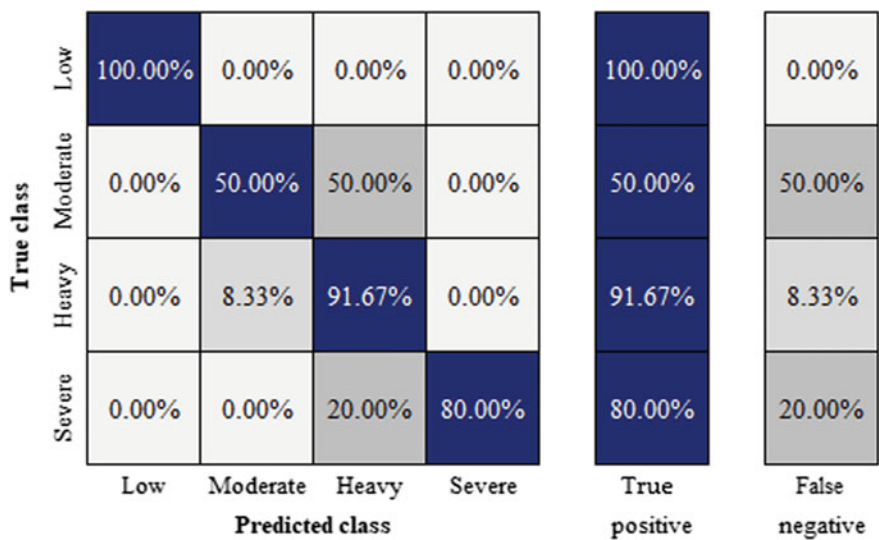


Fig. 2 Confusion matrix using the XGBoosted classifier to predict four levels of physical fatigue in the five soldiers sample

quantification approaches. Even though these physical fatigue models are increasingly available in the recent literature, they mostly evaluate workers during tasks (e.g., simulated construction; Jebelli et al. [20]) that may not characterise the physical demands of firefighting, military or any physically demanding occupation. In their daily duties, these professionals develop changing activities in which they may be sedentary (equivalent to low physical fatigue), take part in training and simulated operations (moderate to heavy levels) or face situations of danger and extreme physiological stress (heavy to severe physical fatigue levels) [15]. Also, these tasks can last prolonged and unpredictable durations, sometimes without the ability to stop [11, 31]. Therefore, data from incremental protocols can help the algorithm retrieve examples of the gradual increment in individuals physiological responses from an unfatigued state until maximal exertion (as available in other research areas like exercise and health; Cardoso et al. [12], Sousa et al. [32]).

The current study used a machine learning approach instead of the traditional decision-based programming addressed in our first study [9] since it does not need the previous identification of the associations among variables and their patterns within each physical fatigue category. The advantage of using the XGBoosted classifier or any similar algorithm (e.g., Random Forests, Vector Machines or K-nearest Neighbours) lies in its ability to determine the adequate category by assessing complex and large datasets without a prior view of inherent structures [29]. Since the main success component of these algorithms is data availability, if the available dataset is too small or lacks examples of every category, our initial approach may be the most appropriate to be used.

In our first study, mean values per minute from the same physiological variables were categorised according to pre-established conditions based on the literature and normative guidelines [14, 19, 26]. In the current study, the algorithm received labelled examples and predicted the categories in new data points according to the previous inputs. Figure 3 presents the data comparison between the two referred approaches, being evident that both followed the same trends even if equivalent results were only reported in the third category. Considering the maximum accuracy reached in the low category (Fig. 2), we can infer that our current approach presented the best results in this level. In contrast, the 50% accuracy from the current study in the moderate intensity suggests that our first approach was more accurate and that we need a bigger sample to improve these predictions. The differences observed in the severe stage might be attributed to two factors: the high (yet not optimal) 80% accuracy reached in the current study and a conservative set of conditions established within the first approach. Thus, although the results are promising regarding the applicability of our model to other groups, future studies are needed to corroborate these findings and reduce the accuracy variability among physical fatigue levels.

Despite the satisfactory 85% overall accuracy resulting from the model implementation, some limitations should be pointed out. Firstly, although the gradual increment in physiological responses through each physical fatigue level was evaluated, our model was developed with data collected in controlled conditions and considering only one activity, i.e., running. Furthermore, the small sample referred for assessment did not permit drawing generalisable conclusions. Future studies

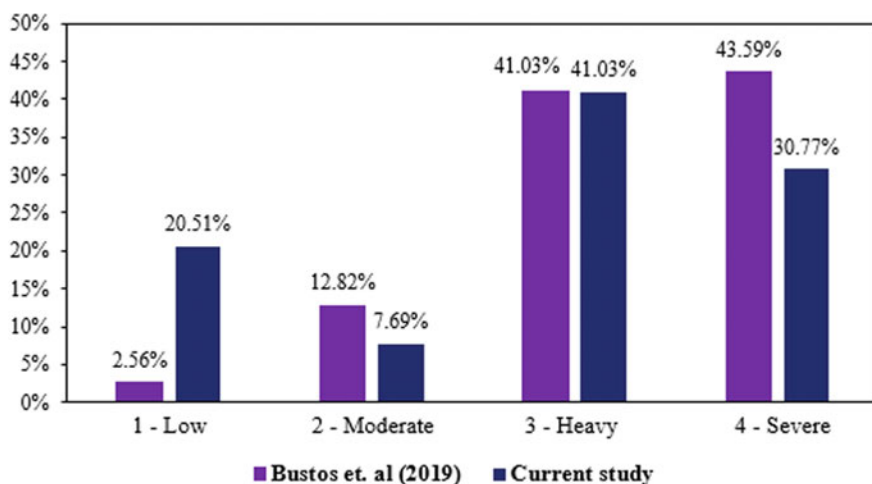


Fig. 3 Comparison between the results from [9] and the current study

should aim to test the model within more extensive samples and under real settings to assess its performance and data quality under those situations. Also, the feasibility of including other variables and/or sensors with observed good performance for occupational settings according to the literature [18] will be evaluated.

4 Conclusions

The applicability of a four-level physical fatigue machine learning classifier based on physiological assessment and its comparability to a traditional programming-based method are reported. Based on the results, we demonstrated the capability of using an integrated modelling method for monitoring physical fatigue for different groups. Our previously developed model evidenced an 85% overall accuracy when tested with data from new individuals, showing its potential for prediction within other samples and contexts. Even though our sample was small, the findings are promising and confirm the model's contribution to current fatigue quantification approaches. Future studies will be oriented to test its validity within a bigger sample and more occupational activities.

Acknowledgements This study was supported by the Foundation of Science and Technology (FCT Portugal) through the PhD studentship SFRH/BD/143608/2019 and the project grant PCIF/SSO/0063/2018. The authors would also like to acknowledge the support of the Doctoral Program in Occupational Health and Safety of the University of Porto.

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Cardiopulmonary, Metabolic and Perceived Exertion Characteristics Among Portuguese Firefighters



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Abstract Background: Firefighting is a strenuous occupation that requires firefighters to be in excellent physical condition. However, some of these professionals are not sufficiently physically fit for duty, negatively impacting their performance. **Objective:** To cardiopulmonary characterize Portuguese firefighters at different exercise intensities to clarify if their physical fitness profile is adequate to overcome their occupational activities demands. **Methodology:** Twenty-four healthy Portuguese firefighters performed an intermittent running protocol (with $1 \text{ km}\cdot\text{h}^{-1}$ increments

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and 30 s intervals) on a treadmill. Cardiorespiratory variables and core temperature were measured continuously during the exercise, while blood lactate and rating of perceived exertion were assessed during the rest periods between steps. **Results:** The increase in velocity along the running protocol resulted in higher values of oxygen uptake (41.5 ± 8.5 mL/min/kg), blood lactate (13.5 ± 4.6 mmol/L) and rating of perceived exertion (19 ± 1). However, there was stabilization of the respiratory quotient and heart rate from heavy to severe intensities. **Discussion/Conclusions:** Portuguese firefighters have a minimum level of cardiopulmonary fitness to perform their professional duties. However, given the high demands on the cardiopulmonary function of firefighting, it is essential that firefighters participate in regular training programs to maintain and develop cardiopulmonary physical fitness.

Keywords Oxygen uptake · Heart rate · Physical fitness · Health and occupational

1 Introduction

Firefighters are exposed to various environmental stressors such as smoke, chemical exposure, heat and intense physical exertion [3, 20, 36]. In addition, and due to the extreme environmental conditions, firefighters are required to wear heavy insulated personal protective equipment that often includes self-contained breathing apparatus, placing severe stress on the workers cardiopulmonary system [25, 34]. Firefighting involves strenuous physical activity and even short duration operations have been shown to increase heart rate to near maximal levels, maximal oxygen uptake values between 50 and 97% and high blood lactate concentrations and perceived exertion values [14, 23]. This activity can trigger sudden cardiac events in individuals with underlying heart disease and the risk of death during or shortly after firefighting operations is 10–100 times higher [9, 19]. Therefore, maintaining good levels of physical fitness is an essential prevention tool not only for the workers cardiovascular system but also for maintaining satisfactory occupational performance [30].

Fitness standards for firefighters have been recommended, but due to the intermittent nature of firefighting, they are not mandatory [20]. It is strongly suggested that their maximal oxygen uptake should not be lower than 40–45 mL/kg/min since some routine firefighting tasks require 30–41.5 mL/kg/min [8, 20]. However, measuring oxygen uptake in active duty firefighters is difficult and costly due to the testing physical demands and the high probability of equipment loss or damage [34]. An alternative for assessing this variable and to characterize cardiopulmonary fitness in a more controlled environment is to perform an incremental treadmill running protocol [4, 33]. This step protocol is also better to measure the blood lactate concentration kinetics, allowing to determine the individual anaerobic threshold [6] and the different exercise intensity domains [4, 26].

Despite the firefighting intense physical demands, not all firefighters have the proper physical condition to perform at peak levels [34]. Since firefighting is an aerobically demanding activity that sometimes requires firefighters to work at maximum

capacity, it is fundamental to evaluate the physical fitness of these individuals [19]. The aim of the current study was to characterize the cardiopulmonary, metabolic and perceived exertion related variables of Portuguese firefighters. It was hypothesized that firefighters would achieve an average maximal oxygen uptake greater than 40 mL/kg/min and an anaerobic threshold closer to 30 mL/kg/min of oxygen uptake to adequately meet the aerobic demands of the work.

2 Materials and Methods

2.1 Participants

A sample of 24 healthy firefighters (18 men) from a local fire brigade (from the Oleiros district of Portugal) participated in the current study. Their main age and anthropometric characteristics are presented in Table 1. They were active volunteer firefighters with no history of cardiopulmonary or intestinal diseases and an absence of musculoskeletal disorders. All experiments were conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the University of Porto (Report 106/CEUP/2021). An informed written consent form with an explanation of the risks and benefits of participating was provided, read and signed by all subjects involved in the trials.

2.2 Experimental Approach

The firefighters, using light clothing with thermal insulation of ~ 0.3 clo [3], performed an incremental intermittent running protocol of seven stages of 4 min (with 1 km/h increments and 30 s rest periods in between, as described previously at [26, 39]). As displayed in Fig. 1, participants performed on a T2100 treadmill (GE, Boston, MA, USA) inside a 3.20 m $\times$ 3.20 m climatic chamber (FITOCLIMA 25000 EC20; Aralab, Rio de Mouro, Portugal) allowing controlling the air temperature to an accuracy of ± 0.2 °C and air relative humidity of $\pm 5\%$ [17]. For the current study, it was selected values corresponding to thermoneutral conditions, i.e., 24 °C and 50%

Table 1 General characteristics of the firefighters

Variables	Men (n = 18)	Women (n = 6)	All (n = 24)
Age (years)	33.67 $\pm$ 10.18	31.33 $\pm$ 8.85	33.08 $\pm$ 9.73
Weight (kg)	76.85 $\pm$ 10.48	73.37 $\pm$ 12.30	75.98 $\pm$ 10.79
Height (cm)	175.54 $\pm$ 3.58	165.78 $\pm$ 13.18	173.10 $\pm$ 8.12
Fat mass (%)	18.74 $\pm$ 6.27	34.51 $\pm$ 12.37	22.69 $\pm$ 10.85

scale [5, 26]. Intraabdominal core temperature was continuously retrieved from low-frequency radio waves transmitted from the gastrointestinal capsules to an external logger (e-Viewer Performance monitor, BodyCAP, France) at 15 s intervals [2].

2.4 Data Analysis

Collected ventilatory data were processed to exclude erroneous breaths due to coughing or signal interruptions. For the analysis, only data between the mean $\pm$ 3 SD were considered, which were subsequently smoothed with a moving and time average of three breaths and 10 s, respectively [12, 28]. The mean values of the last 30 s of exercise were used for comparison between experimental conditions, using conventional physiological criteria to define maximal oxygen uptake (e.g. occurrence of a plateau $<2.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and blood lactate at the end of exercise $\geq 8 \text{ mmol}\cdot\text{l}^{-1}$ [21, 26]. The blood lactate versus velocity curve modelling method, through the determination of interception point of the best fit of a combined linear and exponential pair of regressions (Fig. 2), was used to determine each firefighter's anaerobic threshold [3, 6, 13]. Exercise intensity domains (see Fig. 2) were then established using the maximal oxygen uptake and the anaerobic threshold as physiological indicators: the low, moderate and heavy (the stages under, at and above the anaerobic threshold, respectively) and severe (the stage where maximal oxygen uptake was observed) [7, 12].

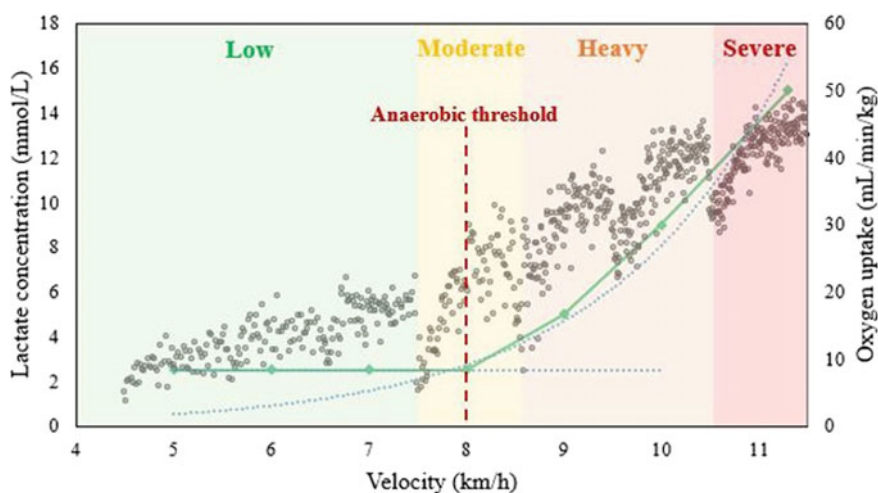


Fig. 2 Example of the oxygen uptake and blood lactate responses during the incremental running protocol allowing the identification of the low, moderate, heavy and severe exercise intensity domains

2.5 Statistical Procedures

A sample size of 19 participants was required (our 24 participants sample deemed adequate) for a paired sample design (one-tailed test) to detect a moderate effect with a 5% significance level and 80% power using G*power statistical software. The normality of distribution was checked using the Shapiro–Wilk test for all the assessed variables and mean values $\pm$ SD were calculated for every exercise intensity domain. One-way repeated measures ANOVA was used to determine the incremental behavior of the physiological variables across the intensity domains using partial eta-squared (η^2) for effect size calculation (0.05–0.25 small, 0.25–0.64 moderate and ≥ 0.64 strong; [11]) and pairwise multiple post hoc comparisons were conducted with Bonferroni correction. Statistical significance level was set at $p < 0.05$.

3 Results

The mean respiratory, metabolic, thermoregulation and perceived effort responses at the different running intensity domains are shown in Table 2. The velocity increase along the intensity spectrum implied a raise in all the assessed variables ($\eta^2 = 0.13$ – 0.82 , $p < 0.001$). However, it was observed a stabilization of the respiratory quotient, heart rate and tidal volume values from heavy to severe exertions, and of the core temperature after moderate intensity domains.

4 Discussion

The overall aim of the current work was to characterize Portuguese firefighters regarding their cardiorespiratory response to exercise at different intensities and to understand whether their physical fitness is sufficient to cope with the demands of their specific occupational activities. The main hypothesis that the firefighters would achieve an average maximal oxygen uptake of, at least, 40 mL/kg/min to meet the aerobic demands of the job was confirmed, although it should be noted that the tests were performed without the weight and other constraints of their personal protective equipment.

Although of similar ages, the male firefighters of the current study were smaller and lighter than trained firefighters registered competitors at the World Championship Scott Firefighter Combat Challenge [35], but presented higher body fat values (18.75 vs. 15.94%, respectively). This comparison shows that even being lighter, our evaluated firefighters presented lower muscular mass (based on the differences of body fat percentage), evidencing that their fitness level was lower. The Portuguese

Table 2 Incremental running protocol assessed variables (mean ± SD) at each intensity domain

Variables	Low	Moderate	Heavy	Severe
Running velocity (km/h)	5.5 ± 1.2 ^{a,b,c}	7.1 ± 1.7 ^{b,c}	9.7 ± 2.0 ^c	10.7 ± 2.0
Oxygen uptake (mL/min/kg)	19.0 ± 5.7 ^{a,b,c}	26.2 ± 8.2 ^{b,c}	37.4 ± 8.7 ^c	41.5 ± 8.5
Oxygen uptake (mL/min)	1440.8 ± 467.9 ^{a,b,c}	1987.6 ± 680.6 ^{b,c}	2827.5 ± 686.9 ^c	3138.8 ± 678.4
Respiratory frequency (l/min)	26 ± 6 ^{a,b,c}	31 ± 8 ^{b,c}	45 ± 7 ^c	52 ± 8
Tidal volume (L)	1.32 ± 0.45 ^{a,b,c}	1.55 ± 0.4 ^{b,c}	1.96 ± 0.43	2.04 ± 0.38
Ventilation (L/min)	34 ± 11 ^{a,b,c}	49 ± 17 ^{b,c}	87 ± 19 ^c	105 ± 19
Carbon dioxide production (mL/min)	1307.1 ± 445.1 ^{a,b,c}	1887.6 ± 641.1 ^{b,c}	2943.7 ± 620.9 ^c	3324.7 ± 660.7
Respiratory quotient	0.92 ± 0.14 ^{a,b,c}	0.97 ± 0.16 ^{b,c}	1.06 ± 0.18	1.07 ± 0.20
Heart rate (bpm)	115 ± 15 ^{a,b,c}	141 ± 19 ^{b,c}	176 ± 13	181 ± 20
Blood lactate (mmol/L)	2.2 ± 0.9 ^{a,b,c}	3.1 ± 1.1 ^{b,c}	9.6 ± 3.6 ^c	13.5 ± 4.6
Rate of perceived exertion (6–20)	10 ± 2 ^{a,b,c}	13 ± 2 ^{b,c}	17 ± 1 ^c	19 ± 1
Core temperature (°C)	37.37 ± 0.37 ^{a,b,c}	37.58 ± 0.43	37.95 ± 0.42	38.11 ± 0.44

^{a,b} and ^c differences from moderate, heavy and severe intensity domains, respectively (p < 0.05)

women firefighters presented similar height and weight than American women firefighters [22], but their body fat percentage values were in average $> 34\%$, indicating a cardiovascular disease risk factor and obesity criteria [24].

The running incremental test allowed us to determine the Portuguese firefighters response to a large spectrum of intensity domains and to understand how they respond to progressive increases in exercise demands. The testing velocities performed during the step protocol are much lower compared to recreational runners, with all the firefighters studied beginning the protocol by walking in the first steps [1, 41]. These low velocities during testing may be related to the need to wear heavy and insulated personal protective equipment, which often includes self-contained breathing apparatus that, weighing 25–28 kg, places a tremendous burden on the cardiovascular system [8, 15]. So, for firefighters to be able to simulate the use of these clothes and materials in working low-oxygen conditions, they walked or throttled rather than run in the less exigent intensity domains. Respiratory quotient, heart rate, blood lactate concentration and rate of perceived exertion behavior confirmed the correct performance of the incremental test and the intensity domains assessment [5, 26].

Oxygen uptake and blood lactate concentrations are one of the most frequently used physiological indicators to describe metabolic contributions during exercise [6, 29, 39]. The maximal oxygen uptake values of Portuguese firefighters meet the minimum criteria for their activity requirements, i.e., 40–45 mL/kg/min [8, 20] and are similar to very low trained or sedentary individuals [27]. However, they were lower compared to firefighters of similar age from other studies (41.5 vs. 45.8 mL/kg/min), suggesting Portuguese firefighters lower fitness level [15, 42]. Studies of simulated firefighting tasks showed values ranging from 30 to 45 mL/kg/min of oxygen uptake as being the minimum aerobic capacity required to safely perform these kind of efforts [8]. Since the higher the maximum oxygen uptake of firefighters, the lower the relative intensity of their task, the studied Portuguese firefighters must use 100% of their aerobic capacity to meet the demands of the more arduous tasks. Complementarily, the anaerobic threshold, as the highest exercise intensity whose energy demands can be supported (almost) exclusively by the aerobic metabolism, is also a fundamental cardiovascular and metabolic indicator [5, 6]. The analyzed Portuguese firefighters reached this boundary at 63% of their maximum oxygen uptake (26.2 mL/kg/min) after which it was observed a progressive loss of body homeostasis. Since it represents the superior limit of the moderate intensity domain, the observed data showed that they perform all their specific tasks above this threshold, increasing the physiological pressure on their bodies and significantly rising their fatigue state.

The primary goal of firefighters is to work as efficiently and economically as they could, using as little air as possible for a given work intensity, because the response time to fires often depends on the capacity of the breathing air cylinders. It is likely that increased physical fitness may lead to better ventilation efficiency and, consequently, to longer autonomy [42]. In endurance athletes, the relative oxygen uptake values at the anaerobic threshold intensity can exceed 80% [5]. Exercising at this intensity (and above) increases the percentage of oxygen uptake sustained during long periods of work [18]. It was previously shown that oxygen uptake associated

with performing live fire rescue and suppression tasks under operational conditions ranges from 62 to 82% of the maximal oxygen uptake with heart rates being closer to maximal levels [42].

The core temperature of our firefighters increased from low to moderate intensities, in accordance with the values expected [16], but stabilized along the protocol until the severe intensity domain. This temperature plateau suggests that firefighters are well prepared to handle the stress of demanding activities, probably because they are at ease with the protective equipment they use during their work and, especially, in the course of the fire combats [15]. Moreover, firefighters are required to perform strenuous tasks (like emergency rescue, first aid and resuscitation, as well as emergency extrication from vehicles), many happening while working at irregular hours [10, 37]. The most demanding working time periods for firefighters are the fire seasons when they combine the above-mentioned activities with fire combat. In Portugal, the fire season extends from March to September [38], meaning that the firefighters physical capabilities probably are not similarly stimulated throughout the year. However, regular exposure to exercise is a necessity to maintain high levels of aerobic capacity for rescue personnel, such as firefighters [8].

Firefighters are required to wear protective gear to accomplish their tasks well, indicating that the fact that no additional weight were used along the current study physiological characterization may be a limitation. Accordingly, since the oxygen uptake determination varies when protective clothing and self-contained breathing apparatus are used/not used and between laboratory versus field tests [31, 32], might also somehow affected the current findings. Therefore, future studies should expand the intensity domains analysis by including the assessment of anaerobic threshold and maximal oxygen uptake in conjunction with protective clothing and respiratory equipment, as well as to test the different intensity conditions during field tasks. The inclusion of biomarkers to assess muscular damage will also be a nice upgrade in studying these workers.

5 Conclusion

From the physiological profile obtained in the current work, we can conclude that the studied Portuguese firefighters have a minimum level of cardiovascular fitness to perform their professional tasks. However, given the high standards fitness requirements of their profession, it is essential that these workers achieve and maintain sufficient levels of maximal oxygen uptake and anaerobic threshold (and the corresponding running velocities). Of fundamental importance is the development of a well-defined training strategy throughout the year(s), with systematic and specific exercises and, if possible, regular monitoring. We suggest that the firefighters overall physical fitness should be targeted to that of recreational or regional level athletes, who have a maximal oxygen uptake >55 mL/kg/min and an anaerobic threshold at 40 mL/kg/min of oxygen consumption (within the 70–75% range of their maximal oxygen uptake).

Acknowledgements This study was supported by the Foundation of Science and Technology (FCT Portugal) through the Ph.D. studentship SFRH/BD/143608/2019 and the project grant PCIF/SSO/0063/2018. The authors would also like to acknowledge the support of the Doctoral Program in Occupational Health and Safety of the University of Porto.

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Towards an Integrated Approach on Occupational Health to Tackle COVID19 Pandemic



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Abstract Background: Serological screening is crucial for the prevention of infection, ensuring the maintenance of the workers' health, thus promoting occupational health. It was reported that SARS-CoV-2 can survive in aerosols and on dry surfaces for several days to weeks. **Objectives:** We aimed to apply an integrated approach on Occupational Health to tackle COVID19 pandemic. **Materials and methods:** We performed a rapid immunoglobulin IgM-IgG immunoassay, ELISA and hematologic profile among workers (N = 740), in a Public Higher Education Institution from Portugal and an environmental assessment by two sampling methods (Air N = 49; Surfaces N = 101) and RT-PCR. **Results:** Regarding workers serologic surveillance, 1.89% of rapid test positivity was observed for SARS-CoV-2 IgM antibodies and a low prevalence of positivity for IgG (1.21%) in which only 33.3% were confirmed by ELISA. Hematologic surveillance data revealed the presence of 10.44% of abnormal hematological profiles, being anemia (3.78%) the most relevant. All the environmental samples analyzed were negative regarding SARS-CoV-2

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detection. **Discussion:** Low SARS-CoV-2 immunization and the negative environmental samples strongly indicate the effectiveness of the preventive measures. Nevertheless, COVID19 disease alters hematologic parameters. **Conclusion:** This study it was possible to implement an integrated approach on Occupational Health combining efforts with the Occupational Health Services.

Keywords Integrated approach · Occupational health · COVID19 pandemic · Seroprevalence · Environmental assessment

1 Introduction

A new Coronavirus (SARS-CoV-2) was reported at the end of 2019 and identified as the etiological agent of Coronavirus disease 2019 (COVID-2019) [1, 2]. The World Health Organization (WHO) has announced the COVID-19 pandemic on March 11, 2020 [3].

Although the positive impact of the vaccination in the pandemic, important research efforts are still ongoing, including investigations into the transmission routes of this virus. However, there are still numerous knowledge gaps concerning the understanding of what are the main drivers that foster the virus transmission, and what are the measures to control its dissemination in the population and workplaces [1, 2].

It is estimated that more than 50% of transmission of SARS-CoV-2 have originated from exposure to asymptomatic individuals [4]. These findings suggest that effective control of spread will require measures to reduce the risk of transmission on individuals that are not ill [4]. Carrying out serological screening tests is an important tool for the prevention of new cases of infection, ensuring the maintenance of the health of workers, thus promoting occupational health. Furthermore, during the evolution of a SARS-CoV-2 infection the hematopoietic system and hemostasis of individuals may suffer significant impact that can lead to several cardiovascular complications [5]. Although some studies showed that there was no significant alteration in red blood cell (RBC) and hemoglobin levels it is not yet fully known the impact of SARS-CoV-2 infection on these parameters [6]. Thus, monitoring of hematological parameters is essential to a better understanding of COVID-19 pathophysiology, to choose more appropriated treatment strategies and provide accessible methods for classifying and predicting the severity and disease outcomes of patients [7].

Hospital infections related to SARS-CoV-2 have been reported worldwide, and are probably linked to ineffective prevention and control measures [2, 8–10]. The drawbacks in having straightforward measures to avoid transmission in workplaces can be due to the fact that the transmission dynamics is multifactorial as proved by the previous observations of the relevant impact of contaminated air and surfaces in the transmission dynamics of diseases such as Severe Acute Respiratory Syndrome (SARS), Middle East Respiratory Syndrome (MERS), influenza, and others [2, 11, 12]. Additionally, it was reported that SARS-CoV-2 can survive in aerosols and on

dry surfaces for several days to weeks [13, 14] and several studies reported outbreaks associated with the air-conditioning systems [15].

Thus, all these virus features combined with the need to collect sufficient airborne viruses for detection by molecular techniques [16], can pose a real challenge for every industrial hygienist.

In the pursuit to obtain information a cross-sectional study design, applying an integrated approach on Occupational Health to tackle COVID19 pandemic, was performed aiming at estimating the point seroprevalence of SARS-CoV-2 antibodies using a rapid immunoglobulin IgM-IgG combined point-of-care lateral flow immunoassay and hematologic profile among workers from a Public Higher Education Institution from Portugal. The study also comprises environmental assessment of SARS-CoV-2 by Real Time PCR, achieved by two sampling methods, in the facilities of the same Academic Institution. This study was performed in a period prior to the introduction of SARS-CoV-2 vaccine in Portugal.

2 Materials and Methods

2.1 Workers Population Assessed

Among a total of 1050 workers, 740 volunteers were enrolled in the study (70% of the total expected). Workers of all units of the engaged Public Higher Education Institution from Portugal were invited to voluntarily participate in the surveillance project. The volunteers were scheduled for the screening tests during a 4-months period, from September to December 2020.

Before the enrolment in the screening tests, all volunteers filled a written informed consent and a questionnaire. This survey instrument consisted of a 37-item questionnaire assessing contact information, sociodemographic characteristics (age, sex, nationality, ethnicity, household size), habits and behaviours (diet, physical exercise and hours of sleep), health status (alcohol and smoking status, health conditions, continuous medication in prior 6 months, use of antibiotics or vitamins prior 3 months, status of the National Vaccine Program, namely the receipt of BCG, influenza or pneumococcal vaccine) and COVID-19 exposure characteristics (previous diagnostic, symptoms, and history of close contact with COVID-19 cases). The study was performed in a period before SARS-CoV-2 vaccine introduction in Europe.

The data obtained were subsequently entered into an anonymous questionnaire programmed in REDCap (Research Electronic Data Capture) to estimate the prevalence of individuals with SARS-CoV-2 antibodies and the hematologic alterations in the studied population.

This study complied with the Helsinki Declaration and Oviedo Convention and all data were stored and analyzed in accordance with the Portuguese General Data

Protection Regulation (GDPR) law nº 58/2019. The study protocol was approved by the ESTeSL-IPL ethics committee (CE-ESTeSL-Nº.45-2020).

2.2 *Serologic Surveillance*

For rapid serologic screening, capillary blood was collected through capillary puncture with a lancet in which a 20ul of blood was collected using a micropipette for the Immunochromatographic rapid test for the detection of IgM and IgG antibodies to SARS-CoV-2 virus in human whole blood, plasma or serum samples using VedaLab COVID-19-CHECK-1 kit (Ref.:200081-4-2-3L VEDALAB) with a calculated diagnostic sensitivity of 91.45% and specificity of 97%.

Serologic surveillance regarding IgG and IgM screening results were analyzed accordingly with the Kit manufacture guidelines. For positive IgM screening cases, nasopharynx swab was immediately performed for Real Time PCR diagnosis at CEDOC (NOVA Medical School). For positive IgG screening cases, venous blood was collected through venipuncture to a dry tube (serum) for IgG quantification by Enzyme-Linked Immunosorbent Assay (ELISA), specifically designed against the S1 domain of SARS-CoV-2 Spike protein. ELISA titers quantification was performed with the Anti-SARS-CoV-2 ELISA (IgG) EUROIMMUN kit (ref EI2606-9601 EUROIMMUN) in the equipment Optic Ivyman; System 2100C, with a calculated sensitivity of 94.4% after 10 days or more after symptom onset or positive direct detection and specificity of 99.6%. The default result units for this SARS-COV-2 IgG essay are the index calculated by the ratio of the sample optical density (OD) over the calibrator OD. According to the manufacturer's instructions, IgG results were deemed positive if the cut-off index (S/C) was ≥ 1.1 , while negative results were defined by a cut-off of <0.8 . Borderline values (index ≥ 0.8 to < 1.1) were considered inconclusive results.

2.3 *Hematologic Surveillance*

For hematologic screening, venous blood was collected through venipuncture to an EDTA tube (blood count) and the blood counts were processed in the Horiba 60 series automatic device and the hematological results analyzed. For each participant was determine complete blood count (RBC $\times 10^{12}/L$, Hgb g/dL, Hct %, VGM fL, HGM pg, CHGM g/dL, RDW %, Leukocytes (total), Neutrophils, Eosinophils, Basophils, Lymphocytes, and Monocytes and platelets).

For hematologic surveillance, the collected blood was analyzed and complete blood count was performed. The hematological analyzed parameters indicated the presence of normal and abnormal hematological profiles. Among abnormal profiles we have assessed profiles with Anemia, including Microcytic and Hypochromic

Anemia and Normocytic and Normochromic Anemia, Erythropenia, Erythrocytosis, Leukocytosis, Thrombocytopenia, and Inverted differential leukocyte count.

2.4 Environmental Assessment

Regarding the environmental sampling campaign, all the ten Academic institution facilities (8 faculties, the Social services and Presidency building) were assessed and environmental samples (air and surfaces samples) were performed from workstations that had an increased risk due to occupation rates, to consider the community transmission risk [17, 18], activities performed that can potentiate the virus transmission [13–15] or based on workers serologic surveillance results.

2.4.1 Sampling Collection

The facilities assessed were the ones presenting 50–80% of the workers present in their workplaces. Two sampling methods were applied combining active and passive methods. Regarding air samples ($N = 49$) 600 L were collected per sample into a conical vial containing 5 mL Buffer NVL (NZY Viral RNA Isolation kit (MB40701) component) by Coriolis μ air sampler (Bertin Technologies, Montigny-Le Bretonneux, France) [19]. The air inlet of the device was disinfected between samples with a 70% alcohol solution). Surface samples ($N = 101$) were collected by swabbing the areas of each local using flocked swabs moistened in sterilized water into a 15 mL falcon containing 1.5 mL Buffer NVL (NZY Viral RNA Isolation kit (MB40701) component). In some specific surfaces were performed composite samples (swabbing different surfaces with the same swab) since the type of use, surfaces material and cleaning procedures were common (Table 1). All collected samples were maintained refrigerated (0–4 °C) in sterilized bags during transportation and prior to analysis.

The sampling campaign was performed in workplaces defined as having higher risk of exposure by the Occupational Health Services. The other criteria applied, and since we were assessing one week after the workers serologic surveillance, was having workers in the workplaces with positive result for IgM+ or IgG+ (see Fig. 1).

2.4.2 RNA Extraction and Environmental SARS-CoV-2 Detection

RNA was extracted from the isolated sample (5 mL in air samples and 1.5 mL in surface samples) with the NZY Viral RNA Isolation kit, from Nzytech, according to manufacturer's instructions. One step-RT qPCR was performed using NZYSpeedy One-step RT-qPCR probe Master Mix with primers and probes published by CDC (available on <https://www.cdc.gov/coronavirus/2019-ncov/lab/rt-pcr-panel-primer-probes.html>), which detect two viral gene regions (N1 and N2) (Table 2). qPCR was performed on BioRad CFX Connect PCR machine. In each analysis a positive (a

Table 1 Faculties and areas assessed and number of environmental samples collected

Facilities	Assessed areas	Air sampling (600L)	Surfaces swabs
Presidency building (PB)	– Communication Office (Doorknob + Ventilation grids) – Drivers Reception (Counter) – Entrance (Coffee machine) – Lunchroom (Microwave + Coffee machine + Refrigerator + Ventilation grids) – Human Resources (Coffee machines + Access card + Staplers and stamps + Ventilation grids) – Financial Resources (Staplers and stamps + Ventilation grids in operation) – Human and Financial Resources (Windows + Doorknobs) – Reception (Printer + Table) – Shopping Department (1st floor) (Windows + Keys and card + – Ventilation grids in operation) – Male Bathroom (1st floor) (Doorknobs + Faucets) – Female Bathroom (1st floor) (Doorknobs + Faucets) – Printer (1st floor) – Academics, Quality and Planning Department (Mobile air conditioning equipment)	0	25
Social Services (SS)	– Lunchroom (Microwave + Refrigerator + Door) – Waiting Room / Classroom (Coffee Machine + Table) – Reception (Counter + Door + Water Machine) – Bathroom (Doors + Faucets) – Service Room (Table + Acrylic Protection) – Accounting (Printer + Doors)	6	10

(continued)

Table 1 (continued)

Facilities	Assessed areas	Air sampling (600L)	Surfaces swabs
Faculty 1	– Logistics (Door + Window) – Accounting / Provisioning (Printer + Door + Stapler) – Academic Services (Printer (SA) + Printer (corridor)) – Reception (Door + Handrail + Balcony) – Bar (Chairs + Door) – Library (Printer + Computer) – Lunchroom (1st floor) (Fridge + microwave) – Lunchroom (2nd floor) (Fridge + microwave) – Printer (1st floor) – Bathroom (1st floor) (Doorknobs + Door + Flush toilet) – Office (1.16) (Mouse + Keyboard + Light switch + Door + Doorknob) – Printer (2nd floor) – Bathroom (2nd floor) (Doorknobs + Door + Flush toilet)	8	8
Faculty 2	– Financial Services (Printers + Stapler) – Teachers Room 1 (Printers + Computers) – Teachers Room 2 (Printer + Computers + TV control) – Cafeteria / Bar (Counter + Tables) – Auditorium (Handrail + Light switch + Door) – Social Room (Door + Fridge + Microwave + Faucet + Coffee Machine) – Library (Printer + Computers) – Human Resources (Printer + Door + Acrylics + Counter + Light switch)	8	8

(continued)

Table 1 (continued)

Facilities	Assessed areas	Air sampling (600L)	Surfaces swabs
Faculty 3	– Library (Computer + Printer + Doorknob) – Lunchroom 1 (Faucet + Doorknob + Chair + Table + Microwave + Coffee machine + Faucet) – Lunchroom 2 (Microwave + Toaster + Kettle + Doorknob + Door + Table + Chair) – Bar 1 (Microwave + Refrigerator + Handles + Cash register + ATM) – Workshop (Machine + Doorknob + Door) – Bar 2 (Cash register + Control + Fridge + Microwave) – Organic Chemistry Lab (Scale + Faucets) – Organic Chemistry Lab – research (Equipment + Door + Doorknob) – Inorganic Chemistry Lab (Computer + Doorknobs + Equipment + Micropipettes + Refrigerator) – Canteen (Faucets + Counter + Acrylic + Cash Register) – Auditorium (Doorknobs + Door + Table + Chair + Eraser)	11	11
Faculty 4	– Library (PC + Windows + Tables) – Canteen (Chairs + Table + PC + Doorknob) – Bar (Counter + Napkin Holder + PC + Coffee Machine + Table) – Grand Auditorium (Doorknob + PC + Chairs) – Small Auditorium – Scenic Interpretation Studio (Door + Table + Doorknob + Chairs) – Computer Room (Switch + Mouse + PC + Keyboard + Door + Doorknob) – Workshop (Doorknob + Tables + Lockers + Equipment)	7	7
Faculty 5	– Bar/Cafeteria (Cash Register + Counters) – Science Laboratory (FQ) (Chairs + Scales + Faucets + Handle) – Social Room (Microwave + Faucet + Windows + Chairs) – Theatre and Choir Room (Switches + Windows + Chairs + Tables) – Changing room / dressing room (Doors + Doorknobs + Faucets) – Gym (Doors + Doorknobs + Table + Chair + Equipment) – Ceramic Workshop (Tables + Chairs + Faucets + Eraser + Doorknob + Door) – Dance Room (Doorknobs + Doors + Eraser) – Music Room (Switch + Handle + Window + Chairs + Piano)	9	9

(continued)

Table 1 (continued)

Facilities	Assessed areas	Air sampling (600L)	Surfaces swabs
Faculty 6	– Grand Auditorium (Chairs + Tables + Piano + Tripods) – Small Auditorium (Switch + Window + Doorknob + Chairs) – Library (Computers + Tables) – Academic Services (Printer + Doorknob + Cabinets) – Printer (corridor) – Academic Services – Customer Service (Acrylic + Pens + Coffee Machine + Tables) – Lunchroom (Microwave + Tables + Chairs + Refrigerator + Doorknobs + Switch) – Choir Room (Chairs + Tables + Piano + Eraser + Switch + Door + Doorknobs) – Music Room (Doorknobs + Switch)	0	9
Faculty 7	– Bar (Chairs + Tables + Cash Register + Acrylic + Counter + Calculator) – Study room (Food and coffee machines + Chairs + Tables) – Printer (corridor) – “Home Food” Space (Microwave + Water machine + Tables + Chairs) – Auditorium (Door + Doorknob + Chairs) – Academic Services (Tables + Switch + Chairs + Acrylic + Printer + Stapler + Hole Puncher + Door + Doorknob) – Library (Tables + Chairs + Acrylic) – Multimedia Warehouse (Printer + Computers + Keyboards + Mouse + Barcode reader + Microwave + TV + Chairs)	0	8
Faculty 8	– Academic Services (Printer + Doorknob + Acrylic + Table) – Dance Reception (Doorknob + Computer + Telephone + Keys) – Teachers room (Doorknob + Printer + Switch + Flush toilet + Table + Chairs) – Atrium Studio C –1 (Bar + Sound System) – Studio D1 (Bar + Sound System) – Studio A1 (Bar + Sound system)	0	6

SARS-CoV-2 positive sample) and a negative (water) sample was included. Moreover, in order to detect possible PCR inhibitors an internal control was added to each PCR (TATAA Universal RNA Spike I). Whenever a sample showed dubious results, including, for example, lack of amplification of both viral gene regions, they were considered inconclusive and the assay was repeated. All the results were analysed by two independent researchers.

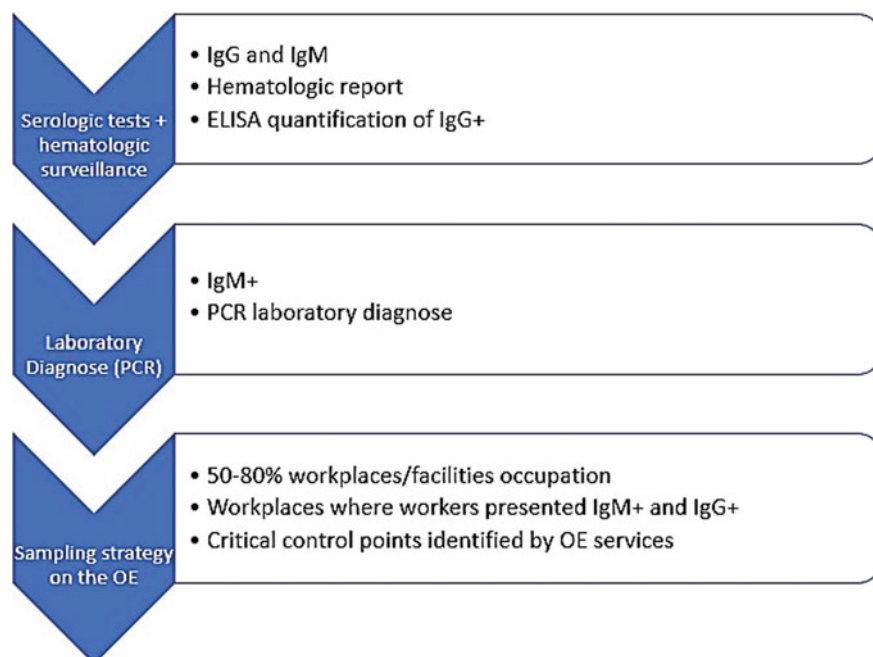


Fig. 1 Flowchart applied regarding the integrated approach on Occupational Health

Table 2 Novel coronavirus (2019-nCoV) real-time RT-PCR panel primers and probes

Name	Description	Oligonucleotide Sequence (5' > 3')	Label
2019-nCoV_N1-F	2019-nCoV_N1 Forward Primer	5'-GAC CCC AAA ATC AGC GAA AT-3'	–
2019-nCoV_N1-R	2019-nCoV_N1 Reverse Primer	5'-TCT GGT TAC TGC CAG TTG AAT CTG-3'	–
2019-nCoV_N1-P	2019-nCoV_N1 Probe	5'-FAM-ACC CCG CAT TAC GTT TGG TGG ACC-BHQ1-3'	FAM, BHQ-1
2019-nCoV_N2-F	2019-nCoV_N2 Forward Primer	5'-TTA CAA ACA TTG GCC GCA AA-3'	–
2019-nCoV_N2-R	2019-nCoV_N2 Reverse Primer	5'-GCG CGA CAT TCC GAA GAA-3'	–
2019-nCoV_N2-P	2019-nCoV_N2 Probe	5'-FAM-ACA ATT TGC CCC CAG CGC TTC AG-BHQ1-3'	FAM, BHQ-1
Spike In		TATAA Universal RNA Spike I	FAM

The SARS-CoV-2 viability was not assessed to ensure safety levels for the professionals engaged in the field and lab work.

3 Results

3.1 Serologic Surveillance

Regarding workers serologic surveillance, data demonstrated a 1.89% of rapid test positivity for SARS-CoV-2 IgM antibodies. For these volunteers, in particular, in order to outlaw a potential active SARS-CoV-2 infection with IgM antibodies immunologic response, nasopharynx and oropharynx swabs were collected and stented for molecular biology diagnose trough PCR (Table 3 and Fig. 2). All samples were negative for SARS-CoV-2 RT-PCR identification, which may indicate either a false positive due to cross reactions or due to a previous SARS-CoV-2 infection with associated IgM positive response but for which the virus is no longer detectable. On the other hand, was reported a low prevalence of rapid test positivity for SARS-CoV-2 IgG antibodies (1.21%) in which only 33.3% were confirmed by ELISA technique (Table 3). These results indicate the presence of false positive test probably due to cross reactions.

Data also demonstrated that Faculty 1 and Faculty 7 reported the higher IgM/IgG positive screening while Faculty 6 and Faculty 8 had no identified cases. Moreover, ELISA confirmed IgG antibodies were detected in workers from Presidency building, Faculty 1 and Faculty 7.

3.2 Hematologic Surveillance

Hematologic surveillance data revealed the presence of 10.44% of abnormal hematological profiles among the tested Higher Education Institution community (Table 4). The most prominent and concerning hematological alteration is anemia (3.78%) which was classified in Microcytic and Hypochromic anemia (2.35%) and Normocytic and Normochromic Anemia (2.35%). Relevant levels of Erythropenia (2.48%) and Thrombocytopenia (2.09%) were also reported as well as other alterations such

Table 3 Serologic screening prevalence of SARS-CoV-2 IgM, RT-PCR for IgM positive confirmation, and IgG and ELISA IgG confirmation

Parameter	IgM (RDT) N = 740	RT PCR N = 14	IgG (RDT) N = 740	ELISA (IgG) N = 9
Positive prevalence	1.89% N = 14	0.00%	1.21% N = 9	33.3% n = 3

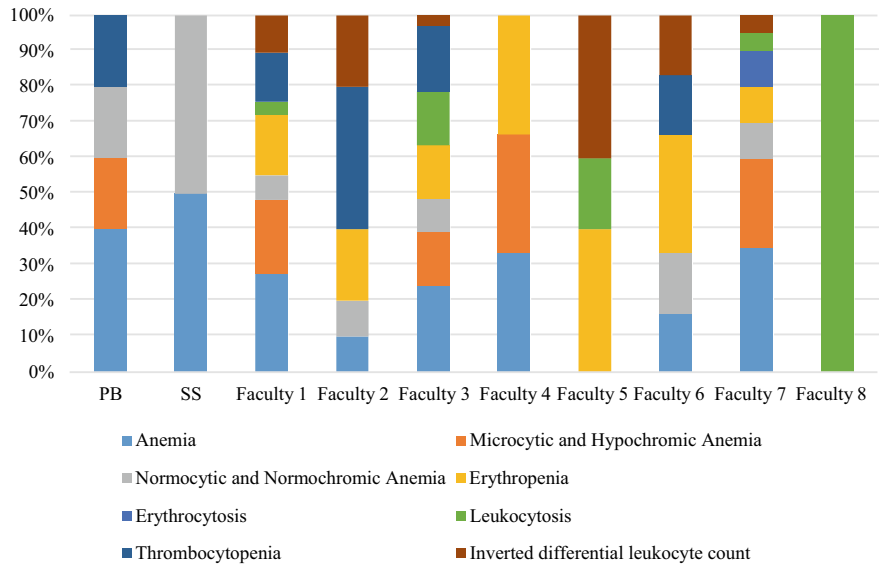


Fig. 2 Hematologic screening data regarding abnormal hematological profiles prevalence and hematological anomalies identification *per* facilities

as increased red blood cells and white blood cells numbers (Erythrocytosis 0.26% and Leukocytosis 1.17%, respectively) (Table 3). Moreover, inverted differential leukocyte count (1.31%) (Table 4) was also reported, revealing that lymphocyte values were higher than neutrophils.

Furthermore, for hematologic surveillance data analysis, potential divergences were also considered in all the facilities. Abnormal hematological profiles were reported in all the assessed facilities with divergent results between them. However, Faculty 7 data demonstrated the higher hematological abnormal profiles, followed

Table 4 Hematologic screening data regarding abnormal hematological profiles prevalence and hematological anomalies identification

Abnormal hematological profile	Prevalence (%) N = 80
Abnormal blood count	10.44
Anemia	3.78
Microcytic and Hypochromic anemia	2.35
Normocytic and Normochromic Anemia	1.44
Erythropenia	2.48
Erythrocytosis	0.26
Leukocytosis	1.17
Thrombocytopenia	2.09
Inverted differential leukocyte count	1.31

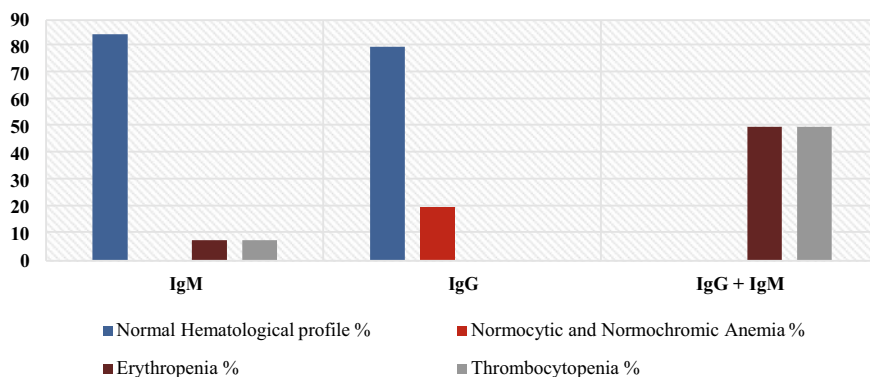


Fig. 3 Graphic representation of serologic and hematological anomalies correlation

by Faculty 1 and Faculty 3 (Fig. 2). Relevantly, these results were not correlated with higher numbers of volunteers since Faculty 7 had $n = 67$ and Faculty 1 $n = 141$ and Faculty 3 $n = 213$.

3.3 Serologic and Hematologic Surveillance Correlation

The performed correlation between serologic results with ELISA confirmation regarding IgG positivity and data from the applied questioners regarding individuals with previous diagnosed *SARS-CoV-2* infections and hematologic surveillance results clearly suggests that *SARS-CoV-2* infection has the ability to affect hematological profile, as all individuals with *SARS-CoV-2* IgG and IgM positive antibodies, which is indicative of recent infection, presented abnormal hematological profiles with decreased red blood cells (Erythropenia) and platelets (Thrombocytopenia) (Fig. 3).

3.4 Correlation Analyses Between Serologic and Hematologic Surveillance and Questionnaires Data

Table 5 shows the population characterization by age groups and prevalence (%) data of *SARS-CoV-2* IgM and IgG by gender. From the 14 and 9 positive samples of IgM and IgG, respectively, 2 of them were simultaneously positive (one male and one female). The highest prevalence of the studied population was between 40 and 60 years old, 72.4% and 69.6% female and male, respectively. From the total female ($n = 428$) in study only 8 and 5 was positive for IgM and IgG, respectively. The

Table 5 Population characterization by age groups and prevalence (%) data of SARS-CoV-2 IgM and IgG by gender

Age group	Female	Male		
	n = 428	%	n = 312	100
18–40	73	17.1	47	15.1
40–60	310	72.4	217	69.6
>60	45	10.5	48	15.4
IgM+	8	1.87	6	1.92
IgG+	5	1.17	4	1.28
Positive COVID-19	3	0.70	1	0.30

prevalence for male was very similar, with around 1.92% and 1.28 for IgM and IgG, respectively. For both genders the prevalence of COVID-19 was lower than 1.0.

The prevalence data from questionnaires sorted by gender. Considering the total assessed population (female n = 428 and male n = 312) more than 90% for both genders have a Mediterranean diet. Prevalence lower than 5%, for both genders, was associated with other diet options (vegetarian, macrobiotic and Fast-Food). Similar results were found for the relation between female and male and follow assessed items: physical activity (ratio male/female = 1.21); diseases (ratio male/female = 0.97); medications ingested in the last 6 months (ratio male/female = 0.67); antibiotics ingested in the last 6 months (ratio male/female = 0.73); vitamins ingested in the last 6 months (ratio male/female = 0.74).

Regarding the vaccines the obtained answers were quite different: 72.4% and 64.1% of females and males, respectively, took BCG vaccine; 9.3% and 15.4% of females and males, respectively, took influenza vaccine; and only 4.2% and 4.5% of females and males, respectively, took pneumococci vaccine.

3.5 Environmental Assessment from SARS-CoV-2

In all the environmental samples analyzed, comprising air and swabs samples, the results were negative regarding SARS-CoV-2 detection. In all PCR experiments positive control amplified and internal control also amplified and at the same CT value for all the samples and controls, indicating no PCR inhibition in the collected samples.

4 Discussion

To our knowledge this was the first study performed in academic environment and comprising serologic and hematologic surveillance coupled with environmental assessment.

This study allowed us to infer that the prevalence of SARS-CoV-2 immunity is very low within workers (about 1%). These results indicate, in the one hand, extremely low immunization levels of the analyzed workers, which suggest a low contact with SARS-CoV-2 virus, and, in the other hand, the effectiveness of the preventive measures endured by the individuals including to keep a safe distance from others, particularly in closed spaces, windows open indoor when possible, wear a mask, keep hands clean at all times, cover coughs and sneezes and not leave home when feeling unwell. Probably this is related with the fact that this specific population is more aware of the dangerous pandemic setting and has strictly followed the National Health Service recommendations thus contributing to a lower incidence of infections. On the other hand, it is relevant to consider the possibility of early infected individuals that tested negative with IgM (i.e. false negative cases due to low sensitivity) as one of the limitations of the serologic screening.

In contrast to amplification approaches, immunoassay methods such as lateral flow immunoassay (LFIA) and microplate enzyme-linked immunosorbent assay (ELISA) offer more straightforward testing and both techniques have been proven to be successful for rapid mass COVID-19 screening in routine clinical settings [20, 21]. However, the sensitivity and reliability of this method are limited by the visual colorimetric detection principle that underlies the evaluation of LFIA testing results. The primary disadvantage of ELISA, in contrast, is extended (several hour) testing.

SARS-CoV-2 infection also affects the hematopoietic system and thus, hemostasis may suffer significant impact leading to several cardiovascular complications [5]. Although previous data has suggested no clear correlation regarding RBC and hemoglobin alterations with SARS-CoV-2 infection, in fact, the true impact in these parameters is not yet fully understood [22]. It is well known that other virus such as influenza can agglutinate erythrocytes [23] and cause hematologic alterations such as higher RDW levels and lower RBC, hemoglobin and hematocrit levels [24]. Moreover, an association between elevated RDW levels and mortality has in fact been reported [25] and frequently identified the thrombocytopenia as an important alteration on SARS-CoV-2 infections [7]. Although some studies showed that there was no significant alteration in RBC and hemoglobin levels it is not yet fully known the impact of SARS-CoV-2 infection on these parameters [22]. Regarding the hematologic study performed, two important concerns were raised. First, it is evident that COVID19 disease alters the hematologic parameters (we have a very small sample for positives that should be confirmed). Second the prevalence of abnormal hematological profiles is high, raising public health concerns that should be evaluated and followed in the future. Furthermore, regarding the reported data of inverted differential leukocyte count, this variation may occur naturally in many people; however,

it is advisable to understand if this variation is physiological, or if there is any factor that may condition this inversion, thus we have recommended blood count repetition in a reference laboratory.

Correlation analyses between serologic and hematologic surveillance and questionnaires data demonstrated no relation between IgM and IgG positivity as well as hematological alterations and genders. Additionally, the large majority of the analyzed individuals have a Mediterranean diet and both genders had similar indications regarding physical activity, diseases, medications, antibiotics and vitamins ingested in the last 6 months and vaccination.

Moreover, environmental samples collected from faculties' facilities were all negative for SARS-CoV-2, as shown by the molecular detection by RT-qPCR, demonstrating once again that the cleaning activities seem to be in accordance with the Portuguese Health Directorate recommendations. Among industrial hygienist's community discussion has been raised and still ongoing about the sampling and analyses methods for SARS-CoV-2 exposure assessment. This is mainly due the fact that studies regarding virus exposure assessment have been very restricted in numbers, due to the reported difficulties in collecting and analysing airborne viruses. Amongst the active sampling methods, several sampling equipment's can be applied in the assessment virus, being the most commonly used the impingers such as the one applied in this study [16, 19, 22, 26–33]. Besides air sampling, also passive methods, such as surface swabs were applied, and their use has been widely employed [6, 19, 22, 34–37]. Indeed, surface swabs have been frequently used in health care facilities [38] or in other indoor environments [39], coupled with air sampling, to assess bioburden exposure (comprising fungi and bacteria). The air sampling volume and airflow rate followed the procedures from a study performed in a health care facility with positive detection [19]. However, a more recent technical suggestion was the use of an airflow rate of 200 L/min and the minimal of 1 m³ of air during each sample collection when using Coriolis μ (impinger method device) for SARS-CoV-2 assessment [40]. Indeed, the lower sampling volume can be a limitation to our study. Nevertheless, all the surface swabs were also negative corroborating the efficacy of the implemented preventive measures.

Impinger methods using liquid medium can ensure the viral integrity and viability [41]. However, in our study the liquid used promoted the inactivation of the SARS-CoV-2 due to safety reasons consider both in the field work and in be lab work. This can be also to be proposed since most of the industrial hygiene laboratories don't have the needed safety conditions to deal with a pandemic virus, such as SARS-CoV-2. Furthermore, safety measures to be recommended should be implemented when positive detection is achieved, regardless of the viability status of the virus.

Concerning assays used to detect SARS-CoV-2, the high sensitivity of the RT-qPCR method, widely used to accurately detect the virus load in nasal swab samples, would enable detection of viral particles in case they were present. The fact that none of the samples were positive strongly indicates that the cleaning procedures have been effective.

5 Conclusions

Overall, this study corroborated the efficacy of the preventive measures implemented in the assessed academic environment, since low contact with SARS-CoV-2 virus was verified among workers and environmental samples collected from faculties' facilities were all negative. It was possible to implement an integrated approach on Occupational Health combining efforts from the Occupational Health Services, by informing the workplaces with higher risk, and the results of the serological surveillance to prioritize the workplaces to be assessed.

Acknowledgements H&TRC authors gratefully acknowledge the FCT/MCTES national support through the UIDB/05608/2020 and UIDP/05608/2020. Authors acknowledge financial support by Instituto Politécnico de Lisboa, "IPL Momento Zero: Assegurar a retoma letiva em pandemia COVID19". Scientific support and guidance was given by CEDOC, NOVA Medical School, NMS, Universidade Nova de Lisboa, as well as Instituto de Medicina Molecular João Lobo Antunes, Faculdade de Medicina, Universidade de Lisboa.

Conflicts of Interest The authors declare no conflict of interest.

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Occupational Health and Safety Development Needs in the Home Care Sector in Finland



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Abstract Due to demographic developments and the need for cost-effective solutions to provide social and health care services, home care has increased. At the same time, there is a shortage of personnel, partly due to unfavorable working conditions. In this study, occupational health and safety (OHS) development needs are identified by home care personnel. Material was gathered through a survey ($n = 160$), semi-structured interviews ($n = 55$), and workshops ($n = 9$) from spring to autumn 2022. The most commonly mentioned OHS development needs were assistive equipment and work tools, how the employee calls for and receives help in emergency situations, information about customer, education, filming employees, the home as a working environment, making sure that employees leave their customer visits safely, the organization of work, safety orientation, guidance and instructions, physical ergonomics, psychosocial, mental and ethical loads, and threats of physical and psychosocial violence. The results indicate that there has not been much improvement in home care working conditions, which is a major concern for the future when considering the growing need for home care services. Further research is needed to focus on the abovementioned themes and to develop effective intervention programs to make working conditions more desirable.

Keywords Customer · Health care · Personnel · Risk · Social care

1 Introduction

Because of demographic developments in Europe and the need for cost-effective social and health care facilities outside hospitals and nursing homes, services are increasingly brought to care recipients' homes [4, 21]. Care recipients' homes are

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challenging as workplaces because they are not designed for work. Home care workers must work in varying conditions, and they face many safety hazards and risks. Home care services include a wide variety of tasks, such as basic medical attention, personal care, cleaning, and cooking [18, 20]. The employer's ability to influence working conditions and work in homes is limited.

Home health care workers face many challenges at work that can threaten their safety and well-being. They may be challenged with heavy physical exertion, psychosocial stress factors, accident risks, and verbal and physical violence, such as home care recipients' inappropriate use of language, attacks with objects, and sexual harassment [3]. Furthermore, they encounter forceful exertions and awkward postures [8, 14]. They also struggle with time pressure, which can be due to cost-effectiveness, declining resources, and organizational changes in recent years [17, 21].

Home care staff face many personal safety risks. The risk factors are related to unsafe conditions that direct care staff must work in; organizational and administrative issues that impede or promote the personal safety of staff; ethical issues staff face daily; protective factors associated with maintaining safety; issues of gender, race, age and experience; and education and training [5]. Home care workers work mostly alone. They have no timely backup, and help may not be available [12]. Information about patients' health conditions is often lacking. Employees feel that the detailed documentation is problematic [9, 12]. During the Covid-19 pandemic, the main concerns of home care aids were putting themselves at risk in clients' home, accessing personal protective equipment, and transportation challenges. The pandemic had also a strong impact on increasing caseloads, and it made new challenges for everyday tasks [1]. The occupational stressors of home care nurses, which have a negative influence on their job satisfaction, include the documentation process, the work environment, unsafe encounters with pets, family members, unsanitary homes, and trying to reach patients' physicians [9].

Healthcare workers are exposed to many biological, chemical, physical, ergonomic, and psychosocial risks at work. The combination of these diverse risks makes healthcare very risky for workers. In addition to the known risk factors, the health and social care sector must deal with a number of new changes and trends in Europe, such as demographic and epidemic trends affecting current treatment models and social, technological, and cultural trends, which have led to many new occupational safety challenges that must be addressed [2].

This study aims to contribute to previous discussions by consulting home care personnel to identify key occupational health and safety (OHS) development needs.

2 Materials and Methods

Material was gathered from both the municipal sector (eight teams in three municipalities) and the private sector (two companies and one non-profit organization) in Finland. In Phase 1 (spring–summer 2022), a survey ($n = 160$) and semi-structured

Table 1 Background information from the survey

Background	<i>n</i> (~%)
<i>Organization</i>	
Municipality A	26 (16%)
Municipality B	10 (6%)
Municipality C	41 (26%)
Private company D	9 (6%)
Private company E	67 (42%)
Non-profit organization F	7 (4%)
<i>Employment relationship</i>	
Permanent	118 (74%)
Other	42 (26%)
<i>Gender</i>	
Female	136 (85%)
Male	23 (14%)
Other	1 (1%)
<i>Age</i>	
20–30 years	17 (11%)
31–40 years	28 (18%)
41–50 years	24 (15%)
51–60 years	43 (27%)
61 years and over	48 (30%)

interviews ($n = 55$) were conducted. Ninety-eight participants were interviewed. In Phase 2 (autumn 2022), workshops ($n = 9$) were held. The workshops had 36 participants in total. The respondents to the survey and participants in the interviews and workshops included both supervisors and employees. The material was analyzed using thematic categorization [6]. In the survey and interviews, the focus in this study was on what the participants and respondents wanted to be addressed. The background information from the survey is presented in Table 1, and the interview data are described in Table 2. This study adheres the ethical principles issued by the Finnish National Board on Research Integrity. The participants include only employees, and the clients and their information are not under consideration. The participants in each data collection phase were told what data is gathered, how it is used and how their background information is used. They had the right to refuse to participate. This study did not involve intervening in the physical integrity of research participants, the principle of informed consent did apply, the research subjects were not minors, did not expose research participants to exceptionally strong stimuli, did not cause long-term mental distress that goes beyond the risks usually encountered in daily life, nor did it entail a security risk to the participants or their family members. Hence, an ethical review from the Ethics Committee of the Tampere Region was not required [19].

Table 2 Interview data

Organization's sector	Municipal (organizations A, B, and C), private companies (organizations D and E), non-profit organization (organization F)
Interviews per organization	Organization A (n = 9), organization B (n = 5), organization C (n = 17), organization D (n = 10), organization E (n = 7), organization F (n = 7)
Interviewees per organization	Organization A (n = 23), organization B (n = 10), organization C (n = 40), organization D (n = 10), organization E (n = 8), organization F (n = 7)
Interview medium	Teams, face-to-face, phone
Interview type	Individual interviews (n = 34), group interviews (n = 21)
Duration of the interviews	Average: 45 min (± 16)

In the workshops, the results of Phase 1 were presented to the participants. The participants chose between one and three themes as most relevant to their safety. Afterwards, the participants were divided into two groups if possible, and the groups started to work on the themes. The groups began with one of the chosen themes and discussed which problems were related to it and how the problems should be solved. In this study, the focus was on identifying the themes the participants deemed most important to their safety and what they saw as the most important development needs.

3 Results

The main OHS development needs arising from the survey, interviews, and workshops are combined in Table 3. In response to the survey question “What are the most important development needs in safety when working in a client's home (e.g., three most important)?” the most commonly mentioned development needs were assistive equipment and work tools, safety orientation, guidance and instructions, aid with physical burdens, information about customer, and the home as a working environment. In addition, themes such as the organization of work, predictability of work, training, and information flow were mentioned.

When asked about ideas to “improve safety when working in clients' homes related to, for example, instructions, training, communication, working practices, or risk assessment,” not all comments were ideas but rather matters that need to be developed. The respondents wished for more safety orientation, guidance, and instructions for themselves and instructions for the customers. Likewise, they hoped to receive more training, hold more frequent team meetings, have more pair work, and receive more support overall. Other themes mentioned included information about customers, assistive equipment and work tools, communication, and the home as a working environment.

The interviewees discussed a wide variety of themes in addition to the above-mentioned ones. The themes included how the employee calls for and receives help

Table 3 Main OHS development needs

OHS development need	Matters discussed
Assistive equipment and work tools	The lack of proper equipment and tools and of knowledge of how to use them; customers do not accept equipment or the use of tools
How the employee calls for and receives help in emergency situations	What is the most efficient way to call for help; alarm button does not locate employees accurately enough; distances are long in remote areas
Information about customer	Lack of information; problems in communication and in information flow between cooperating parties; not all necessary information from customer visits is written down
Education	Education needed about physical ergonomics and how to deal with mental health and substance abuse; no time to participate in the training
Filming employees	What is allowed; how to act
The home as a working environment	Accessibility; clutter/number of belongings; cleanliness; lighting; fire safety; smoking; guns; pets; drug injection needles; heat
Making sure that employees leave their customer visits safely	No systematic monitoring
Organization of work	Time is short; commuting during the workday from customer to customer; shift planning; lack of breaks; no time for customer-related office work; unclear job description (what is included in work tasks and what is not)
Physical ergonomics	Lifting and moving the customer; lack of knowledge; pair work; lack of assistive equipment and work tools; showering the customers
Psychosocial, mental, and ethical loads	Customer's self-determination; work is rushed; number of customers; behavior of the customers and their relatives; time and opportunities for peer support; lack of a work community; wondering if the customer is going to be okay at home; work interruptions and constant changes

(continued)

Table 3 (continued)

OHS development need	Matters discussed
Safety orientation, guidance, and instructions	Needed about physical ergonomics, how to use assistive equipment, how to plan the workday, clear instructions for different situations, and instructions for assessing the occupational safety in the first customer visit; more orientation and guidance about safety issues overall; guidance should be repeated from time to time
Threats of physical and psychosocial violence	Inappropriate behavior of customers and their relatives; sexual harassment; outsiders in the apartment

in emergency situations; psychosocial, mental, cognitive, and ethical loads; physical and psychosocial violence and threats of violence; physical ergonomics; delivering customers' medicine; risk assessments; cooperation with other parties; work clothes and shoes; driving customers around in the employees' own cars; use of security guards; accident reports and near-miss events and reporting them; chemical safety; commuting during the workday from customer to customer; making sure that employees leave their customer visits safely; and employees being filmed.

In the four first workshops, information about customer was chosen as the most relevant theme for care workers' safety. For the other five workshops, researchers decided to remove it from the list so that other themes would also be chosen and worked on. Thus, other themes highlighted were safety orientation; how the employee calls for and receives help in emergency situations; psychosocial, mental, and ethical loads; organization of work; physical ergonomics; the home as a work environment; working alone; getting safely away from customer visits; receiving instructions; cooperation with different parties; peer support; and the information flow.

4 Discussion and Conclusions

In recent decades, there has been a shortage of health care professionals in most European countries, including the Nordic countries [15, 16]. In home care services, the shortage of personnel is expected to grow. One reason for this is unfavorable working conditions. The protection of home care employees based on occupational safety legislation is lacking compared to the protection for those employed in institutions [2].

In this study, insight into OHS development needs in Finnish home care is provided. The results indicate that there is a wide variety of OHS development needs. The themes needing attention were both generic and specific: assistive equipment and work tools, how the employee calls for and receives help in emergency situations, information about customer, education, filming the employees, home as

a working environment, making sure that employees leave their customer visits safely, organization of work, safety orientation, guidance and instructions, physical ergonomics, psychosocial, mental and ethical loads, and threat of physical and psychosocial violence.

This study's results agree with those of previous studies, which indicates that there has not been much improvement in home care working conditions. For example, heavy physical exertion and psychosocial stressors [11, 13], and verbal and physical abuse [3, 13] have been reported earlier and are similar to this study's results. In addition, Covid-19 has been recognized as affecting home care aides' OHS [1]. It was one of the main factors behind the OHS development needs mentioned in this study—for example, the organization of work. In this study, employees being filmed arose as a new OHS development need and as a problem to be solved.

The limitations of this study include the limited number of respondents in the survey, interviews, and workshops and homogeneity of the research sample. The participants in the interviews and workshops were chosen by supervisors, which could have affected the results. However, the participants had different backgrounds in terms of education and work experience. In addition, using three different methods or data sources is a type of triangulation [7]. Similar issues were presented regardless of the data collection method used, indicating that saturation was achieved and that the study had a satisfactory number of participants.

Interactions between the researchers and the participants may have affected the conduct of the study and the results. The semi-structured nature of the interviews ensured that all topics were discussed while providing the participants with an opportunity to speak more freely and deeply when necessary [10].

The lack of improvement in OHS and in working conditions in the home care sector is of great concern as the need for home care increases. It is important to promote public discussion to increase understanding between all parties about home care personnel's OHS risks and working conditions and to improve OHS in home care. Further research is required to focus on the OHS needs highlighted in this study in order to develop effective intervention programs and make working conditions more desirable. Because this work is most often performed alone in customers' homes, employers' abilities to influence OHS are limited, and traditional solutions may not be applicable. Preventive measures, risk assessments, and the participation of all parties (including employers, employees, customers, customers' relatives, and the government) are needed to ensure concrete development.

Acknowledgements The authors would like to acknowledge the Finnish Work Environment Fund, Tampere University and participating organizations for funding this research. In addition, the authors are grateful to the individuals who participated in this study.

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Use of Urinary Creatinine to Assess Occupational Exposure as a Firefighter: A Preliminary Study



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Abstract Recently, it was described that occupational exposure as a firefighter can causes bladder cancer. Although the creatinine is a renal biomarker commonly used in the diagnosis of acute kidney injury (AKI), the characterization of urinary creatinine changes in firefighters due to their active participation in fire events remains poorly characterized. An exploratory study was conducted to determine, for the first time, the urinary creatinine levels of 15 firefighter trainees during a controlled urban fire event. The range of urinary creatinine concentrations were slightly increased in the day after firefighting (48.76–308.03 mg/dL) than pre-fire levels (31.36–243.78 mg/dL). A total of 27% of firefighters presented an increase of, at least, 1.5 times in the urinary creatinine levels after participation in firefighting. Also, 6.7% of participants presented urinary levels of creatinine that exceeded the recommended guidelines (30–300 mg/dL). The findings of this preliminary study highlight the need to explore the relationship between urinary creatinine and kidney injury in firefighters. Further studies, with a superior number of individuals and including other biomarkers of early kidney damage are needed to characterize firefighters' renal function and explore its relationship with exposure to health-relevant pollutants, heat, and associated physiological disorders (e.g., dehydration and muscle damage).

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Keywords Occupational safety · Kidney injury · Urinary biomarkers · Firefighters · Health risks

1 Introduction

Creatinine results from the non-enzymatic conversion of creatine, an organic acid found almost exclusively in muscular tissues [1]. Creatine is involved in the production of energy by muscles during high-intensity physical exercises [2]. Besides the natural synthesis of creatine by liver, creatine is also absorbed through diet (e.g., foods rich in protein, such as red meat) maintaining a constant level in the organism [1–3]. This compound is secreted by renal tubular cells and excreted by tubular secretion in the urine at a constant rate [3]. The urinary excretion of creatinine is an indicator of the glomerular filtration rate. When the renal function is affected, the glomerular filtration rate decreases and promotes the accumulation of creatinine in the human body, increasing the serum and urinary levels of this biomarker of renal function [4, 5]. The excretion of creatinine is influenced by different factors, such as creatine dietary intake, medication, and muscle mass [3]. For example, a vegetarian diet decreases the dietary intake of creatine, leading to lower creatinine excretion rates. Also, patients with advanced liver disease, malnourishment, neuromuscular diseases, or hypoalbuminemia may have reduced creatinine production due to the muscular mass reduction [6]. On the other side, increased values of urinary creatinine can be an indicator of acute kidney injury (AKI). AKI is a syndrome characterized by a fast deterioration of kidney function, leading to the accumulation of urea and creatinine in the human body, reduced immunity, and dysfunction of other organs [7–10]. Patients with AKI present a risk 10 times higher to develop chronic kidney disease as well as a risk of death 2 times superior than individuals without AKI [11]. The exposure to heat stress and physiological disorders (e.g., dehydration and/or muscle damage) are risk factors that can potentiate the development of AKI [12–15]. The available literature suggests that occupational heat stress can induce tubular kidney injury and can be exacerbated by work activities that expose the individual to high core temperatures and muscle-damaging exercises, causing dehydration over long working periods [12, 14, 15]. Heat stress generally reduces the renal blood flow, which can promote ischemia, hypoxemia, and adenosine triphosphate reduction in the renal system. These factors can trigger inflammation and oxidative stress processes that will increase the risk of AKI [13]. Moreover, heat stress can also cause the reduction of the glomerular filtration rate, which will potentiate the accumulation of creatinine [16]. Dehydration results in increased aldosterone and vasopressin concentrations that will stimulate the fluid reabsorption, contributing to reduce the production of urine and increase the accumulation of waste products in the human body, including creatinine [16]. Prolonged AKI leads to the development of chronic kidney diseases [12, 13].

During a regular work day, firefighters perform different activities, i.e., fire combat, rescue, and support in vehicle accidents, extrication, etc., which routinely

expose them to physical stress, heat, and dehydration [17–20]. Recently, the occupational exposure as a firefighter was classified as carcinogenic to humans (Group 1) by the International Agency for Research on Cancer [17]. It was found sufficient scientific evidence that this occupational activity can cause bladder cancer and mesothelioma; limited evidence suggests the development of melanoma, colon, prostate, and testicular cancers, and non-Hodgkin lymphoma [17]. During firefighting activities, firefighters are exposed to a countless number of health-hazardous pollutants, e.g., particulate matter, metals and metalloids, carbon monoxide, nitrogen oxides, and several volatile organic compounds that are formed and/or released during the combustion processes [21–24]. The occupational exposure to these pollutants occur via inhalation, dermal contact, and ingestion, and it is many times combined with heat stress and physiological disorders, which may synergistically contribute to the development of kidney diseases in firefighters [25–27].

Despite the recognized health risks associated to the occupational exposure as a firefighter, the characterization of firefighters' renal function remains poorly studied. To the best knowledge of these authors, only four studies assessed the characterization of urinary creatinine levels before and after participation in firefighting activities [28–31]; no information regarding the characterization of renal function is available for Portuguese firefighters. Therefore, there is an urgent need to study the relationship between urinary biomarkers of AKI and regular exposure to extreme heat, changes in physiological disorders, and the different tasks performed by fire-fighters. In this study, the urinary creatinine levels of Portuguese firefighter trainees were assessed for the first time, as an exploratory study, before and in the morning after their active participation in a controlled urban fire.

2 Materials and Methods

2.1 Selection and Characterization of Participants

The participant's selection was performed in close collaboration with agents from Autoridade Nacional de Emergência e Proteção Civil and commanders of local firefighting forces. A total of 15 sapper firefighters (Porto, Portugal) at the end of their recruitment course were invited to participate in a biomonitoring survey program. A descriptive explanation of the study was presented to all participants. Fire-fighter trainee's voluntary agreed to participate in this study. The volunteers fulfilled an individual characterization questionnaire that was adapted from a previously validated questionnaire [32]. The individual questionnaire collected data related with personal (age, weight, height, existence of diagnosed chronic disease and current health status, smoking habits, and frequently consumed meals) and professional information (recent participation in firefighting activities and use of personal protective equipment). The participants signed an informed consent form that was previously reviewed and approved by the Ethics Committee of the University of Porto.

2.2 Sampling Campaigns

The sampling campaigns were performed between February and March 2022. All firefighters actively participated in controlled urban fire events. Participants were invited to collect a spot urine sample immediately before their participation in fire combat activities. A spot urine sample of the first-morning urine on the day after the firefighting training was also collected. The urine samples were collected in sterilized polycarbonate containers, coded, and stored at -80°C until analysis.

2.3 Determination of Creatinine Levels

Creatinine levels were determined by a standard protocol based on the Jaffe colorimetric method [33]. Briefly, an aliquot of urine was mixed with reagent A [solution of sodium hydroxide (Labkem, Spain, 4.4 g), trisodium phosphate (Honeywell, Germany, 9.5 g) and sodium tetraborate (Honeywell, Fluka®, Spain, 9.5 g)] and picric acid (Sigma-Aldrich®, Germany), in the presence of 0.1 M hydrochloric acid (Honeywell, Fluka®, Austria). The mixture was incubated at room temperature for 30 min in the absence of light. The absorbance was measured in an ultraviolet–visible spectrophotometer (Nicolet Evolution 300, ThermoElectron, USA) at 505 nm [33]. Blanks and standards were daily prepared, and the measures were performed in triplicate. Calibration curve was daily prepared for the concentration range between 1 and 14 mg/dL of creatinine. Limits of detection (LOD) and quantification (LOQ) were determined according to Eqs. 1 and 2, respectively, $S_{y/x}$ represents the standard deviation of the residuals. Overall, the determined LOD was 0.604 mg/dL and a LOQ of 2.01 mg/dL. Urine samples were analysed in duplicate.

$$\text{LOD} = 3 \times \frac{S_{y/x}}{\text{Calibration curve slope}} \quad (1)$$

$$\text{LOQ} = 10 \times \frac{S_{y/x}}{\text{Calibration curve slope}} \quad (2)$$

2.4 Statistical Analysis

Statistical analysis was performed using Microsoft Office Excel (v. 16.0. Microsoft Corporation, EUA) and SPSS (version 28.0, Armonk, NY, USA). Data were tested for normality being the Mann–Whitney U test applied to compare data when a normal distribution was not verified. Differences between the creatinine levels were estimated using the non-parametric Kruskal Wallis test when data did not meet normality

Table 1 Characterization of participants

Age (average ± SD, range; years)	BMI (average ± SD, range; kg/m ²)	Time of exposure (average ± SD, range; hours)
24.7 ± 2.27 (20–29)	23.9 ± 1.90 (19.1–27.7)	5.33 ± 0.47 (5–6)

SD: standard deviation

and homogeneity of variances assumptions. A *p* value ≤0.05 was considered as significant.

3 Results and Discussion

3.1 Characterization of Participants

The biometric characterization of firefighter trainees who participated in the controlled fire events is presented in Table 1. Overall, all participants were male and presented an average age of 24.7 years. The average body mass index (BMI) was 23.9 kg/m², with maximum values reaching 27.7 kg/m² (Table 1). The majority of the participants (80%) presented a BMI (19.1–24.8 kg/m²) within the accepted healthy weight range defined by the World Health Organization (WHO), i.e., 18.0–25.0 kg/m²; only 3 firefighters were considered overweight (BMI > 25.0 kg/m²) [34, 35]. All firefighters were directly involved in fire combat activities between 5 and 6 h on the sampling day (Table 1).

All participants reported being healthy and with no pre-existing or diagnosed diseases (e.g., cardiovascular, pulmonary, or renal diseases). They described a common diet, i.e., without dietary protein restriction, and stated that medication was not used in the days preceding the sampling campaign. For these reasons, it can be assumed that all participants are healthy and, thus, it is expected they have a daily renal load and stable urinary excretion [36].

3.2 Creatinine Levels

The levels of creatinine determined, for the first time, in the urine of Portuguese firefighters before and in the morning after the fire event are presented in Fig. 1. The range of creatinine levels of firefighter trainees were slightly higher in the morning after the fire event (133.07 mg/dL; range 48.76–308.03 mg/dL) than in pre-firefighting (145.84 mg/dL; range 31.36–243.78 mg/dL); no significant differences were found between preand post-exposure levels (*p* = 0.378). Twelve of the fifteen participants (i.e., 80%) presented an increase in the urinary levels of creatinine in the morning after the firefighting activity, comparatively with pre-fire values.

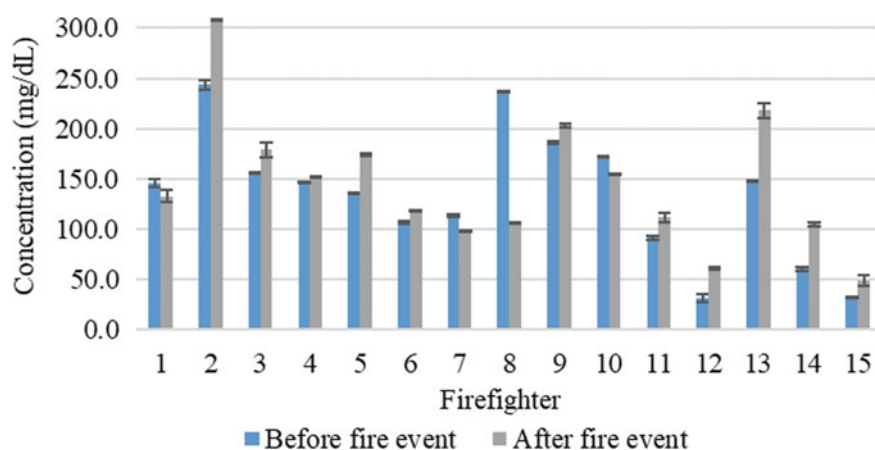


Fig. 1 Mean Concentrations of creatinine (mean $\pm$ SD; mg/dL) determined in the urine of firefighters before and in the morning after the fire event

The creatinine ratio, i.e., the quotient between the levels determined in the pre- and post-exposure samples, were determined for each participant (Table 2). Overall, creatinine ratios varied between 1.03 and 1.95 (3.23–94.52%), indicating an increase on creatinine levels after the active participation in the fire combat. For participants 1, 7, 8 and 10, the ratio was inferior to 1, representing a decrease on urinary creatinine in the morning after the fire event (Table 2). Additionally, four individuals (i.e., 27%) presented ratios ≥ 1.5 (Table 2), suggesting for an alteration on the urinary levels of creatinine which can promote possible kidney injury for prolonged exposure periods. AKI, in an early stage, presents a reversible condition being the human body able to recover from the possible short-term injury in a few days [7, 8, 11]. However, prolonged periods with high ratios of urinary creatinine can potentiate some health risks, including the contribution to develop/aggravate AKI [8, 9].

The dehydration, the muscle damage due to the intense physical activity and/or the heat stress can potentiate changes in the urinary excretion of creatinine and, when prolonged over time, can promote the development or aggravation of some disorders already observed in firefighters, e.g., proteinuria and rhabdomyolysis [12–15].

According to the WHO and the American Conference of Governmental Industrial Hygienists (ACGIH), the recommended urinary creatinine levels in a healthy adult should range between 30 and 300 mg/dL [37, 38]. Among participants, only one subject (participant 2) exceeded this guideline value in the urine collected in the morning after firefighting (Fig. 1). Some authors recommended that clinical laboratories adjusted their own reference intervals according to the characteristics and specific local populations [39].

Some studies also reported increased levels of urinary creatinine after participation in fire combat activities when compared with the values found in the urine samples collected in the beginning of the work-shift [29–31]. Yasuda and Ruby [31]

Table 2 Differences between pre- and post-fire urinary creatinine levels in firefighters

Firefighter	Ratio	Increment (%)
1	0.91	−8.76
2	1.26	26.36
3	1.15	14.78
4	1.03	3.23
5	1.28	28.49
6	1.12	12.13
7	0.86	−13.89
8	0.45	−54.90
9	1.09	9.20
10	0.90	−9.93
11	1.22	21.95
12	1.95	94.52
13	1.47	47.03
14	1.73	73.42
15	1.52	52.46

determined the urinary creatinine levels of wildland firefighters during three consecutive days of firefighting training. The authors concluded that the intensity of work had more impact on the urinary creatinine level changes than in the total work output, since a significant correlation between the loss of body weight during the training and the increase on urinary creatinine levels were observed [31]. Naehrer et al. [29] determined the concentrations of levoglucosan and corrected the values with urinary creatinine levels in firefighters working at prescribed burns. According to the authors the post-shift creatinine corrected levels should not be only associated with smoke exposure, highlighting the need to investigate the contribution of other factors for the increased creatinine levels [29]. Neitzel et al. [30] analysed the urine samples from 13 wildland firefighters after the participation in prescribed burns, urine samples were collected before and after the work shift. The authors reported mean urinary creatinine values ranging between 199.1 and 221.6 mg/dL, for pre- and post-shift samples, respectively, with some samples (31% and 15% of samples before and after shift, respectively) exceeding the recommended guideline of WHO and ACGIH [30].

4 Conclusions

The occupational exposure as a firefighter, including firefighting, can trigger the development of AKI with an early alteration in urinary biomarkers of renal disease, such as creatinine. In this preliminary study, it was determined for the first time, the variation of urinary creatinine levels in Portuguese firefighters before and after their

active participation in a controlled urban fire event. Urinary creatinine levels of fire-fighter trainees during controlled urban fire events were slightly increased after fire-fighting. The urinary creatinine levels in 6.7% of firefighters exceeded the available recommendation of 30–300 mg/dL defined by WHO and ACGIH. Additionally, 27% of firefighters presented ratios pre- to post-firefighting higher than 1.5, which demonstrate short-term alterations on urinary creatinine levels and, if prolonged over time, can potentiate future risk of developing AKI due to fire combat.

Further studies with a superior number of participants performing different tasks during firefighting should be addressed to explore the results achieved in this preliminary study and to evaluate the relation between the occupational exposure as a firefighter and the biomarkers of effects on renal function, which can help predicting the development of AKI in a preliminary stage of the disease. Since AKI can also be associated to some physiological disorders (e.g., dehydration and muscle damage) and heat stress, the influence of these occupational conditions on additional urinary biomarkers should also be evaluated in firefighters.

Acknowledgements This work received support by UIDB/50006/2020, UIDP/50006/2020, LA/P/0008/2020, 2022.05381.PTDC, and PCIF/SSO/0017/2018 by FCT-MCTES.

M. Oliveira and F. Rodrigues are thankful for the scientific contracts CEECIND/03666/2017 and CEECIND/01886/2020, respectively. The authors are also thankful to all firefighters and the agents of Autoridade Nacional de Emergência e Proteção Civil for their collaboration and support.

Funding This work received financial support from the project PCIF/SSO/0090/2019 by the Fundação para a Ciência e a Tecnologia, Ministério da Ciência, Tecnologia e Ensino Superior (FCT-MCTES), through national funds.

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Characterization of Metal Content in the Saliva of Firefighters: A Preliminary Study



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Abstract Exposure to chemical pollutants, such as metals, can cause adverse health effects on human health. Firefighters are occupationally exposed to metals during firefighting activities as well as at fire stations. The aim of this study is to characterize the levels of metals in the saliva of firefighters during regular activities performed at fire stations. Non-smoking firefighters collected spot saliva samples during a regular working day at the fire station. Samples were treated and analyzed by inductively coupled plasma mass spectrometry. The cumulative concentrations of the 16 metals in the saliva of firefighters varied from 10.87 to 73.64 $\mu\text{g/L}$ (median of 25.40 $\mu\text{g/L}$). The individual metal concentrations ranged between $6.361 \times 10^{-3} \mu\text{g/L}$ for Cd and 4.550 $\mu\text{g/L}$ for Mn. The salivary metal concentrations determined in firefighters were lower than the values reported for workers from industries whereas the levels were

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higher than in non-smokers and non-occupationally exposed groups. The analysis of saliva is a promising biomonitoring tool to characterize occupational exposures to metals. Additional studies including a higher number of participants performing different tasks and the inclusion of other biological fluids are needed to corroborate these findings and to better characterize firefighters' occupational exposure.

Keywords Occupational exposure · Firefighters · Human biomonitoring · Saliva · Metals

1 Introduction

Every individual, when performing his work, is exposed to different occupational risks, and depending on the nature of the work activities, the hazards can be of chemical, biological, physical, ergonomic, and psychological nature [1]. The so-called occupational hazards are responsible for work-related accidents and/or the development and aggravation of diseases [1]. One of the most well-known and characterized activities is the occupational exposure as a firefighter [2–8]. On a daily basis, firefighters are exposed (through inhalation, dermal contact, and ingestion) to different pollutants *e.g.*, those released from biomass burning and fires (wildland, structure, and industrial fires) such as carbon monoxide, metals and heavy metals, particulate matter, and several volatile organic compounds (*e.g.*, polycyclic aromatic hydrocarbons among other persistent organic pollutants) [3, 4, 8]. Firefighters can also be exposed to ultraviolet radiation, biological hazards, and high temperatures, being involved in several tasks that demand high physical exercises (*e.g.*, fire combat and investigation, search and rescue missions, etc. [4, 9]. Moreover, firefighters are also exposed to some of these hazards at fire stations, where they can spend a substantial amount of their work shift [4, 6, 8]. Recent literature demonstrates that firefighters are exposed to gaseous and particulate pollutants released from fires during the maintenance and cleaning activities of firefighting vehicles and personal protective equipment at the fire station [4, 8, 10, 11]. Recently, the International Agency for Research on Cancer (IARC) classified the occupational exposure as a firefighter as carcinogenic to humans (Group 1), with sufficient scientific evidence for the development of mesothelioma and bladder cancer [4].

Some metals and metalloids are known toxic and carcinogenic substances, *e.g.*, nickel (Ni), arsenic (As), cadmium (Cd), antimony (Sb), mercury (Hg), thallium (Tl), and lead (Pb) [12, 13]. Occupational exposure to metals occurs not only in firefighters but also in other workers, *e.g.*, those from the mining, industry, and petrol sector [1, 3, 14]. Exposure to the referred elements and other metals and metalloids (*e.g.*, lithium (Li), manganese (Mn), cobalt (Co), copper (Cu), strontium (Sr), molybdenum (Mo), cesium (Cs), barium (Ba), and selenium (Se)) can occur during activities involving the direct contact with dyes/pigment extenders, automobile components such as batteries, wires, or metal alloys present in the vehicles' infrastructures as well as during job tasks performed at industrial plants [12, 15–22]. The burning of materials

containing metals and metalloids in its composition (*e.g.*, fuels, wastes, plastics/rubbers, paints, and electric/electronic devices) can also be a source of exposure to firefighters [3]. Exposure to metals and metalloids can cause headache, muscle fatigue, promote the development/aggravation of neurologic and respiratory diseases, and some types of cancer [12, 15–22]. The development of skin and lung cancer and Parkinson's disease, are some of the health diseases that can be developed/aggravated due to prolonged exposure to metals [23]. Human biomonitoring usually involves collecting and analyzing blood and urine to determine the level of exposure to metals [3, 14, 24]. Although still not quite common, saliva is a biological fluid that can be used to complement the existing human biomonitoring surveys and widen the potential of human biomonitoring, with a particular interest in the identification of tasks that can potentiate short-term occupational exposure to metals via ingestion. This acidic oral secretion fluid has many biological functions and can be used in the assessment of hormonal and immunological status. Available literature highlights that saliva can be used in the evaluation of recent exposure to organic and inorganic (including metals) pollutants [14, 25, 26]. Oppositely to blood analysis, the collection of saliva is simple, inexpensive, non-invasive and can be performed by workers, without the request of a health professional [27]. Nevertheless, the information related to the use of saliva in human biomonitoring of occupationally exposed workers is scarce [14, 26, 28–31]. To the best knowledge of these authors, the characterization of metal content in firefighters' saliva is inexistent. This work aims to determine the levels of 16 metals—Li, Mn, Co, Ni, Cu, Sr, Mo, Cs, Ba, Cd, Hg, Tl, Pb, As, Se, and Sb—in the saliva of firefighters during their regular work-shift at fire stations.

2 Materials and Methods

2.1 Study Population and Sampling Campaigns

The studied population consisted of 12 healthy and non-smoking firefighters from three fire stations in the district of Oporto (North of Portugal). All participants were invited to voluntarily participate in the study by filling out an anonymous self-characterization questionnaire to collect general information about each individual (*e.g.*, age, body height and weight, years of experience as a firefighter, smoking and eating habits, use of medication, and global health status). All firefighters signed an informed consent that was previously validated and approved by the Ethical Committee of the University of Porto.

The sampling campaigns were performed between November 2021 and April 2022. All participants who reported that were not exposed to any type of fire event in the three days before the sampling campaigns were invited to collect a spot sample of saliva at the end of their work shift. The saliva collection followed a straightforward procedure that consisted of spitting five spots of non-stimulated saliva into a sterile

sample collection cup. After collection, saliva samples were coded and stored at -20°C until chemical analysis.

2.2 Determination of Metal Content and Data Treatment

Saliva samples were centrifuged at 4000 rpm (Beckman Coulter, Microfuge 22R Centrifuge) for 10 min. An aliquot of 100 μL of supernatant was digested with 900 μL of a diluent solution containing a mixture of 2% (v/v) of nitric acid (67–69% w/w TraceMetal® Grade, Fisher Scientific), 500 ppb of Au, 1.5% (v/v) absolute anhydrous Ethanol (Carlo Erba Reagents), and a solution of 10 ppb of internal standard (Ga, Ir, and Rh in 5% ethanol). Samples were analyzed by inductively coupled plasma mass spectrometry (ICP-MS), with an iCAP™ Q (Thermo Fisher Scientific, Germany) equipped with a Meinhard® (Golden, CO) TQ+ quartz concentric nebulizer, a Peltier cooled, high purity quartz, baffled cyclonic spray chamber and a demountable quartz torch with a 2.5 mm i.d. quartz injector. A total of 16 metals Li, Mn, Co, Ni, Cu, As, Se, Sr, Mo, Cd, Sb, Cs, Ba, Hg, Tl, and Pb, were analyzed. Limits of detection (LODs) were calculated by multiplying the standard deviation of the measurement of ten blank solutions by 3.3. As for the limits of quantification (LOQs), these were determined by multiplying the LODs by 3.3 [32]. LODs and LOQs varied between $4.657 \times 10^{-3} \mu\text{g/L}$ (Tl) and $1.329 \mu\text{g/L}$ (Cu) and from $1.537 \times 10^{-2} \mu\text{g/L}$ (Tl) to $4.386 \mu\text{g/L}$ (Cu), respectively. The samples were analyzed in triplicate and in a random order to avoid sequence effects.

Data treatment was accomplished using Microsoft Excel (Microsoft Corporation, USA) software. Elemental concentrations were presented in $\mu\text{g/L}$ and when the results were below the LOD, the value was replaced by $\text{LOD}/\sqrt{2}$ [33].

3 Results and Discussion

3.1 Characterization of Firefighters

The main characteristics of the 12 non-smoking firefighters are summarized in Table 1. Overall, participants (11 males and 1 female) presented a mean age of 29 years and 7.36 years of work as a firefighter. The body mass index (BMI) was calculated as the body mass (kg) of the participant divided by the respective height's square (m^2). The mean BMI of all participants was 25.3 kg/m^2 , a value that demonstrates the existence of some participants in pre-obesity, according to the recommendations of the World Health Organization [34].

Table 1 Characterization of firefighters

Variable	Firefighters
N	12
Gender (%)	92% Male; 8% Female
Age (mean $\pm$ SD; min–max; years)	29.1 $\pm$ 7.80 (22.0–45.0)
Number of years as a firefighter (mean $\pm$ SD; min–max; years)	7.36 $\pm$ 9.41 (1.00–25.0)
BMI (mean $\pm$ SD; min–max; kg/m ²)	25.3 $\pm$ 2.69 (22.1–30.8)

3.2 Levels of Metals in Saliva

All the 16 metals considered were detected in 100% of the saliva samples, except Ni (67%), Cd (42%), and Hg (58%). The total metal composition in firefighters' saliva was 25.40 $\mu\text{g/L}$, with values ranging between 10.87 and 73.64 $\mu\text{g/L}$. Table 2 displays the concentrations of each metal in the firefighters' saliva. Mn was the most abundant element (4.550 $\mu\text{g/L}$; maximum value of 15.78 $\mu\text{g/L}$), followed by Cu (4.360 $\mu\text{g/L}$; maximum of 35.09 $\mu\text{g/L}$), Sr (4.242 $\mu\text{g/L}$; maximum value of 12.28 $\mu\text{g/L}$), Li (2.414 $\mu\text{g/L}$; maximum of 6.583 $\mu\text{g/L}$), and Se (2.091 $\mu\text{g/L}$; maximum value of 4.362 $\mu\text{g/L}$). Together these elements accounted for 78.12% of the total elemental content (Fig. 1). The Tl (0.1325 $\mu\text{g/L}$; maximum of 0.4734 $\mu\text{g/L}$), Sb (0.1264 $\mu\text{g/L}$; maximum of 1.014 $\mu\text{g/L}$), Pb (0.1069 $\mu\text{g/L}$; maximum of 0.4499 $\mu\text{g/L}$), Hg (3.836 $\times 10^{-2}$ $\mu\text{g/L}$; maximum of 0.1768 $\mu\text{g/L}$), and Cd (6.361 $\times 10^{-3}$ $\mu\text{g/L}$; maximum of 6.468 $\times 10^{-2}$ $\mu\text{g/L}$) presented the lowest levels, corresponding to 1.816% of the total metal content (Table 2). Regarding metalloids, the median concentrations determined in firefighters' saliva were 2.091 $\mu\text{g/L}$ (9.251% of the total content) for Se, 0.4651 $\mu\text{g/L}$ (2.058% of the total elements) for As, and 0.1264 $\mu\text{g/L}$ (0.5592% of the total elements) for Sb (Table 2 and Fig. 1).

The presence of four known toxic (Tl) and carcinogenic (Pb, Hg, and Cd) heavy metals was demonstrated in the saliva of firefighters (Table 2). Cd was quantified at a median concentration of 6.361 $\times 10^{-3}$ $\mu\text{g/L}$, followed by Hg at 3.836 $\times 10^{-2}$ $\mu\text{g/L}$, Pb at 0.1069 $\mu\text{g/L}$, and Tl at 0.1325 $\mu\text{g/L}$, corresponding, respectively, to 2.814 $\times 10^{-2}\%$, 0.1697%, 0.4729%, and 0.5861%, of the total elements found in firefighters' saliva. Overall, these well-known toxic and carcinogenic elements may contribute to affect important organs such as the lungs, stomach, kidneys, and brain [13]. However, the occupational exposure limit values for these metals are still not described for saliva. Exposure to carcinogenic metals is associated with the development of skin diseases as well as skin, stomach, and liver cancer [13].

So far, a limited number of studies characterized the levels of metals and metalloids in the saliva of occupationally exposed workers. Pb is the most characterized element in the literature, with reported concentrations varying between 3.03 and 129 $\mu\text{g/L}$ for workers from the steel and iron industries and from the battery recycling industry, respectively [35, 36]. The values found in the saliva of firefighters were significantly lower than the values found in the literature. Cd was characterized in

Table 2 Elemental composition ($\mu\text{g/L}$) of firefighters' saliva samples

Element	Median (range)	Mean $\pm$ SD	Contribution (%)
Li	2.414 (1.198–6.583)	3.032 ± 1.661	10.68
Mn	4.550 (1.291–15.78)	5.479 ± 4.564	20.13
Co	0.5581 (0.3071–1.944)	0.8317 ± 0.5197	2.470
Ni	0.7524 (0.1241 ^a –6.295)	1.330 ± 1.796	3.329
Cu	4.360 (2.017–35.09)	9.956 ± 11.31	19.29
As	0.4651 (0.3077–0.8963)	0.5272 ± 0.1806	2.058
Se	2.091 (0.9867–4.362)	2.227 ± 1.014	9.251
Sr	4.242 (2.098–12.28)	5.406 ± 2.967	18.77
Mo	0.3708 (0.1457–0.7149)	0.3936 ± 0.1734	1.640
Cd	6.361×10^{-3} (6.361×10^{-3a} – 6.468×10^{-2})	$1.855 \times 10^{-2} \pm 1.964 \times 10^{-2}$	2.814×10^{-2}
Sb	0.1264 (2.153×10^{-2} –1.014)	0.1945 ± 0.2718	0.5592
Cs	1.809 (1.109–4.979)	2.459 ± 1.279	8.004
Ba	0.5782 (0.1941–1.158)	0.6412 ± 0.3111	2.558
Hg	3.836×10^{-2} (1.730×10^{-2a} –0.1768)	$5.684 \times 10^{-2} \pm 5.184 \times 10^{-2}$	0.1697
Tl	0.1325 (4.480×10^{-2} –0.4734)	0.1777 ± 0.1306	0.5861
Pb	0.1069 (2.050×10^{-2} –0.4499)	0.1414 ± 0.1134	0.4729

^a When the concentration was below the LOD, the value $\text{LOD}/\sqrt{2}$ was used [33]

three studies performed with steel industry workers, with values ranging between 0.14 and 59.7 $\mu\text{g/L}$ [36, 37]. Again, the levels of Cd in the saliva of firefighters were substantially lower than the values reported in those occupationally exposed workers. The content of Hg in human saliva was characterized in three studies that characterized workers from navy divers performing underwater cutting and dentists, with levels ranging from 2.0 and 11.1 $\mu\text{g/L}$, respectively [38]. The reported values were up to 195 times higher than the levels found in firefighters. Mn was also characterized in the saliva of exposed workers of the steel industry and the mean concentrations were comprehended between 0.12 and 70.47 $\mu\text{g/L}$ [36]. These values appeared in concentrations 13–46 times higher than in firefighters. Regarding Cu, the values observed in workers from navy divers performing underwater cutting varied between 10.00 and 200.0 $\mu\text{g/L}$, being almost 20 times higher than in the present study [38]. The salivary content in Ni was evaluated in a study with steel industry workers and the values were comprehended between 0.12 and 188.5 $\mu\text{g/L}$, being 11 to 142 times higher than in firefighters [36]. Kim et al. [39] quantified the concentrations of 11 metals in the saliva of ten South Korean office workers in dentistry and in students of a dentistry college. Overall, the reported levels of Pb (0.080 $\mu\text{g/L}$), Tl (0.012 $\mu\text{g/L}$), Cd (0.023 $\mu\text{g/L}$),

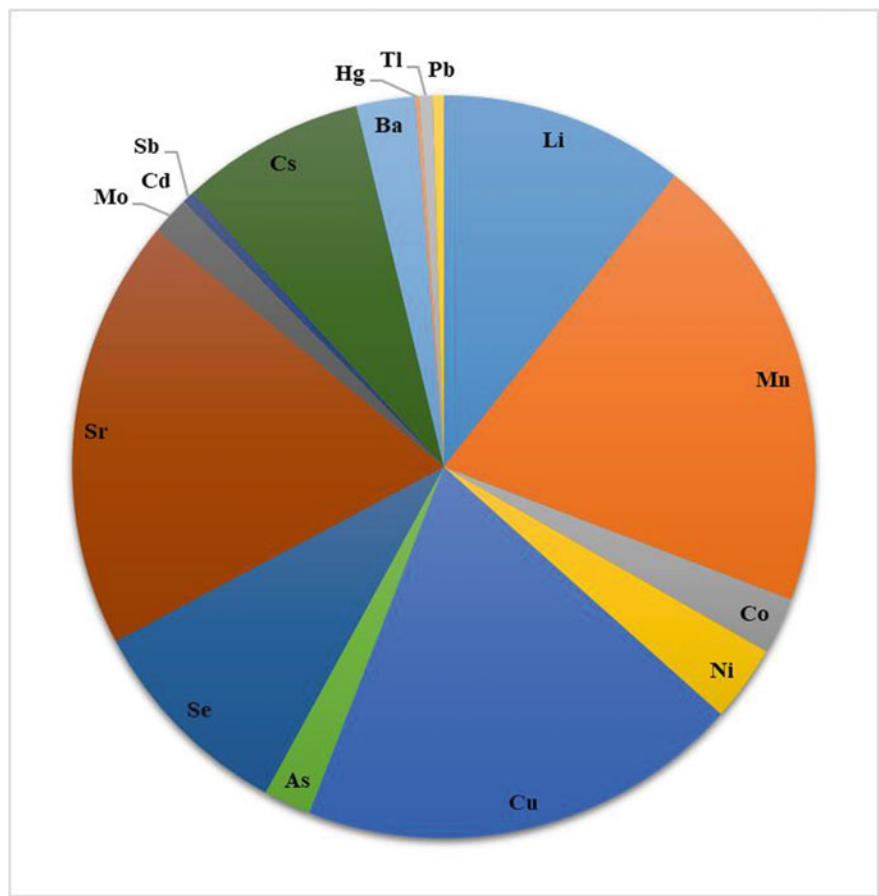


Fig. 1 Contribution of each element (%) to the total median cumulative concentration

Mo (0.29 $\mu\text{g/L}$), Sr (2.16 $\mu\text{g/L}$), Cu (1.53 $\mu\text{g/L}$), and Mn (2.94 $\mu\text{g/L}$) were 1.3 to 11 times lower than the values found in the saliva of firefighters (Table 2; an exception was observed for Cd (6.361×10^{-3} versus 0.023 $\mu\text{g/L}$), for which the value was 3.5 times lower in firefighters' saliva [39]. Regarding the non-occupationally exposed and non-smoking subjects, Khabour et al. [40] determined the levels of Cd, Pb, and Zn in the saliva of forty Jordanian citizens and reported mean Pb and Cd values that were 20 (2.8 versus 0.1414 $\mu\text{g/L}$) and 34 (0.64 versus 1.855×10^{-2} $\mu\text{g/L}$) times higher than the values quantified in this study, respectively. However, some caution needs to be taken in the comparison of the salivary content between different studies since limited information regarding the environmental and/or occupational activities as well as the subjects' personal habits (e.g., smoking habits, or diet) and the years of work experience in the respective industries is reported. Additionally, increased levels of metals are somehow expected in the saliva of some occupationally exposed

groups, principally in those that daily handle metals and their derivatives. Concerning occupational exposure as a firefighter, it is expected to find increased levels of salivary metals at the end of a working day that included some specific work tasks, such as, fire combat in vehicles, industries, and infrastructures containing different metal-related raw materials, interventions on hazardous material contention, among many others. Moreover, levels of mineral content found in the saliva of firefighters can be related with some tasks performed at fire station, including the cleaning/maintenance of PPE, fire combat vehicles, and other materials used during firefighting. Some literature already highlights the presence of metals and metalloids in the particles released from fires where materials such as coal and other fossil fuels, plastics/rubber, electronic devices, light bulbs, batteries, paints, and waste are burned [12, 13, 15–22]. However, additional studies are needed to better explore the sources of metals and metalloids in the saliva of firefighters when attending at the fire stations and when performing firefighting activities.

Despite limited, available literature and the findings of this study suggests human saliva as a potential biomonitoring tool to better characterize recent human (environmental and occupational) exposure to metals. Moreover, its use in the characterization of long-term exposure to some bioaccumulative metals (*e.g.*, Cd, Pb, and Hg in buccal tissues) is yet to be characterized. Moreover, the monitorization of this matrix also provides information about the fraction of xenobiotics that are bioavailable/bioaccessible to be absorbed by the buccal cavity tissues and be distributed to other body tissues [25–27]. Data regarding the presence of occupational pollutants in workers saliva should be considered to create regulations and guidelines for exposure using workers' saliva as a monitoring tool. However, there is a gap in protocols for the collection and methodologies to quantify metals and other health-hazardous pollutants in human saliva. Moreover, there is also a lack of (maximum/acceptable) reference values for metals and metalloids in human saliva. Future human biomonitoring studies should include saliva as well as other biological matrixes (urine and blood) in order to better characterize exposure to metals and metalloids and to explore the relationship between the different matrixes.

4 Conclusion

In the present study, 16 metals were analyzed in firefighters' saliva with a total cumulative metal content ranging between 10.87 and 73.64 $\mu\text{g/L}$ (median of 25.40 $\mu\text{g/L}$). All 16 metals were detected in 100% of the samples, except Ni, Hg, and Cd which presented lower detection rates. Mn, Cu, Sr, Li, and Se were the predominant compounds, accounting for 78.12% of the total metal content. The hazardous metals, Cd, Hg, Pb, Sb, and Tl represented 1.816% of the total metal content in the saliva of firefighters. The salivary values found in firefighters were lower than the levels reported for workers from different industries. To the best knowledge of these authors, few studies employed saliva to evaluate its metal content in occupationally exposed

workers. Therefore, saliva should be taken into consideration in future occupational monitoring procedures to determine workers' exposure via ingestion to metals.

Acknowledgements This work received support from UIDB/50006/2020, UIDP/50006/2020, LA/P/0008/2020, PCIF/SSO/0017/2018, and 2022.05381.PTDC by FCT/MCTES. M. Oliveira, and F. Rodrigues, are thankful to the scientific contracts CEECIND/03666/2017 and CEECIND/01886/2020, respectively. G. Sousa thanks the PhD grant 2021.08526.BD, supported by FCT-MCTES, Programa Por_Norte, and European Union through Fundo Social Europeu. The team would also like to acknowledge the commanders and firefighters for the participation in this study.

Funding This work received financial support from the project PCIF/SSO/0090/2019 by the Fundação para a Ciência e a Tecnologia (FCT), Ministério da Ciência, Tecnologia e Ensino Superior (MCTES), through national funds.

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Cardiorespiratory Symptoms and Disease Among Firefighters



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Abstract Firefighters' exposure has been linked with cancer development. However, the direct link between cardiorespiratory illness development and occupational exposure is particularly challenging in these workers. The aim of this study is to gather recent information concerning the incidence, prevalence and risk of cardiorespiratory symptoms and disease among firefighters. Literature search was conducted in three databases (2017–2021); after applying the defined inclusion criteria, 27 studies were selected. Wildland, structural, military, industrial, rescue team and/or paramedic firefighters and fire service instructors were included. The incidence ratios in career firefighters were different of those in volunteer firefighters. Cardiorespiratory symptoms were more prevalent among exposed firefighters, whereas a higher incidence ratio for asthma, chronic obstructive pulmonary disease, hypertension, and myocardial infarction was highlighted in cohorts. Firefighting comprises a severe health burden. There is a need to increase awareness of cardiorespiratory disease development and set more frequent occupational surveillance actions, which should also be extended to volunteer firefighters.

Keywords Firefighting · Occupational health · Respiratory diseases · Cardiovascular diseases

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1 Introduction

Cancer development as an occupational-related consequence in firefighters (FF) has been established recently by the International Agency for Research on Cancer (IARC) [1, 2]. A causal association was found for mesothelioma (meta-analysis estimate of 58% increased risk, 95% confidence interval (CI): 14–120%) and for bladder cancer (meta-analysis estimate of 16% increased risk; 95% CI: 8–26%) [2]. Also, there was a “limited” association for colon, prostate, and testicular cancers, and for melanoma and non-Hodgkin lymphoma, which causality was not certain due to the “high heterogeneity in the meta-analysis estimates, inconsistent positive findings from informative studies, or little evidence for firefighting exposures known to be associated with these cancer types” [2]. The work as a firefighter includes a complex occupational exposure. Fire combat encompasses hazardous situations in which several pollutants and biological hazards can be present. Fire scenarios may include forest, prescribed burnings, urban settings, automobiles, and fires at specific microenvironments such as factories, among others. Therefore, depending on the burnt material, the released emissions may vary greatly in terms of composition and pollutants concentrations (*e.g.*, particulate matter of different sizes, volatile organic compounds, phthalates, dioxins, flame retardants) [3]. Personal protective equipment (PPE) is used during firefighting, thereby, reducing exposure. However, despite its mandatory use, the emitted pollutants have been showed to be absorbed by firefighters via inhalation, ingestion, or/and dermal contact [4]. In that sense, the contact with pollutants may also occur via cross-contamination of firefighting gear and fire station, especially in the case of forest firefighting [5]. Once absorbed into the human body, most of these compounds have the potential to cause adverse health effects depending on their toxic characteristics and latency. The main toxicological pathways include DNA damage, oxidative stress, and inflammation, which can lead to the development of cardiorespiratory diseases and contribute to carcinogenesis [6]. Besides exposure to pollutants, firefighters can also be paramedic and assist the general population during health-related emergencies [7]. These activities can also be an important source of exposure to biological threats. The recent pandemic related with coronavirus disease 2019 (COVID-19) caused by the virus SARS-CoV-2 showed the vulnerability of emergency personal, including firefighters. Moreover, other long-term consequences, such as post-traumatic stress disorder, depression, obesity, insulin resistance, and metabolic syndrome have been identified in firefighters [8].

Long-term diseases concerning the respiratory, cardiovascular system, and cancer are the most reported in FF [8]. Despite the link between firefighter activities and cancer being recently recognized [1, 2], the occupational-driven association between exposure as an FF and cardiorespiratory disease development is yet to be agreed on. The main challenges reside in the influence of other factors such as individual health status (*e.g.*, obesity, previous disease diagnosis), lifestyle, PPE use, type of firefighting decontamination procedures, among others. Moreover, most of FF are volunteers or part-time workers (65% in the United States of America (USA) alone; [9]), which creates obstacles in establishing prospective follow-up investigations.

This is particularly difficult since obligatory occupational monitoring by law usually implies a professional link to the institution. Moreover, the reported studies are mainly focused on the evaluation of cardiorespiratory risk factors (*e.g.*, lung function decline, heart rate, blood pressure, dyslipidemia, *etc.*), and effect biomarkers. Nevertheless, despite exposure hazard being well established, the true health impact is better analyzed by recurring to incidence and prevalence of cardiorespiratory disease or by calculating the associated occupational risk. Therefore, the aim of this study is to systematically review the latest (five years) literature on respiratory and cardiovascular symptoms or disease incidence/prevalence that have been reported among FF.

2 Materials and Methods

Available literature was searched (January 1st, 2017–December 31st, 2021) in Web of Science database (Web of Science Core Collection, in documents of all editions and fields), PubMed, and Scopus (Boolean “AND”, search in Article title, Abstract, Keywords), using three keywords: “incidence, firefighters, respiratory”, “incidence, firefighters, cardiovascular”, “risk, firefighters, respiratory”, “risk, firefighters, cardiovascular”, “prevalence, firefighters, respiratory”, and “prevalence, firefighters, cardiovascular”. The following exclusion criteria were applied after the elimination of duplicates: (i) not English written publications; (ii) reviews, letters, not peer-reviewed papers, editorial material, and corrections; (iii) studies that did not include FF in their study population; (iv) data on other health outcomes; (v) studies on (bio)markers of effect (except clinical diagnosis biomarkers); (vi) interventional studies; (vii) case-control studies. To assure that all possible studies were included, an additional search based on the references of the selected studies was done. Case-control studies are important to distinguish differences in potential risks among groups, however, these studies cannot be used to establish causality (exposure leads to effect). On the other hand, a cross-sectional design provides a random selection, which decreases the selection bias related with the choice of proper case-control groups. Moreover, follow-up investigations such as cohort studies are more suited to establish a connection between exposure and effect, whereas subject selection in a cross-sectional study does not depend on the exposure or outcome, it rather reflects a point-in-time evaluation of the population of interest. Therefore, only peer-reviewed studies published online within the last five years that were either cohort or cross-sectional studies and included the incidence, prevalence or calculated risk of respiratory and cardiovascular symptoms or disease diagnose among FF were selected.

3 Results and Discussion

A total of 810 results were found, after the applied exclusion criteria, 27 studies remained to conduct this systematic review.

3.1 Respiratory Outcomes

Inhalation is the main potential route of exposure to air pollutants which, depending on the composition and complexity of the chemical mixture, can cause different toxic effects. The human airway ramification intensifies within the lung, bigger size airborne gaseous and/or particulate matter are retained in the upper respiratory tract whereas smaller-sized can reach deeper into the lung and even diffuse into the bloodstream. Regular exposure to airborne pollutants can promote acute respiratory symptoms (*e.g.*, cough, sore throat, congestion, wheeze, *etc.*) or long-term diseases, such as asthma and chronic obstructive pulmonary disease (COPD) [6]. Moreover, since FF can also be first responders to medical emergencies, biological pollutants (*e.g.*, viruses, fungi, and pathogenic microorganisms) are also important to consider when assessing occupational health impacts in paramedic firefighters [7]. Viral infections include for example flu (influenza virus), COVID-19 (coronavirus disease 2019 caused by the virus SARS-CoV-2), and other additional types of viruses. Among the available literature, 15 studies reported the incidence, prevalence, or risk of respiratory symptoms/disease among FF and fire service instructors (Table 1).

Most of the studies presented a cross-sectional design ($n = 13$), whereas only three were cohorts. The number of FF involved varied between 47–11,968 FF (wildland, structural, military, industrial, rescue team and/or paramedic; range of mean age: 29–44.1 years), and 130 fire service instructors (mean age 43 years) were also evaluated (Table 1). Respiratory infections (*i.e.*, coronavirus disease 2019 (COVID-19), common cold or flu; $n = 8$) were the most reported, followed by respiratory symptoms ($n = 6$), and disease incidence or prevalence (respiratory, asthma and COPD; $n = 5$). The seroprevalence of COVID-19 infection in USA FF varied 0.24–21.2% (Table 1). Most studies found results that were similar or below the prevalence in the general population; only McGuire et al. [11] observed a 3-fold increase in seroprevalence in FF. These results highlighted the importance of specific PPE use by first responders along with a higher frequency of hygiene-related tasks (*e.g.*, washing hands) which provided an effective protection against COVID-19 infection [10, 12–14]. In Brazil, between January 1st and May 31st (2020) there was a 312% increase in the proportion of sick leave due to acute respiratory infections in FF in comparison to 2019 [18]. However, the authors reported that among those with sick leave ($n = 396$ FF) only 20 FF tested positive for COVID-19 infection. Approximately 27% of French FF were infected with coronavirus, and among them, ~82% were symptomatic (Table 1). Regarding cold and flu, in the United Kingdom (UK), ~46% of fire service instructors and ~51% of FF recalled having periods of infection once

Table 1 (continued)

Country	Study design	Symptoms/disease	Firefighters (FF)	Type of exposure	Results	Reference
USA	Cross-sectional	COVID-19 infection	Total participants: $n = 22,647$; Fire services personnel: $n = 4,310$	FF as first responders (includes fire inspectors and fire marshals)	Incidence of infection: 21.2%	[13]
USA	Cross-sectional of the OCFA cohort	COVID-19 infection	OCFA personnel: $n = 923$	Fire combat and paramedic services	COVID-19 was 5.3% (49 cases) Among 49 cases 13 (26.5%) were asymptomatic	[14]
USA	Cross-sectional	Upper respiratory ^b lower respiratory ^c symptoms	Career ($n = 8$) and volunteer ($n = 53$) FF $n = 61$; mean age 39.4 years	Pipeline explosion	61% of responders reporting new or worsening symptoms were FF No significant associations between responder type and development of symptoms	[15]
Canada	Cohort (established on May 2016, follow-up in October 2018 to January 2019)	Asthma and airway hyper-reactivity (increase in hyper-reactivity with bronchial wall thickening)	Industrial, structural, and wildland FF: $n = 955$ FF with exposure data: $n = 582$; mean age 38.2 years	Fort McMurray fire	OR for new onset asthma: 2.56 (95%CI: 1.75 to 3.74). 12.5% prevalence of airway hyper-reactivity in non-smoking FF without pre-fire chronic lung disease FF with ongoing problems: higher estimated exposure during the fire (mean (SD): 10.8 ± 1.4 versus 10.1 ± 1.8 log PM _{2.5} $\mu\text{g}/\text{m}^3/\text{h}$; $p = 0.005$)	[16]
Canada	Cross-sectional	Respiratory symptoms	FF: $n = 779$, mean age 41.6 years	Québec (November–December 2015)	Of 748 FF with data: prevalence of shortness of breath (8.6%)	[17]

(continued)

Table 1 (continued)

Country	Study design	Symptoms/disease	Firefighters (FF)	Type of exposure	Results	Reference
		Respiratory disease			Of 757 FF with data: prevalence of respiratory disease (7.7%)	
South America						
Brazil	Cross-sectional	Acute respiratory infection leaves and COVID-19 Infection	Active FF: $n = 5,627$	Employed at the Fire Department	7.0% ($n = 396$) were signed off work due to conditions compatible with acute respiratory infection. Among them, 20 (0.36%) tested positive for COVID-19	[18]
Europe						
UK	Cross-sectional	Cold or flu infection*	Fire service instructors (FSI): $n = 130$; mean age 43 years FF: $n = 232$; mean age 41 years	Live fire scenarios (median wears): FSI: 13; FF: 1	Recall periods of cold or flu over the last year: FSI: 27 none; 60, 1 or 2-times, 20, 3-6 times; 1, once a month; 2, 2-4 times a month FF: 51 none; 134, 1 or 2-times; 40, 3-6 times; 4, once a month	[19]
France	Cross-sectional	COVID-19 infection	Military FF: $n = 91$; mean age 29 years $n = 85$ (at work during the outbreak)	FF that also provide emergency medical assistance	Of 85 FF, 23 were confirmed positive for COVID-19 infection, being 83% symptomatic and 17% asymptomatic	[20]
Greece	Cross-sectional	Respiratory symptoms	Wildland FF $n = 60$; mean age 32.4 years	Forest firefighting operations for several days continuously	Wheezing, cough, chest tightness, sneezing, and expectoration were statistically significantly higher after firefighting as compared to off-season status ($p < 0.05$)	[21]

(continued)

Table 1 (continued)

Country	Study design	Symptoms/disease	Firefighters (FF)	Type of exposure	Results	Reference
Denmark	Cohort (1977–2015)	Asthma and COPD	FF: $n = 11,968$ Comparison group: military employees: $n = 396,963$	Employed or volunteers at the fire department	In comparison to military employees (standardized incidence ratio (95%CI)): Asthma: Full time: 1.58 (1.32–1.88); volunteer: 0.97 (0.78–1.20) COPD: Full time: 1.14 (0.98–1.32); volunteer: 0.94 (0.77–1.15)	[22]
Africa						
Nigeria	Cross-sectional	Respiratory symptoms	Professional FF: $n = 47$; mean age 44.1 years	Employed at the fire station	46.8% had cough; 48.9% had breathlessness; 12.8% nasal itching. Most reported symptoms: cough, breathlessness, sore throat, itchy throat and globus	[23]
Asia						
Iran	Cross-sectional	Respiratory symptoms	FF: $n = 110$, mean age 32 years	Active FF of the central cities of Fars province	Prevalence of shortness of breath (18.2%), chest compression (6.4%), coughs (10.0%), phlegm (17.3%), coughs and phlegm (8.2%), wheezing (9.1%)	[24]
Taiwan	Cross-sectional, three weeks after the earthquake	Respiratory symptoms	FF: $n = 414$, mean age 38.8 years	Response to the 2016 earthquake	Ongoing symptoms (% of FF): Shortness of breath (4), wheezing (2), cough (35), rhinorrhea or nasal congestion (37), chest tightness or pain (11), any symptoms (54); New or worsened symptoms (% of FF): Shortness of breath (2), wheezing (1), cough (23), rhinorrhea or nasal congestion (22), chest tightness or pain (6), any symptoms (37)	[25]

(continued)

Table 1 (continued)

Country	Study design	Symptoms/disease	Firefighters (FF)	Type of exposure	Results	Reference
		Respiratory disease diagnosis			Before exposure: Asthma: 6%; Chronic bronchitis: 7%; Sinusitis: 18%; Postnasal dripping: 23%	

CI: Confidence interval; COPD, Chronic obstructive pulmonary disease; COVID-19, coronavirus disease 2019 caused by the virus SARS-CoV-2; FF, Firefighters; FSI, Fire service instructors; OEFA, Orange County Fire Authority; OR, Odds ratio; SD, Standard deviation; UK, United Kingdom; USA, United States of America.

^aInclude fever or chills, cough, shortness of breath or difficulty breathing, headache, sore throat, new loss of taste or smell, congestion or runny nose, nausea or vomiting, or diarrhea.

^bInclude cough and runny nose.

^cInclude wheezing and difficulty breathing.

*Flu is caused by influenza viruses only, whereas the common cold can be caused by a number of different viruses.

or twice a year [19]. A recent review highlighted that respiratory infections such as COVID-19 could increase the vulnerability to smoke exposure symptoms, as well as influence the severity of COVID-19 infection in FF [7]. The highlighted mechanisms behind this association were based on the transport of SARS CoV-2 virus via particulate matter and the upregulation of angiotensin-converting enzyme II, which is a trans-membrane receptor that enables the entry of the virus into the lung epithelial cells [7]. Therefore, more studies are needed to confirm the impact of acute respiratory infections on increased vulnerability to respiratory symptoms and pathologies in FF.

Considering respiratory symptoms of the emergency responders that attended to a pipeline explosion in Kentucky, USA, 61% of the subjects reported having new or worsening upper or lower respiratory symptoms; however, there were no significant differences between responder function and development of symptoms [15] (Table 1). On the other hand, for FF from Québec, Canada, a prevalence of 8.6% of shortness of breath was observed outside the fire season months (November–December; [17]). Further, in the 2016 earthquake disaster in Taiwan, three weeks after the event, 0.5–13% of FF presented ongoing symptoms and 0.2–9% of all FF had new or worsen respiratory symptoms [25]. Nevertheless, there were significantly higher respiratory illness indicators such as wheezing, cough, chest tightness, sneezing, and expectoration after forest firefighting (several days continuously) in contrast with the off-season status in Greek FF [21]. None of the characterized Greek FF had been previously diagnosed with asthma, COPD, disease, bronchiectasis, or any other chronic condition of the lung, and only 2% had allergic rhinitis [21]. Moreover, a high prevalence of respiratory symptoms in Nigerian and Iranian professional FF was observed, being breathlessness, cough, phlegm, sore throat, itchy throat and globus the most frequently reported [23, 24].

Concerning respiratory diseases, in a cross-sectional study of Québec FF there was a 7.7% prevalence of respiratory disease [17]. A Canadian cohort included (industrial, structural, and wildland) FF who were exposed to the Fort McMurray Fire, a devastating wildfire that spread and destroyed around 2,400 homes and buildings [16]. The probability of new onset asthma was 2-fold higher for exposed FF, whereas the prevalence of airway hyperreactivity was 12.5% in non-smoking FF without pre-fire clinical diagnosis of chronic lung disease [16]. In a Danish cohort (1977–2015), there was an augmented standardized incidence ratio of asthma and COPD, 58% and 14% increase, respectively, in comparison to a cohort of military employees [22]. These findings were evident for Danish full-time FF but not for volunteers, standardized incidence ratios of 1.58 *versus* 0.97 for asthma, and 1.14 *versus* 0.94 for COPD, respectively (Table 1). In this cohort, despite the evidence for respiratory disease incidence in FF, the causes (occupational or not) remained to be determined [22]. Lastly, FF that were exposed to the 2016 earthquake in Taiwan, displayed a prevalence of asthma (6%), chronic bronchitis (7%), sinusitis (18%), and postnasal dripping (23%) [25].

The available findings (Fig. 1) further confirm that the rise of respiratory symptoms is tightly linked to the nature of exposure. Moreover, the type of PPE (*i.e.*, structural, wildland firefighting, paramedic) and tasks performed can also influence the different

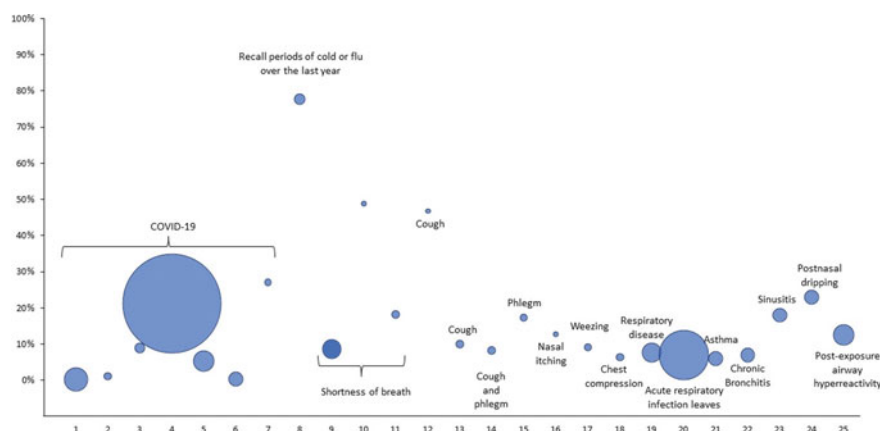


Fig. 1 Reported prevalence (%) of respiratory outcomes in firefighters. COVID-19: coronavirus disease 2019 caused by the virus SARS-CoV-2. 1: [10]; 2: [11]; 3: [12]; 4: [13]; 5: [14]; 6, 20: [18]; 7: [20]; 8: [19]; 9, 19: [17]; 10, 12, 16: [23]; 11, 13–15, 17, 18: [24]; 21–24: [25]; 25: [16]

impacts on short and long-term respiratory effects. Regarding structural FF, a recent review highlighted a high variability in findings concerning lung function decline among FF [26]. The lower lung function decline found in structural FF suggested that the use of self-containing breathing apparatus (SCBA) constitutes an effective protection against inhalation hazards. On the other hand, wildland firefighting' PPE could be less effective regarding respiratory protection (a SCBA cannot be worn due to the wildland fire combat conditions). The fact that most FF are volunteers and not career workers can also influence the health impact assessment. Therefore, these differences need to be considered in future research.

3.2 Cardiovascular Outcomes

The strenuous work during firefighting increases the physiological burden on the cardiovascular system. Heart rate augments, higher blood pressure, metabolic alterations, and rise in body temperature are important mechanisms that allow FF to do their job under stressful situations. However, frequent exposure to high demanding tasks can lead to body exhaustion and deregulation of important pathways that can later contribute to cardiovascular disease (CVD) development. The FF highest mortality cause in line-of-duty is CVD-related diseases [27]. Moreover, several factors such as obesity, dyslipidemia, metabolic syndrome (*i.e.*, combination of diabetes, hypertension, and obesity), tobacco consumption, and sedentarism are among the most important CVD risk factors, which were observed to be frequently prevalent in FF from the USA, Malaysia, Chile, Belgium, Iran, Brazil, Italy, Finland, and Germany [28]. Therefore, it is imperative to understand if increased risk factors

are reflected on an increased CVD or related symptoms in this occupational group. Within the available literature, 12 studies performed an evaluation of CVD symptoms and disease incidence or prevalence among FF and fire service instructors (Table 2).

Cross-sectional ($n = 8$) and cohort studies ($n = 6$) explored the incidence/prevalence of CVD-related symptoms ($n = 3$) and diagnosis ($n = 10$) in FF (type: career/full-time and part-time/volunteer; 61–31,743 FF, mean age range: $37.5 \geq 55$ years), and fire service instructors (130 individuals, mean age 43 years) (Table 2). The most reported CVD symptoms (Fig. 2) were heart-related (*e.g.*, angina and elevated heart rate) in USA FF (prevalence of 61%); chest, neck, jaw pain/discomfort, dizziness or syncope, orthopnea or sleep apnea, ankle edema, palpitations or tachycardia, intermittent claudication, and known heart murmur in Canadian FF (prevalence of 4.7–12%), and heart palpitations in UK fire service instructors (prevalence of 3%) (Table 2). These CVD-related indicators were observed in FF that attended an emergency call to a pipeline explosion in Kentucky, FF that were part of the fire service of Québec, and fire service instructors exposed to live fire scenarios with adequate PPE, respectively for USA, Canada, and UK studies.

Regarding all CVD among FF, there was a 10% increase in standard incidence ratio (SIR) in the Danish FF cohort (1977–2015) when compared to the general population employees, but similar SIRs as those of military employees [34]. However, subgrouping into career and volunteer FF, no significant SIR was found for all CVD in the latter group [34]. In a cross-sectional study of South Korean FF, no differences were observed in CVD prevalence when comparing FF with police officers and government officials [37]. However, when Min et al. [37] compared FF with a cohort of the general population, South Korean FF (cohort 2002–2015) presented a higher hazard risk ratio (20% increase) for major adverse CVD events. The most frequently reported CVD disease was hypertension ($n = 4$), in which FF from Canadian and South Africa cross-sectional studies had prevalence of 11% and 33%, respectively (Table 2). These differences among countries are not surprising due the shift on hypertensive population prevalence from high-income to low-income countries that has been observed in the last decades [40]. There was a 69% hypertension prevalence in USA FF (17% were already medicated), which was higher than the prevalence found in the general USA population (11–16%; [32]). In a French FF cohort study, there was a prevalence of 22.4% (note that for the cohort, FF were selected based on CVD risk) [35]. Regarding other related ailments, atherosclerotic CVD life-time prevalence was significantly superior for FF that combat more than 11 fires/year in comparison to those that fight less than 10 fires/year (10.2% *versus* 4.7%, $n = 10,000$ FF, $p < 0.001$; [29]). The associated 60% increased risk for the most yearly exposed FF was independent of other factors such as age, sex, body mass index, diabetes mellitus, hypertension, and consumption of tobacco [29]. Moreover, two additional cohorts observed a 10-year atherosclerotic CVD score ($\geq 5\%$) prevalence of 23.6–25% among FF [30, 31]. In Canadian FF, there was a prevalence of heart arrhythmia (2.5%), bypass surgery/angioplasty (1.6%), other heart surgeries (1.3%), heart attack (1.2%), stroke (0.4%), pacemaker/implantable cardioverter defibrillator (0.1%), valve disorders (0.5%), and congenital heart disease (0.7%); none of the FF suffered from heart failure nor received a heart transplant [17]. Comparing to the

Table 2 Cardiovascular-related symptoms or disease incidence, prevalence or risk reported in firefighters

Country	Study design	Symptoms/disease	Type of firefighters (FF)	Type of exposure	Results	Reference
<i>North America</i>						
USA	Cross-sectional	Cardiac symptoms (<i>e.g.</i> , elevated heart rate, angina)	Career (<i>n</i> = 8) and volunteer (<i>n</i> = 53) <i>n</i> = 61; mean age 39.4 years	Pipeline explosion	61% of responders reporting new or worsening symptoms were FF; no significant associations between responder type and the development of symptoms	[15]
USA	Cross-sectional	Atherosclerotic CVD (ASCVD)	FF: <i>n</i> = 10,000, age ≤ 55 years	From five organizations who represent USA FF	Lifetime prevalence of ASCVD: ≥ 11 fires/year (10.19%); ≤ 10 fires per year (4.70%, <i>p</i> < 0.001); ≥ 11 fires/year independently associated with ASCVD (OR 1.60, 95% CI: 1.31–1.95, <i>p</i> < 0.001)	[29]
USA	Cohort	Atherosclerotic CVD (ASCVD)	FF: <i>n</i> = 647, mean 47.7 years	FF from the Northern Virginia and Arizona	Prevalence of 10-year ASCVD risk ≥ 5% [‡] ; 23.6%	[30]
USA	Cohort	Atherosclerotic CVD (ASCVD)	FF: <i>n</i> = 294, age range 39–≥ 55 years	FF from Colorado	Prevalence of 10-year ASCVD risk ≥ 5% [‡] ; 25%	[31]

(continued)

Table 2 (continued)

Country	Study design	Symptoms/disease	Type of firefighters (FF)	Type of exposure	Results	Reference
USA	Cross-sectional	Hypertension	Professional FF: <i>n</i> = 5,337, mean age 41.8 years	Medical records	Prevalence of 69%, among them, 17% were taking antihypertensive medications. Higher prevalence in FF (11–16%) in comparison to 2015– 2016 and 2017–2018 NHANES	[32]
Canada	Cross-sectional	Hypertension	FF: <i>n</i> = 101, mean age 40 years	Union of Québec	Prevalence of 11%	[33]
Canada	Cross-sectional	CVD symptoms	FF: <i>n</i> = 779, mean age 41.6 years Full-time: 74.5 %, mean age 42.7 years; parttime: 15.4%, mean age 38.3 years; volunteer: 10.1%, mean age 38.9 years	Québec (November–December 2015)	<i>n</i> = 748: prevalence of chest, neck, jaw pain/ discomfort (8.2%), dizziness or syncope (12.0%), orthopnea or sleep apnea (6.0%), ankle edema (5.1%), palpitations or tachycardia (9.4%), intermittent claudication (5.7%), known heart murmur (4.7%)	[17]

(continued)

Table 2 (continued)

Country	Study design	Symptoms/disease	Type of firefighters (FF)	Type of exposure	Results	Reference
		CVD diseases			<i>n</i> = 757; prevalence of heart attack (1.2%), stroke (0.4%), pacemaker/ICD (0.1%), bypass surgery/angioplasty (1.6%), other heart surgery (1.3%), valve disorders (0.5%), congenital heart disease (0.7%), heart arrhythmia (2.5%); heart failure or heart transplant (0%)	
<i>Europe</i>						
UK	Cross-sectional	Heart palpitations	Fire service instructors (FSI): <i>n</i> = 130; mean age 43 years FF: <i>n</i> = 232; mean age 41 years	Live fire scenarios with breathing apparatus or Compartment Fire Behavior Training (median wears); FSI: 13; FF: 1	FSI: 4 self-reported to suffer from heart palpitations	[19]

(continued)

Table 2 (continued)

Country	Study design	Symptoms/disease	Type of firefighters (FF)	Type of exposure	Results	Reference
Denmark	Cohort (1977-2014 ^a)	CVD diseases incidence	FF: <i>n</i> = 11,691, mean age* 52 years Full-time FF: <i>n</i> = 4,678; mean age* 58 years; Part-time/Volunteer FF: <i>n</i> = 7,013, mean age* 48 years	Hospitalized and registered on the Danish National Patient Registry	SIR: all CVDs: 1.10 (95% CI: 1.05–1.15), angina pectoris: 1.16 (95% CI: 1.08–1.24), acute myocardial infarction: 1.16 (95% CI: 1.06–1.26), chronic ischemic heart disease: 1.15 (95% CI: 1.06–1.24), and atrial fibrillation/flutter: 1.25 (95% CI: 1.14–1.36); in comparison to the general population employees (<i>n</i> = 396,906). No differences between FF and military employees (<i>n</i> = 262,548). Significant SIRs: Full-time FF: All CVDs, angina pectoris, acute myocardial infarction, chronic ischemic heart disease, heart failure, cardiac arrest, and atrial fibrillation/flutter (1.12–1.21) versus part-time/volunteer FF: Atrial fibrillation/flutter (1.17, 95% CI: 1.02–1.35)	[34]

(continued)

Table 2 (continued)

Country	Study design	Symptoms/disease	Type of firefighters (FF)	Type of exposure	Results	Reference
France	Cohort (June 2006-May 2013)	Hypertension	FF: $n = 538$, percentage of FF with age > 50 years (31.9%) Career FF: $n = 158$; Volunteer: $n = 400$	Selected according to CVD risk	Prevalence: 22.4% in all FF; 27.8% in full-time FF (age > 50 years: 35.4%), and 20.2% in Volunteer FF (age > 50 years: 29.5%)	[35]
Africa						
South Africa	Cross-sectional	Hypertension	FF: $n = 124$, mean age 37.5 years	City of Cape Town Fire and Rescue Service	Prevalence of 33.1%	[36]
<i>Asia</i>						
South Korea	Cross-sectional	CVD and cerebrovascular disease prevalence	FF: $n = 31,743$, age range 20- > 55 years	Korean National Health Insurance Service database	CVD disease prevalence in FF similar to government officials ($n = 100,467$) and police officers ($n = 1,053,198$)	[37]

(continued)

Table 2 (continued)

Country	Study design	Symptoms/disease	Type of firefighters (FF)	Type of exposure	Results	Reference
South Korea	Cohort (13-year follow-up)	CVD diseases incidence	FF: <i>n</i> = 23,356	Korean National Health Insurance Service database (<i>n</i> = 860,221, mean age 39.6 years)	Significant HR for incident diseases: Angina pectoris (1.06), acute myocardial infarction (1.21) in comparison to national and regional government officers (<i>n</i> = 405,463)	[38]
South Korea	Cohort (2002–2015)	Major adverse CVD events (MACE)	FF: <i>n</i> = 8,242	Korean National Health Insurance Service database (2002–2015)	Significantly higher risk of MACE (HR, 1.20; 95% CI, 1.09–1.31), and myocardial infarction (HR, 1.22; 95% CI, 1.10–1.35) than the general Korean population (<i>n</i> = 28,678)	[39]

ASCVD: Atherosclerotic cardiovascular disease; CI, Confidence interval; CVD, Cardiovascular disease; FF, Firefighters; FSI, Fire service instructors; HR, Hazard ratio; ICD, Implantable cardioverter defibrillator; MACE, A composite of cardiovascular death, myocardial infarction, ischemic stroke, and hemorrhagic stroke; NHANES, National Health and Nutrition Examination Surveys; OR, Odds ratio; SIR, Standard incidence ratio; UK, United Kingdom; USA, United States of America.

*age at the end of follow-up;

¥10-year ASCVD risk based on pooled cohort algorithm published in 2013 American College of Cardiology/American Heart Association Guideline on the Assessment of Cardiovascular Risk [30]. a: follow-up period started from the date of first employment or 1 January 1977, whichever came latest, and follow-up ended on the first date of hospitalization, death, disappearance, emigration from Denmark or 31 December 2014, whichever came first.

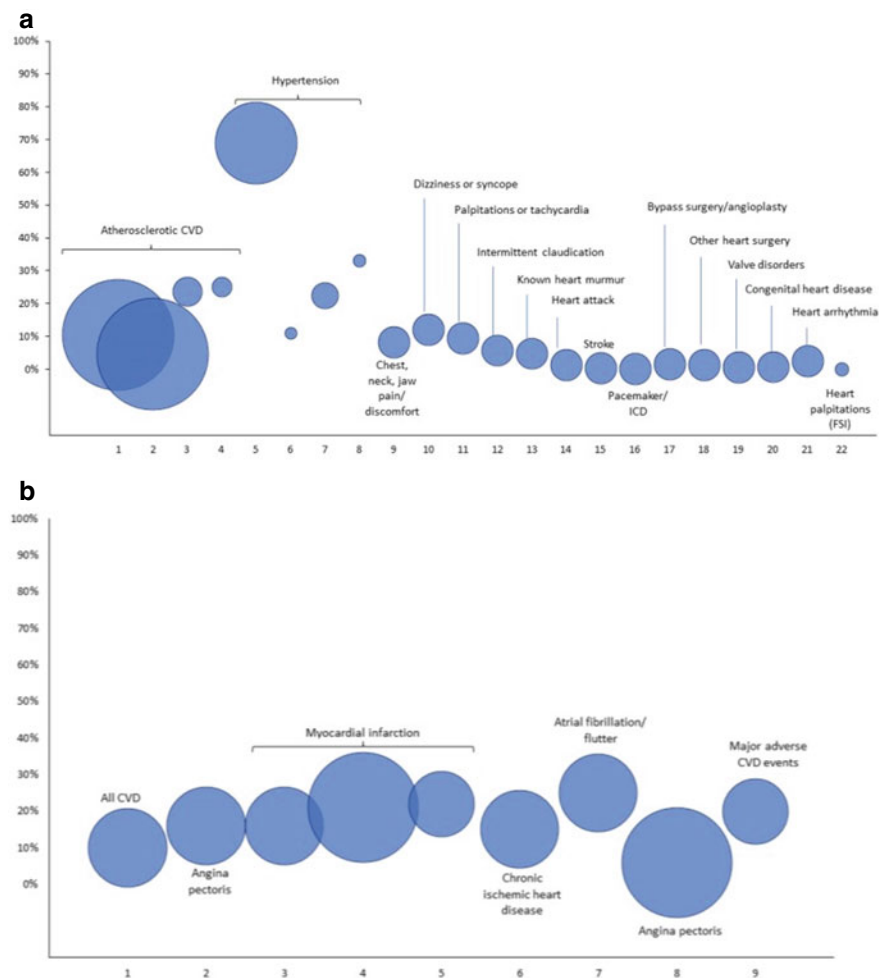


Fig. 2 Reported cardiovascular disease (CVD) outcomes in firefighters: **a** prevalence (%); **b** increase in incidence (%) based on hazard ratios and standardized incidence ratios. ICD: implantable cardioverter-defibrillator; FSI: Fire service instructors. A1, A2: [29], A3: [30], A4: [31], A5: [32], A6: [33], A7: [35], A8: [36], A9–A21: [17]; A22: [19]. B1–B3, B6, B7: [34]; B4, B8: [38], B5, B9: [39]

general population employees, FF presented an augmented SIRs (15–25%) in angina pectoris, acute myocardial infarction, chronic ischemic heart disease, and atrial fibrillation/flutter [34]. Nevertheless, no differences were observed in the incidence ratios between FF and military employees [34]. Full-time Danish FF presented higher and significant SIRs (1.12–1.21) for more types of CVDs than part-time/volunteer FF (only significant for atrial fibrillation/flutter: 1.17; [34]). Lastly, among South Korean

FF, there was an increased risk for angina (hazard ratio: 1.06) and (acute) myocardial infarction (hazard ratio: 1.21–1.22). These results were lower than in FF from other countries, *i.e.*, USA and Denmark, (6% *versus* 16%) for angina, and higher for (acute) myocardial infarction (21–22% *versus* 16%). Min et al. [37] observed that South Korean FF had higher medical costs with cardio-cerebrovascular diseases than other occupations (*i.e.*, military personal and government officials), especially for ischemic heart disease, which represented a 12-times higher investment by FF. Overall, the reported findings (Fig. 2) were consistent for augmented risk of CVD in FF and highlighted that there might be differences between professional and volunteer FF.

4 Conclusions

Working as an FF is carcinogenic to humans, however, the prevalence/incidence of respiratory and cardiovascular disease in association with occupational exposure is yet underrepresented in this context due to a major research focus on risk factors analysis and a higher influence of individual characteristics to the long-term disease development. Most of the studies were cross-sectional studies, yet large cohort studies (*n*: 538–23,356 FF) were available for countries such as South Korea, Denmark, France, Canada, and USA. The findings confirm the presence of cardiorespiratory symptoms related to firefighting activities and fire service instruction. Incidence ratios for asthma and COPD, a higher prevalence of hypertension, atherosclerotic CVD disease, and increased hazard ratios for several CVD, especially (acute) myocardial infarction are identified. Cardiorespiratory disease cases were frequently higher in FF than in other type of workers and in some cases also above what is observed for the general population. This review was limited by the search period (last five years) and using only one database (Web of Science). However, the generated evidence suggests the need of more regular occupational surveillance programs. In particular, more attention should be given to volunteer FF because they may have several years of service, they are less likely to be monitored regularly. Future studies should aim to establish the molecular mechanisms underlying the development of occupational-related diseases in firefighting context.

Acknowledgements The FCT support by UIDB/50006/2020, UIDP/50006/2020, LA/P/0008/2020, 2022.05381.PTDC and PCIF/SSO/0090/2019 projects through national funds is acknowledged. M. Oliveira and B. Barros thank FCT to the CEEC Program Contract CEECIND/03666/2017 and the grant 2020.07394.BD, respectively.

Funding This work received financial support by the project PCIF/SSO/0017/2018 by the Fundação para a Ciência e a Tecnologia (FCT) through national funds.

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Indoor Air Quality in Fitness Centers with/without the Restrictions of COVID-19



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Abstract After the lockdown due to COVID-19, the sports facilities were subjected to specific public health rules, namely in terms of the type of ventilation, hygiene and sanitation and restrictions for occupancy. This study aimed to evaluate the impact of public health restrictions on levels of gaseous pollutants (CO₂ and total volatile organic compounds—TVOCs) and comfort parameters (temperature—T, relative humidity—RH) in the indoor air of fitness centres. Indoor air sampling (CO₂, TVOCs, and comfort parameters) were continuously (24 h) monitored (Gray-wolf probe) in five fitness clubs (Oporto Metropolitan Area, Portugal) for 10–12 days under two scenarios—during and after the period with specific public health restrictions. The results showed that the implemented restrictions have affected all parameters. Occupancy-level limitations resulted in reduced CO₂ (1.1–2.6 times) and RH (0.97–1.4 times). On the contrary, requirements for cleaning and frequent use of cleaning products and disinfectants led to increased (1.0–2.2 times) TVOCs. Finally, the prohibited use of air conditioning resulted in difficulties maintaining temperatures within the recommended values. In general, the restrictive measures to control COVID-19 have significantly changed indoor environmental quality of fitness centres. Further studies about air quality occupants related indicators are required.

Keywords Gaseous pollutants · Comfort parameters · Air quality · Ventilation restrictions · Cleaning Guidelines

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1 Introduction

Physical activity is an essential factor for the quality of life; frequent exercises, such as walking or bicycling, present excellent health benefits [1]. To maintain the current level of health, the World Health Organization (WHO) recommends for adults (aged 18–64 yrs.) either a minimum of 150–300 min of moderate-intensity aerobic physical activity per week or a minimum of 75–150 min per week of vigorous-intensity aerobic; or an equivalent combination of both types of intensity-activity throughout the week [2]. Further recommendations are then provided for additional health benefits [2]. Despite the known positive aspects of exercising, the worldwide trend has shifted towards less daily physical activity. It has been estimated that approximately 30% of the worldwide adult population is insufficiently active [3, 4], being linked to a higher risk for cardiovascular diseases [5, 6]. A clean environment is also essential for human health and well-being. Considering the environmental perspective, one of the most relevant health concerns is air quality in spaces in which people spend their time, both indoors and outdoors [7, 8]. Exposure to air pollution has been linked with increased mortalities and cardiorespiratory morbidity, including many adverse health effects (cancers of different organs, impaired neuro- and cognition development, diabetes—type 2) [9]. Health clubs and fitness centers then represent a unique indoor microenvironment where, due to highly intense inhalation induced by physical activities, occupants may be exposed to greater risks of some relevant indoor pollutants [10]. When the COVID-19 pandemic occurred, sports facilities such as gyms and fitness centers were closed in Portugal due to the general lockdown of the country. In the phase immediately after, to re-establish societal life, the sport facilities were still subjected to specific health rules (ventilations, social distancing, etc.), which aimed to prevent a new wave of infection [11, 12].

Thus, this study aims to evaluate the levels of gaseous pollutants (namely carbon dioxide—CO₂ and total volatile organic compounds—TVOCs) and comfort parameters (temperature—T, and relative humidity—RH) in the indoor air of fitness centers during the period of public health restrictions and after lifting them (i.e., without any ventilation/occupancy restrictions).

2 Materials and Methods

The study was conducted in five fitness centers (FC1–5) that belonged to a chain of low-cost fitness centers. Concerning the position, the health clubs were located either in urban-background or urban-traffic areas of the Oporto Metropolitan Area (north of Portugal). The detailed characteristics of the five FC are summarized in Table 1, but they generally showed similar organizations and structures. All FCs were equipped with Heating, Ventilation, and Air Conditioning (HVAC) systems. Daily occupancy ranged from 200 to 210 visits (FC1) to 2300–2500 (FC2); FC3–FC5 exhibited between 400 and 530 fitness practitioners per day.

Table 1 Characterization of the five studied fitness centers (FC1–FC5)

	FC1	FC2	FC3	FC4	FC5
Year of constructions	2018	2019	2018	2019	2021
Outdoor characterization	Urban-traffic	Urban-background	Urban-background	Urban-traffic	Urban-background
Location	– Located on the ground floor of a commercial area; – Without any protective closing or main entrance; – Located next to an industrial area and a high-traffic main road	– Located at the bottom of a building (at the level of the garages); – Situated in an urban environment with greenery around it; – Next to the Wastewater Treatment Plant's green park; – Close to the airport and some factories	– Located in a shopping mall, on the top floor; – With a direct connection to the restaurant area; – Mall located in a residential environment	– Located in a large shopping mall; – The entrance independent of the entrance to the mall; – Located in an industrial environment; – Area with a lot of car traffic, next to the motorway accesses	– Located at the bottom of a building; – At street level; – Located in an urban environment; – Lots of vegetation around it and land without housing

(continued)

Table 1 (continued)

	FC1	FC2	FC3	FC4	FC5
Main construction materials	Brick, concrete, ceramic, plastic tiles, glass, plasterboard, wood and mirrors	Brick, concrete, ceramic, plastic tiles, glass, plasterboard, wood and mirrors	Brick, concrete, ceramic, plastic tiles, glass, plasterboard, wood and mirrors, Portuguese cobblestone (limestone)	Brick, concrete, ceramic, plastic tiles, glass, chipboard, plasterboard and mirrors	Brick, concrete, ceramic, plastic tiles, glass, plasterboard, wood and mirrors
Ventilation	HVAC	HVAC	HVAC + mall ventilation	HVAC	HVAC
Swimming pool	No	No	No	No	Yes
C&B area (m ³)	Located on 2 floors 5040/725	Located on 1 floor 1610	Located on 1 floor 818	Located on 2 floors 1509/189	Located on 1 floor 980
Studios for group classes (m ³)	2 296/232	2 525/1066	1 526	2 749/ 226	1 230
Studio for cycling (m ³)	1 241	1 353	1 268	1 235	1 244
Note	Without barriers, direct connection to the streets	Without barriers, direct connection to the	Unusual architectural layout; Functional zones directly connected to the restaurant areas; No barriers to separate air environment in these two zones (fitness areas and shopping areas)		

The air quality monitoring was carried out in each fitness center during two different phases: under specific public health regulations (autumn/winter 2021/2022) and repeated under normal conditions with all the restrictions lifted (autumn/winter 2022/2023). During the first period with the epidemiological restrictions (controlled—C), the sports facilities were subjected to specific and temporary sets of rules, namely for hygiene, control of occupancy and ventilation. Firstly, aeration of spaces through natural or mechanical ventilation was conducted 6 times per hour. In case of mechanical ventilation systems, the air must be drawn in directly from the outside and without any possibility of air recirculation. It is necessary to emphasize that during this phase, the air conditioning of the HVAC system was constantly turned off (even for group activity classes) [11]. Regarding the occupancy, the maximum capacity of spaces had to be reduced to guarantee the physical distance of users, with a minimum of 3 m between the subjects. Lastly, equipment and space regular disinfection was obligatory (before and after each use of equipment/space) and was continuously conducted both by users and staff; disinfection product types were mandatory based on the respective equipment/space surfaces. Further guidelines emphasized frequent hand disinfection and other general hygiene recommendations [12] for club users. The second sampling period (not controlled—NC) was conducted under normal conditions when ventilation was fully achieved by HVAC systems, including frequent use of air conditioning; occupancies were permitted according to the maximum capacity allowed in each health club.

The air monitoring was performed for 10–12 days in each FC, with all measurements performed continuously (24 h) during the weekdays (Monday to Friday). Gaseous pollutants (CO₂ and TVOCs) and comfort parameters (T and RH) were continuously monitored by a multi-gas sensor probe (model TG 502; GrayWolf Sensing Solutions, Shelton, USA) with a logging interval of 1 min. Before the sampling campaign, all equipment was calibrated at the manufacturer and regularly checked during the sampling period. The technical note NT-SCE-02 that establishes the methodology for periodic audits of IAQ in service buildings (discontinued by Decree-Law n° 101-D/2020) indicates that the measurement points must not be less than 1 m from the sources of contamination and all measurements must be made at the level of the airways, at the points deemed most unfavorable for the parameter in question. Thus, according to previous studies [13, 14], the equipment was positioned at approximately 1.3 ± 0.2 m above the floor surface and at least 1.5 m from walls to minimize the influence on pollutant dispersion. All direct emission sources that might interfere with data acquisition (i.e., air conditioners, ventilation points, entrance exits) were avoided. Additional information (such as occupancies, physical activities, unusual or pertinent occurrences relevant for ventilation or possible emission sources, etc.) was collected by a research team member who was always present at the site. When necessary, the staff clarified further required details and unusual occurrences.

Statistical data analyses were conducted using Microsoft Excel (Microsoft 365 MSO) and SPSS (IBM SPSS Statistics 28). As normal distributions of the obtained data was not confirmed, nonparametric Kruskal–Wallis test and All Pairwise Method

was used to compare the respective medians (threshold of statistical significance set at $p < 0.05$).

3 Results and Discussion

3.1 CO_2 and TVOCs

A summary of the CO_2 levels at five fitness centers is shown in Fig. 1, with obtained results indicating that overall CO_2 concentrations were significantly higher in 80% of FC during the period without any ventilation restrictions (NC).

When restrictive public measures (period C) were in place, mean CO_2 at five FC ranged from 1265 to 2018 mg/m^3 (overall range: 761–8296 mg/m^3). When control measures were no longer mandatory (NC), the respective values increased (1.1 and 2.6 times) all FC1–FC5, with means of 1459–4184 mg/m^3 (overall range: 1236–4744 mg/m^3). Since 2013, indoor air quality audits have been no longer mandatory in Portugal. However, existing commercial buildings and services are subject to compliance with protection thresholds and reference conditions for indoor air pollutants as stipulated in Ordinance n° 138-G/2021. For CO_2 , the protective limit value is set to 2250 mg/m^3 . Despite the overall increase of CO_2 levels during the not-controlled scenario, CO_2 exceeded the respective protection limits only in FC2, which exhibited much higher occupancy of users (5–12 times) than other FC.

In sports facilities, CO_2 is the main result of human respiration [16]. Its production rate primarily depends on the number of people in the room and their metabolic

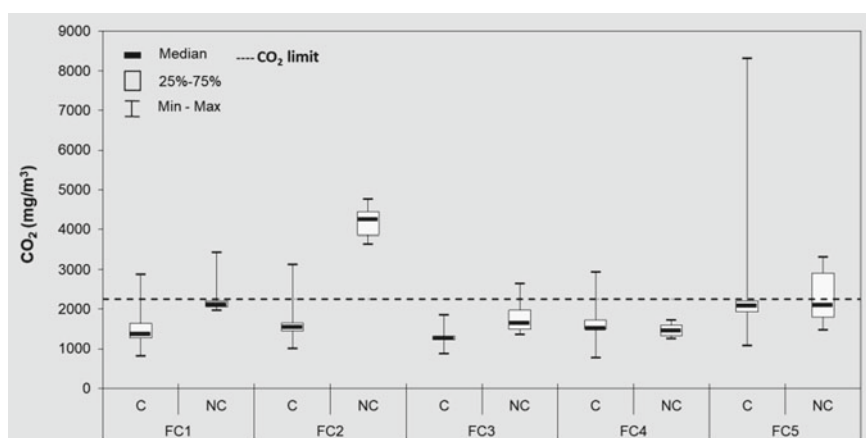


Fig. 1 CO_2 levels at five fitness centers during two different periods: under specific public health regulations (C) and normal conditions with all public health restrictions lifted (NC). The horizontal lines represent the Portuguese protection threshold [15] for CO_2 (2250 mg/m^3)

levels [16, 17]. CO₂ concentration is also considered one of the main parameters for evaluating ventilation performance in buildings [18]. When the specific sanitary restrictions were in force, observed CO₂ levels were lower than the previously reported [19, 20]. This decrease was most likely caused by the lesser occupancies in the spaces (due to occupants' number per surface area restrictions) and, consequently, lower CO₂ associated with the occupants' activity [19]. Whereas CO₂ does not pose any hazard to human health at the concentration levels observed in clubs, exposure to moderate concentrations can cause changes in human performances and influence decision-making [21, 22].

Figure 2 summarizes TVOC levels in the five FC. Under the restricted period (phase C), mean concentrations ranged from 0.41 to 3.14 mg/m³ (overall range: 0.06–24.6 mg/m³). These results showed that TVOCs exceeded the Portuguese protective threshold (0.600 mg/m³; Ordinance n° 138-G/2021) in 80% of the clubs (namely in FC2–FC5). Furthermore, the secondary stipulation expressed as a margin of tolerance (100% of the protective threshold) was also surpassed, with maximum TVOC concentrations being 2.4–20.5 times higher. When public health restrictions were lifted (NC), the observed mean TVOCs were 0.89–2.15 mg/m³ (range: 0.26–6.05 mg/m³). These results demonstrate that under the usual not-controlled scenario, when compulsory disinfection procedures and occupancy limitation were no longer required, the TVOC protective threshold was still exceeded in all FC. However, the respective TVOC levels decreased (1.1–1.8 times) in three (i.e., 60%) fitness centers (namely FC2, FC3 and FC5).

In sports facilities, the typical sources of TVOCs include using cleaning products to disinfect spaces, equipment and hands, rinse aid, surface impregnation, and anti-slip agents [23]. Other studies [24, 25] observed increased indoor TVOCs directly emitted from the occupants (through exhaled breath and perspiration; [26,

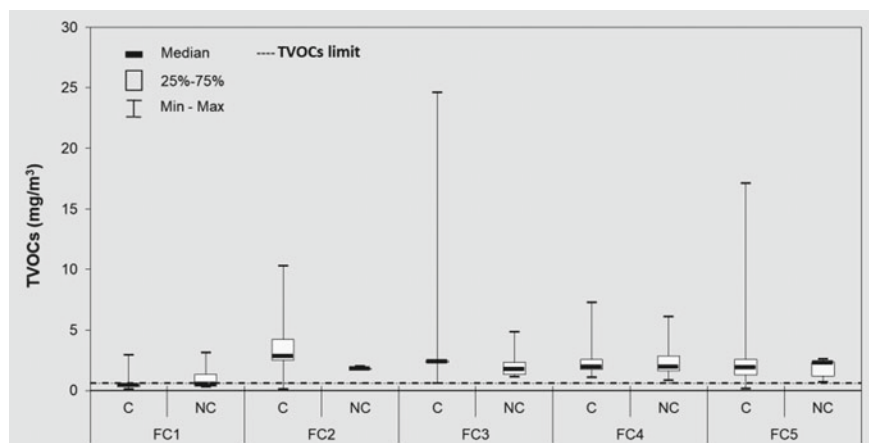


Fig. 2 TVOCs levels at five fitness centers during two different periods: under specific public health regulations (C) and normal conditions with all public health restrictions lifted (NC). The horizontal lines represent the Portuguese protection threshold [15] for TVOCs (0.600 mg/m³)

27]. Finally, some authors also previously reported the relevance of personal care products in sports facilities (such as deodorants, perfumes and hair sprays; [28]) or specific fitness products, such as talcum powder [23]. Under the period with public health restrictions, the use of bathrooms was limited at first [11, 12]. Additionally, many users (per personal preference) opted to refrain from using the shower rooms. Hence it is assumed that increased TVOCs resulted mainly from the regular cleaning procedures throughout the day and excessive use of cleaning products and disinfectants [29]. At the same time, the limited air recirculation of indoor space may have led to the accumulation of indoor pollutants, as reported previously [13].

3.2 *RH (%) and $T (^{\circ}C)$*

Relative humidity and temperature affect the thermal comfort of the respective occupants in indoor spaces. The levels of RH in five fitness centers during the two sampling periods are shown in Fig. 3.

The mean RH values obtained during the period with public health regulations varied between 50 and 64%. When the specific sanitary restrictions were lifted, RH increased in 60% of the health clubs, ranging between 61 and 72%. In sports facilities, indoor relative humidity mainly results from breathing and human sweat during physical exercise, generating a substantial amount of water vapor [31]. The increased RH during the not-controlled scenario was probably due to the higher number of occupants during this phase. Portuguese legislation also includes an ordinance that approves the Technical Regulation of Sports Facilities [30] and provides the values of

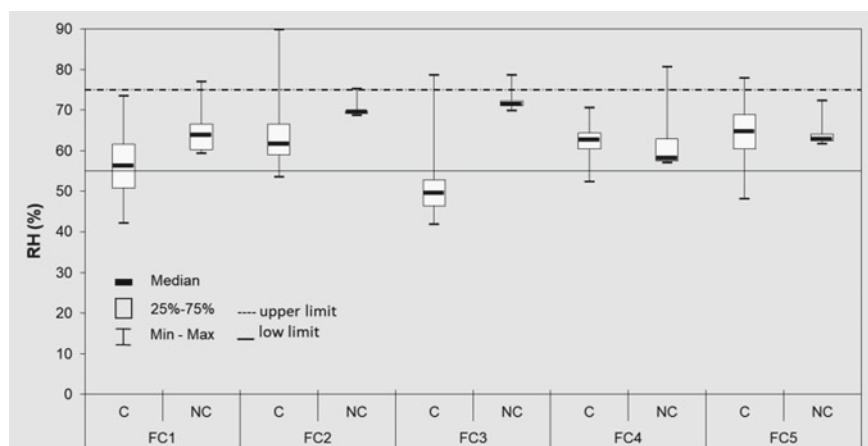


Fig. 3 Relative humidity (RH) levels at five fitness centers during two different periods: under specific public health regulations (C) and normal conditions with all public health restrictions lifted (NC). The horizontal lines represent the Portuguese protection threshold [30] for RH (upper limit: 75% and low limit: 55%)

temperature and relative humidity recommended for sports facilities. The reference values for relative humidity are 55–75% for the temperature range from 16 °C to 22 °C in winter and 18 °C to 26 °C in summer. The obtained RH means were within limits established by the comfort guidelines, except for FC3 (mean of 50% when the restrictions took place) most likely due to the combined effect of lower occupancy and the unusual layout of the respective FC. All functional spaces of FC3 were situated in mezzanine of shopping mall directly above restaurants areas. No barriers existed to separate air environment in these two zones. Ventilation was provided to the system of shopping mall.

Concerning the temperature, the obtained results are shown in Fig. 4. During the first sampling period, when public health restrictions took place, the mean T values varied between 21.5 °C and 23.6 °C. Under the typical not-controlled scenario, the obtained averages were lower in each FC, with mean values between 19.6 °C and 21.6 °C. Considering the temperature guidelines for winter, under the standard not-controlled ventilation/occupancy scenario, all FC fulfilled the required reference value.

As the human body adds to room heat, accumulating a larger number of room occupants can increase air temperature [31]. The inability of air conditioning when public restrictions were implemented [11, 12] may result in overall higher T levels (1.01–1.10 times), despite the lower occupancy during that period. In agreement, three FC (namely FC1, FC3, and FC5) exceeded the recommended reference value during the restricted period, which reinforces the need to maintain comfort parameters

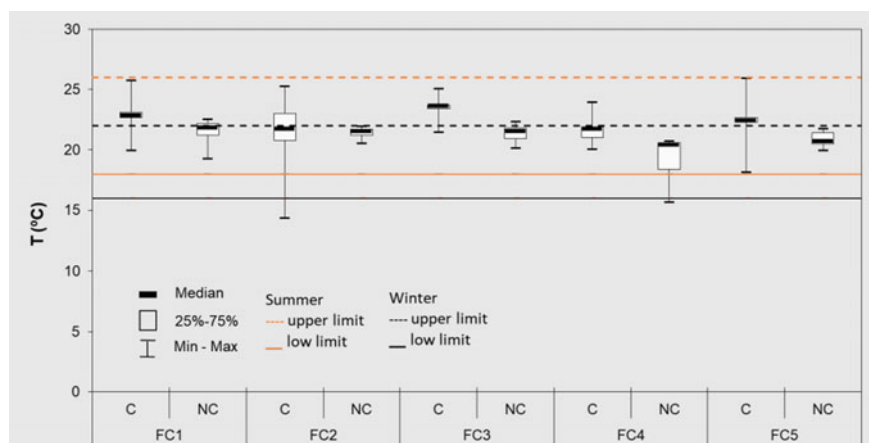


Fig. 4 Temperature (T) levels at five fitness centers during two different periods: under specific public health regulations (C) and normal conditions with all public health restrictions lifted (NC). The horizontal lines represent the Portuguese protection threshold [30] for T (orange line for summer with upper limit threshold: 26 °C and lower limit: 18° (black line—winter with upper limit: 22 °C and low limit: 16 °C)

within the recommended ranges by the proper use of air conditioning systems, isolation of environments, sun/heat reductions, etc., as the variation of these parameters can cause several consequences to health [32–34].

4 Conclusions

This work evaluated the levels of gaseous pollutants (CO₂ and TVOCs) and comfort parameters (T and RH) in the indoor air of five health clubs during the period of public health restrictions related to COVID-19 and after lifting them. The results showed that implemented public health restrictions had impacted all parameters, but the demonstrated trends differed. Occupancy-level COVID-19 restrictions helped improve indoor RH and CO₂, significantly decreasing (RH: 0.97–1.4 times and CO₂: 1.1–2.6 times) when specific sanitary restrictions were in force due to the limited number of users in the respective sports facilities. Unlike in previous studies, only positive correlations were obtained between CO₂, RH and occupancy levels in some sampling days. Due to the ventilation requirements imposed at the time of sampling, the same was not obtained for all days, making it impossible to correlate these parameters. On the contrary, requirements for frequent cleaning throughout the day [11, 12] and the excessive use of cleaning products and disinfectants during the restricted period led to increased TVOCs (1.1–2.0 times). Finally, the prohibited use of air conditioning resulted in difficulties maintaining temperatures within the recommended values. The impossibility of air conditioning use when public restrictions were implemented resulted in globally higher T levels (1.01–1.10 times).

This study assessed the impact of public health restrictions on levels of two main parameters (i.e., concentration of air pollutants and physical parameters). However, other factors, such as different buildings ventilation systems, specific types of locations (within the sports facilities), type of the activities conducted, or used building and furnishing materials should be included in the further considerations. It needs to be emphasized that this study was an exceptional one and carried out in accordance with the limitations and restrictions in force during the specific period of COVID-19 post-pandemic. Unfortunately, the guidelines imposed at the time do not allow for its duplication (specific rules for ventilation and occupancy) which would allow for more conclusive results. However, the exceeded TVOC protective thresholds all FC, even when compulsory disinfection procedures and occupancy limitation are no longer required, indicate that future studies require identification and quantification of individual TVOCs in order to fully address IAQ in sport facilities and the source identification of these compounds.

Acknowledgements This work was financially supported by Portuguese national funds through projects UIDB/50006/2020, UIDP/50006/2020 and LA/P/0008/2020 (REQUIMTE), and by LA/P/0045/2020 (ALiCE), UIDB/00511/2020 and UIDP/00511/2020 (LEPABE), from the Fundação para a Ciência e a Tecnologia (FCT)/Ministério da Ciência, Tecnologia e Ensino Superior (MCTES). Additional funding was provided by PCIF/SSO/0017/2018 FCT through national funds. Cátia Peixoto would like to acknowledge FCT for her fellowship SFRH/BD/147185/2019.

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General Occupational Health Conditions in Slave Labour



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Abstract Until the 19th century, the Brazilian economy was based on slave labour. In the 21st century, Brazil is one of the countries where conditions analogous to slavery persist. In many of these situations, it is difficult to apply the penal code due to the lack of technical-scientific support that establishes unequivocally if a specific situation configures, or not, neo-slavery work. From an Occupational Safety and Health (OSH) perspective, this study analyses the health conditions of slave labour in the 19th century better to understand the conditions of neo-slave labour in Brazil. The study was designed as a Thematic Review with data collection from articles, theses, dissertations and books. The most observed diseases and injuries were the direct or indirect result of poor general conditions of food, lodging and clothing, exhaustive working hours and accidents resulting from environmental conditions in which work was developed. Healthcare existed as a form of preservation of financial assets, keeping slaves fit for work for the time necessary to amortise their market value and obtain the profit expected by the farmer. Although health care did exist, analysed occupational health conditions show a high mortality rate, above the average of the free population.

Keywords Slavery · OSH · Diseases · Injuries · Healthcare

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1 Introduction

Until the 19th century, the Brazilian economy was mainly based on agriculture, with a labour structure where enslaved people performed most tasks [1]. In this historical period, slave workers were both workers and assets [25]. Due to the high monetary amounts involved and to ensure financial return, labour activities were performed for long periods, under poor working conditions and with insufficient food intake [11, 12]. However, these very precarious working conditions are still a reality in the first decades of the 21st century [14, 10, 13]. The ILO declaration on fundamental principles and rights at work [17], which underlies ILO conventions 29, 87, 98, 105, 138 and 182, ratified by ILO member countries [17], has not been sufficient to prevent situations analogous to slavery, nor its harmful effects on the most vulnerable populations. Working conditions analogous to slavery persist in many countries [24].

Brazil is one of the countries where conditions analogous to slavery continue. However, its characterisation is possible by identifying aggravating factors directly associated with OHS conditions, namely being subject to long working hours and degrading working conditions [3]. These conditions are also described in the Brazilian Health and Safety Regulation as the minimum required working conditions. However, because these are working conditions defined by the law, these situations are not considered a crime, but an offence punishable by a simple fine. Therefore, in many of these situations, the penal code is not applied, and the “employers” of neo-slavery work can avoid the legally applicable penalties [14, 26].

The absence of technical-scientific support that can be used to establish, unequivocally, if a specific situation configures neo-slavery work ends up strengthening the thesis of simple violation of labour rules.

Studies on slavery do not usually address the problem of slavery from an OHS perspective. However, this approach is necessary for a better understanding of the conditions of slave labour today. This approach is expected to contribute to better defining the health conditions of slave labour in the 19th century and better understand the conditions of neo-slavery labour in Brazil. It is expected, from this approach, that there will be a better distinction between neo-slavery and direct violations of labour laws. This work also intends to contribute to studies in other countries with similar problems.

2 Materials and Methods

This study was designed as a Thematic Review [23]. Descriptive studies that reported enslaved people’s general occupational health conditions in Brazil in the 19th century were selected. The following databases (DB) were searched: Science Direct, SCOPUS, Web of Science, Criminal Justice, Ebsco, Business Source Complete, as of 2014. The same keyword combinations were used in all these DBs: slavery and labour. No language filter was used, and the duplicate records were excluded.

Relevant papers were selected from the analysis of titles and abstracts. Papers that did not describe the general occupational health conditions of the enslaved were excluded. The inclusion criteria used were: (1) a direct description of the subject of this study, (2) being related to Brazilian slavery in the 19th century, and (3) being recognised as a reliable source. After analysis of the full texts, the articles that allowed the extraction of relevant information in a standardised form (reference, region of the country, common accidents and diseases and health care) were included. The bibliographic references of the selected articles were analysed and led, in a snowballing process, to a collection of data from several theses, dissertations and books—including some originals published in the 19th century.

The results were compared with data on poor but free workers from the same period to filter out only the common situations of exposure of slave workers. They were also compared with workers subjected to contemporary slavery in Brazil.

3 Results

The database searches initially provided 36,355 records. After applying the exclusion criteria, nine were selected to read the full texts. The temporal cut-out eliminated 28,498 of the initial amount, and 4,312 were removed after the requirement of publication in journals. Finally, 3,444 papers were excluded for being off-topic and 92 after reading their abstracts for not indicating the possibility of positive results and relevance to the research. Besides these, 19 more papers were selected in the snowballing process. After analysing the full texts of all these works, 16 were included in the systematic review: 8 articles and eight books, 4 of which were published in the 19th century.

Table 1 presents the most common accidents and diseases of enslaved workers, by geographic region, according to the selected record, with the identification of the principal author and year of publication.

The illnesses and injuries most often cited by the authors were commonly described as a direct or indirect result of the poor general conditions of food, housing and clothing, the exhaustive workdays and accidents resulting from the environmental conditions in which the work was developed.

Injuries appear as the leading cause of illness and death among enslaved adults. In the sugar cane mills, the most common physical consequences of these injuries were mutilations with amputation of limbs due to crushing in the mills. Illnesses and deaths due to overwork are among the most commonly described problems, with the most severe consequences occurring after age 50. The high exposure to mosquito vectors of diseases is especially serious in clearing virgin forests and plantations during rainy periods.

Of all the observed problems, the recurring suicides are highlighted, which are related to depression [1, 5], being described at the time as a deep sadness for their condition as enslaved people or for missing Africa.

Table 1 General health conditions of slave laborers

#	Geographic area of the study	Common accidents and diseases	Health care
[1]	Southeast Brazil	Amputation; Yellow fever; Malaria; Suicides	Farm nursery; medicines; vaccine
[2]	Maranhão	Amputation; Yellow fever; Malaria; Suicides	Farm nursery
[4]	All of Brazil	Suicides	Maternity protection
[5]	Bahia and Rio de Janeiro	Injuries; infectious diseases; alcoholism; suicides	Treating suicide with benevolence and fun
[6]	Southeast Brazil	Amputation; intoxication; exhaustion	Farm nursery
[7]	Minas Gerais	Verminosis, obstructions, digestive diseases; respiratory diseases; alcoholism; injuries; yellow fever and malaria	Farm nursery; Better food for the sick
[30]	All of Brazil	exhaustion	Farm nursery
[20]	São Paulo	Injuries; infectious diseases; digestive diseases	Medicines
[16]	All of Brazil	–	Farm nursery; Medicines
[18]	All of Brazil	Digestive diseases; Alcoholism; respiratory diseases	Farm nursery
[25]	All of Brazil	Injuries	–
[29]	All of Brazil	Injuries	Farm nursery; Better food for the sick
[28]	All of Brazil	Injuries, amputations, wounds, inflammations, rheumatism and hernias	–
[31]	Bahia	Amputation; yellow fever; malaria; exhaustion	Farm nursery; medicines; better food for the sick
[33]	All of Brazil	Exhaustion; suicide; abandonment of patients	Farm infirmary; medicines; better food for the sick
[9]	All of Brazil	Abandonment of patients	Farm nursery; Medicines

Regarding the general health care of enslaved people (Table 1), the financial investments in health on the farms are noteworthy. These were investments in medical manuals to be used by non-professionals in the local treatment of diseases in nursing wards located on the farms, supply of medicines and improvement in the diet of the patients concerning the other slaves. However, to have access to health services, it was necessary that the illness of these slaves not be interpreted as laziness, which often forced them to face the heavy work of slavery despite being ill.

This care was intended to prolong the life of these individuals and ensure that they survived long enough to amortise the financial investment in their acquisition and generate profit. After the expected financial return had been generated, the slaves' lives no longer had much value, especially since they were programmed, like a machine, to be at the end of their useful life.

4 Discussion

Enslaved people were acquired mainly to perform the heavy physical work required on the long working days of the farm activity [14, 13]. The acquisition of enslaved people involved a great search for economic profits, which made the conditions of life of this population extremely degrading and the work exhausting. In fact, their whole lives took place in precarious conditions [2, 25, 31].

It was not rare, cases in which the large landowners exceeded the human limits of their slaves and made them work in conditions that could lead to injuries and illnesses that could evolve to death [6, 18, 33].

5 Admission Examination

Because of the high market value [2], [25, 31] and as a way to ensure the financial security, each slave trade was preceded by an evaluation of his general health condition [18] performed by a doctor or surgeon. The evaluation aimed to identify health problems that could evolve into a limitation, incapacity or death, besides identifying existing physical limitations. The healthier and higher the physical vigour, the higher the market value [2], [18, 33].

Despite the pecuniary character, aiming to give security to a commercial transaction, the health evaluation worked as an admission exam for the worker. It was important to be careful not to acquire a slave unfit for the function. The book "Manual do Fazendeiro" (Farmer's Manual) [18] stated that the acquired slave should present the physical and health conditions favourable "to the arduous services that are expected of him" and, therefore, should not have "any of the abnormalities that have just been mentioned" [18]. These precautions were taken since the buyer could suffer severe financial losses if the worker did not have a sufficient working life [6, 18, 33].

The recommendations of the Farmer's Manual [18] begin with a recognition of the geographical origin of the enslaved person, in which, in each African region, people had distinct characteristics (height, robustness,). Next, the recognition of desirable physical attributes consisted of measures, proportions and anthropometric characteristics that could compromise the best physical performance or even indicate health problems. The health assessment should always be concluded with a complete clinical examination [18].

6 Diseases and Accidents

The Manuals of the time instructed the farmers to take a series of care to avoid diseases and early death for patrimonial preservation. The suggested precautions included the presentation of a minimum energy replacement diet for the efforts required of the captives, which did not meet their needs but avoided early death. Food quality was also described as a great influence on diseases, especially those related to the digestive system [18].

However, despite being the farms' driving force and generally representing these rural properties' greatest financial assets, these slaves were not well-fed. Several studies [2], [1, 7, 8, 15, 18, 27, 30, 31] classified their diet as insufficient for energy replacement and, at the same time, constituted of food of poor quality and its preparation was performed without care for hygiene or proper cooking of the food. This diet, repeated daily, with an almost invariable composition, is cited as the cause of recurrent digestive system diseases [7, 18].

Adequate clothing was also not provided and in sufficient quantity. Another of the recommendations of the 19th-century Manuals [6, 18, 33], which was neglected by the farmers at the time and used to be pointed out as a cause of many diseases—in this case, diseases of the respiratory system. Mainly because they were forced to work in adverse climatic conditions such as rain and cold, which did not occur with the free population. The situation worsened during a night resting in poorly built shacks, with deficient sealing both in the roof and the walls [6, 18, 33].

Infectious diseases, such as malaria and yellow fever, were more difficult to control, directly related to the environmental conditions in the plantations. These diseases were common to the entire Brazilian population but were especially severe among the slave population of the sugar mills. The specific characteristics of this agricultural culture potentiated the proliferation of mosquitoes that were vectors of diseases [2], [1, 7, 20, 31] and to the slaves who cleared virgin forests for new agricultural fields because they were also more exposed to these vectors [2].

The illnesses were generally aggravated when the sick workers had their illnesses confused with laziness and were forced to work, which occurred quite frequently [2], [7, 31].

Injuries resulting from accidents in the execution of work were another common cause of death among enslaved people [5, 29]. The crushing of limbs in sugar cane mills, mutilations and amputations are described as a combination between exhausting days and excessive work [2], [1, 7], but it is also possible to add the inexistence of protective measures in the machines.

Exhaustion by excessive workload was also the cause of diseases and deaths [18, 20, 28, 30, 31, 33], especially among slaves over 50 years old [7], mainly in periods with heavier workloads, such as, for example, the sugarcane harvest. The excessive days of work are pointed out as a decisive factor for the discrepancy between the rates of illness and death between the slave and free populations [2], [1, 6, 15, 25, 29, 33].

7 Suicides

One of the possible consequences of the severe conditions described above is the suicide rate among the slave population that was very high throughout Brazil, being calculated at 0.4% of this population [2], which is equivalent to almost 100 times the current suicide rate of the remaining Brazilian population [24], [32]. It was a widespread problem whose cause was indicated as a disease characterised by a lack of spirit, appetite and will live [6, 18, 33]. The main given reasons were homesickness for their native land (Africa) and the rigours of slave labour [1, 4, 5, 33], [2]. Sometimes, in an attempt to avoid these deaths and inherent financial losses, concessions of “benevolence” and various entertainments were made [5].

Alcoholism was another health problem that appeared to be related to slave labour conditions. The landowners guaranteed the enslaved people access to regular quantities of alcoholic beverages so that they would have energy for their strenuous daily workload. This supply was intended to supplement their diet, which was systematically below their energetic needs [2], [1, 6, 15, 25, 29, 33]. However, the consumption of these drinks exceeded the caloric purpose to the point that the rate of alcoholism reached 6.7% of the enslaved population [5].

Medical Care.

The general living conditions of the slaves were, in itself, abbreviating their life span. However, the farmers were unwilling to improve working conditions. Nonetheless, it was also necessary to guarantee survival at least until the financial amortisation of the investment, which occurred between two and five years [2], [21]. After the expected income was obtained, it was not so important that the slave survived, contributing to a life expectancy that was clearly below the free population's.

The Manuals stated the need for health care in a nursery built on the farm to prolong the enslaved people's life and the supply of medicines and special food ([6, 18, 33]. These recommendations were generally followed by the farmers, who kept at least a first-aid box, a few beds in an isolated and clean place, a reserve of better quality food and a service contract with a doctor or surgeon to attend the urgent calls of the farm [2], [6, 9, 18, 31, 33].

8 Comparison to Contemporary Slavery

Regarding exposure to precarious working conditions, there is a similarity between the general occupational health conditions of 19th-century enslaved people and those of 21st-century workers in conditions analogous to slavery who were rescued by the labour inspection services of the Brazilian government [14, 10, 13]. In fact, enslaved people in the 19th century received more health care than those undergoing contemporary slavery. The reason is related to the fact that current enslaved people do not constitute financial assets and, therefore, can be easily replaced by others without significant costs.

The absence of medical examinations on admission and first aid materials among workers subjected to contemporary slavery, contrasts severely with the current practice in classical slavery when such care was almost mandatory. Generally, neo-slave workers do not usually receive individual or collective protection equipment, not even first aid material, which is aggravated by the difficulties or even impossibility of medical aid in the areas where they usually work, isolated in the middle of the forest or in distant areas that are difficult to access by medical aid teams [13].

9 Conclusions

The conditions of occupational health analysed show a general picture with a high mortality rate, well above the average of the free population, as a consequence of the working conditions to which the slaves were subjected. The diseases and deaths originated from insufficient food for the necessary energy replacement, exhausting work days, machines and tools without protection measures, and the general conditions of slave work. Infectious diseases, digestive and respiratory diseases, exhaustion, injuries, amputations and psychiatric problems were part of the enslaved population's routine.

Health care undeniably existed, however, only as a form of preservation of financial assets. This care kept the slaves able to work for the time required to amortise their market value and obtain the profit expected by the landowner. Once these goals were achieved, they became disposable, which is reflected in the significantly lower life expectancy concerning the free population.

Acknowledgements The authors would like to thank the support of Fundação de Amparo à Pesquisa e ao Desenvolvimento Científico e Tecnológico do Maranhão (FAPEMA)/Secretaria de Estado da Ciência, Tecnologia e Inovação (SECTI) and Governo do Estado do Maranhão for funding this research.

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High-Resolution Measurement of Infrasound and Low Frequency Noise in a Subway-Driver Compartment



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Abstract *Background:* Quantification of acoustic energy within the Infrasound (≤ 20 Hz) and Low Frequency Noise (≤ 100 Hz) (ILFN) range is infrequently achieved. Subway-driver compartments are occupational environments where ILFN can impact worker safety and performance. The goal here is to quantify ILFN levels within these compartments. *Methods:* Using high-resolution data acquisition (SAM Scribe system), continuous acoustical recordings were captured within the compartment for a total of 16 h (Day 1, weekday) and 13 h (Day 2, Sunday). Quantification of ILFN (≥ 0.5 Hz) used a spectral resolution of 1/36th octave and 1-s temporal resolution rendering unweighted sound pressure level (SPL). *Results:* For each of the 173, 10-min recordings, sonograms and frequency-distribution plots were constructed. A total of 69 harmonic series with distinct fundamental frequencies were repeatedly identified, the most common being 45.97 Hz ($N = 21$). Within the infrasonic range alone, a total of 35 harmonic series were repeatedly identified, the most common fundamental frequency being 16.0 Hz. SPL at 8 Hz and at 16 Hz were particularly elevated (85–91 dB). *Conclusion:* High-resolution ILFN measurements might provide more appropriate measures with which to establish dose-response relationships, which are still lacking among the scientific and medical communities.

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Keywords Harmonic series · Sonograms · Infrasonic fundamental frequency

1 Introduction

Infrasound (≤ 20 Hz) and Low Frequency Noise (here defined as ≤ 100 Hz) (ILFN) are generally not properly quantified in routine noise assessments, whether in occupational or environmental settings. Broadly, there are three main reasons that encourage this state of affairs: (1) cost of equipment required for proper data acquisition, (2) lack of necessity due to mostly non-existent legislation on the matter, and, (3) the notion that artificially produced acoustical phenomena within these infrasonic and lower frequency ranges have very particular characteristics and can cause much more discomfort, and long-term consequences, than hearing effects.

Subway systems are known sources of ILFN, both in terms of passengers (e.g., [9] workers (e.g., [5] and neighbours of these types of infrastructures (e.g., [10]. The possibility of conducting high-resolution ILFN measurements within the subway-driver's compartment emerged from an ongoing ILFN study within the Porto Subway System, in Portugal. The innovative methodology used in this study to characterize the acoustical environment of this workplace has been used since 2016, but mostly within the context of measuring the acoustic emissions generated by wind power plants [3]. The ultimate goal of this study is to contribute to the ongoing effort to establish proper dose-response relationships for ILFN exposures.

2 Materials and Methods

2.1 Acquisition and Processing of Captured Acoustical Data

For the high-resolution acoustical data acquisition, the SAM Scribe system, model Mk2 (Soundscape Analytics, New Zealand) [4] was used. Equipped with two channels (blue and red) and capable of sampling rates up to 44.1 kHz, it can record continuously (over days, weeks or months), storing the data as recorded .wav files in 10-minute (600 s) segments. As per manufacturer specifications of the two electret condenser microphones, the system can accurately record from 0.1 to 1000 Hz. In this study, all data was acquired with a sampling rate of 11.025 kHz and results are reported within the 0.5–1000 Hz range.

Each 10-minute recording was then processed and data analysed with: (1) a spectral resolution of 1/36th octave, as opposed to the commonly-used 1/3rd octave segmentation; (2) a 1 s temporal resolution, instead of the more common 10 min or 1 min averages; and (3) the elimination of all frequency-weighting systems.



Fig. 1 **a** Blue microphone of the SAM Scribe system, suspended from the ceiling of the subway-driver's compartment, before attachment of wind shield. **b** Eurotram—model of the vehicle in which recordings were performed

2.2 Microphone Positioning and Measurement Procedure

Both red and blue microphones were placed in the subway car. This report will only address the data collected with the blue microphone that was suspended from the ceiling of the subway-driver's compartment, at approximately 1.9 m from the ground and 0.5 m from the side wall. See Fig 1A.

Calibration with a Type I calibrator (94dB/1000 Hz, part of the SAM Scribe system) was performed before and after each recording session, approximately 16 h on Day 1 and 13 h on Day 2. Wind shields were placed on the microphone for the duration of the recordings. After the initial calibration, the system continuously recorded for approximately 16 h on Day 1 and 13 h on Day 2.

2.3 The Yellow Line of the Porto's Subway System

The Porto Metro System, consists of 6 subway lines and a fleet of 102 vehicles, 30 Flexity Swift model and 72 Eurotram model (Fig 1B). All recordings were conducted along the Yellow Line, from Hospital de São João to Santo Ovídio and back to Hospital de São João (Metro do Porto for subway map). This line not only has segments both above- and below-ground, but it also crosses a bridge over the Douro River.

3 Results

A total of 16 h of continuous recordings was achieved on Day 1 (weekday: 96 10 min samples) and 13 h on Day 2 (Sunday: 77 10 min samples). Samples containing the calibration tones were not used. Figure 2 provides an example of the information obtained through the construction of sonograms and frequency–distribution plots. All SPL (sound pressure level) levels are given in unweighted dB.

In general, SPL levels recorded on Day 2 (Sunday) were lower than those obtained during the weekday.

To these authors' knowledge, only the Russian Federation possesses specific (scientifically valid) legislation for permissible exposure levels to infrasound in the workplace [8]. For this particular type of job description, the permissible levels are given in Table 1. For the representative recording example given in Figure 2, levels were calculated (in octaves, as required) and are also provided in Table 1. The trend seen in Table 1 was present in all recordings that were analysed: SPL values at 8 Hz and 16 Hz were consistently out of compliance with the Russian Federation's standard but in compliance with established permissible exposure levels in Europe.

Preliminary analysis of the presence of harmonic series identified 132 series with distinct fundamental frequencies. The most frequent occurrences are given in Table 2.

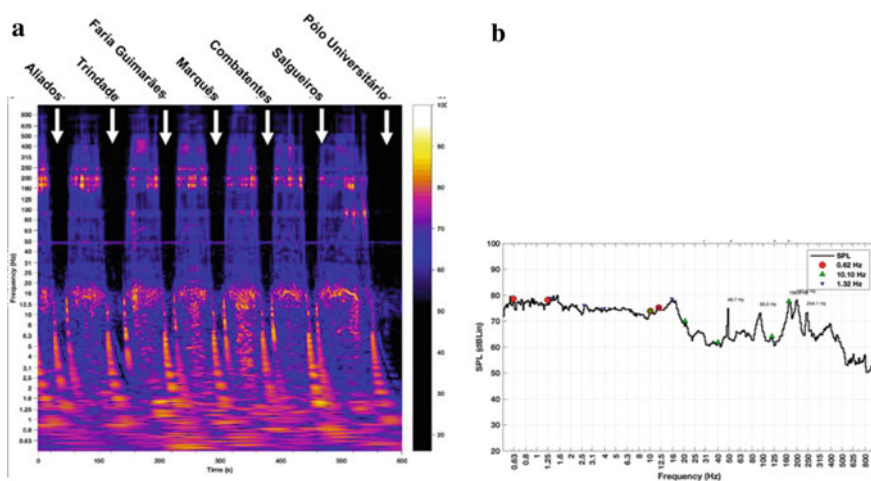


Fig. 2 **a** Sonogram representing a 10 min (600 s) recording, captured on Day 1, starting at 12:10. SPL in unweighted dB are shown in the colour-scale. Subway stops are indicated (white arrows) with the corresponding station name. The continuous horizontal line at approximately 50 Hz is probably associated with the electrical supply. The cone shaped phenomena occurring below 20 Hz, before and after each station stop, are most probably associated with the pneumatic brake system. **b** Frequency distribution of the same time interval (12:10–12:20) showing the identification of 3 harmonic series with fundamental frequencies at 0.62 Hz, 1.32 Hz and 10.10 Hz

Table 1 Comparison of the permissible exposure levels and those obtained in the 12:10 recording, shown in Fig. 2

Frequency (Hz)	Permissible exposure levels	Measured (Data from Fig. 2)
2	95	91.5
4	90	90.0
8	85	88.8
16	80	90.2

Table 2 Number of occurrences of the most frequent harmonic series, by fundamental frequency

Fundamental frequency of the harmonic series (Hz)	Number of occurrences
45.97	19
16.00	12
34.47	10
89.98	10
23.94	9
16.31	8
46.86	5
91.72	5

Data from 173 samples within all 173 recorded samples, a total of 179 incidences of harmonic series were identified, 70 of which occurred within the infrasonic range (≤ 20 Hz), and 109 within the low-frequency range (20–100 Hz).

4 Discussion

This type of data acquisition and analyses of acoustical environments is pioneering, particularly within occupational environments. This is one of the first documented instances where the SAM Scribe system has been used for a systematic study of an occupational environment. The elevated SPL at 8 Hz and 16 Hz may have implications on worker safety, performance and health—a detailed clinical study is now in order to evaluate the seriousness of this situation.

Acoustical harmonic series, as identified within this data, are generated by artificial (human-made) sources. The high number of infrasonic harmonic series (Table 2) is somewhat perplexing, and will be the object of intense study in this ongoing project. It should be noted that 8 occurrences were for fundamental frequencies below 0.58 Hz that corresponds to an airborne acoustical event that has a 591 m wavelength.

There are no established dose–response relationships for ILFN exposure, whether in occupational or environmental settings. As has already been pointed out in

other publications, the current, internationally accepted methodologies for evaluating noisy environments (i.e., using 1/3rd octave band segmentation, A and G frequency weighting systems, and 10 min or 1 min averages) are insufficient for establishing a proper “dose” for ILFN [2]. It should be noted that the standard of the Russian Federation does provide a very basic measure, using unweighted but octave-band averages. However, this is not an internationally accepted standard as is something of a blunt instrument for research. By increasing the acoustic resolution, the parameters relevant to ILFN doses can be revealed and meet some studies carried out regarding health effects such as cardiovascular disease, depression, and sleep disturbances [1] and feeling tired first thing in the morning [7].

5 Conclusions

Acoustical data acquisition with high-resolution capture and analyses was conducted within a subway-driver’s compartment, yielding 29 h of continuous recordings in the form of 173 10 min samples. SPL at 8 Hz and 16 Hz were deemed particularly elevated in all analysed samples. These are preliminary data and further analyses are ongoing.

Acknowledgements The authors would like to thank the Administration of the “Metro do Porto” for their openness to allow this study. The authors would also like to thank Dr. Bruce I. Rapley and Soundscape Analytics for the loan of the SAM Scribe System.

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Occupational Exposure to Particles in Quarries and Its Effects on worker's Health



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Abstract *Introduction:* The exploitation of quarries is considered a high-risk activity, in which workers are exposed to risks that can influence both their health and their physical integrity. *Aims:* Was to assess occupational exposure to particles, namely inhalable and respirable particles during working hours in a quarry, and how they affect or can affect the health of workers. *Material and Methods:* The first moment being the evaluation of inhalable and respirable particles, in which measurements were carried out by dosimetry to seven workers. The second moment was the application of a questionnaire to the workers regarding the work environment to which they are exposed, and the symptoms related to it. *Results:* In all jobs, the concentration values of inhalable and respirable particles presented values below the legally established value. Regarding the symptoms that can commonly be presented, the most verified were headache, followed by fatigue and itching, burning sensation or irritation in the eyes. *Discussion/Conclusion:* Although the particulate concentration values are below the exposure limit value, it is advisable that the employer continues to carry out monitoring to prevent the health of workers, as particulate matter can, in the long term, cause occupational diseases at the forum level respiratory.

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Keywords Inhalable particles · Respirable particles · Occupational exposure · Workers · Quarry

1 Introduction

Quarrying is considered a high-risk activity, in which workers are exposed to risks that can influence both their health and their physical integrity [16]. The extraction of minerals and rocks can generate significant impacts on health and the environment when measures to minimize and prevent the various risks inherent to this type of industrial activity are not applied, either directly for workers or for the surrounding populations [3, 9].

Occupational Health is an area that intervenes and values the workplace as a privileged space for the prevention of occupational risks, the promotion and protection of health [6]. The activity carried out in an aggregate quarry in the open is essentially made up of tasks such as rock drilling and blasting fireworks tacking, loading, transport, unloading and rock processing to obtain aggregates of different granulometries [3]. The exploration of quarries, among all the activities that are included in the extractive industry, is considered in Law no. professional activities, workers are exposed to risks that can influence both health and physical integrity [16].

Exposure to the multiple risks inherent to the production process of the Extractive Industry, which is carried out in the open, under the influence of weather conditions, with excavations at great depths and consequent unevenness in the ground, with the movement and use of work equipment large and powerful furniture, use of explosives, among others, resulting in the classification of these activities as being of high risk. Thus, extractive industry workers are subject to the risks of exposure to physical, chemical, ergonomic and psychosocial parameters [22].

In the production process of the extractive industry, one of the most frequent, common and serious problems is the generation, emission and dispersion of particulate material—dust, into the atmosphere [10]. Dust comes in several dimensions, the finer ones can stay for some time in suspension and resuspension in the air and spread through areas surrounding the quarries, depending on weather conditions [3]. Particulate matter has different dimensions, depending on the materials and substances that originate them, being identified by their physical, chemical, biological characteristics and by the measurement method. The concentrations of this particulate matter in the ambient air are related to the source of particulate matter, which can be stationary or mobile, and to the transformations that occur in the atmosphere [15]. As for working conditions and productivity, dust can affect the visibility of workers, when there is a large amount in suspension and its granulometry is very fine, and can also contribute to reducing the life cycle of equipment when they are not subject to proper maintenance and cleaning [16].

Inhalable particles are complex mixtures of liquid and solid particles suspended in the air, the main components of which are sulfates, nitrates, ammonia, sodium chloride, coal, powdered minerals and water. The most dangerous category is particles

with a diameter equal to or smaller than $10\text{ }\mu\text{m}$, also known as PM10 or inhaled particles, as they enter and lodge deep in the lungs. Fine or respirable particles (PM2.5) have a long residence time in the atmosphere and can penetrate deeply into the respiratory system, thus, the toxicity of fine particulate matter is higher than that of coarse particles in the air [8]. The effects of inhalable particles on human health are manifested mainly in the respiratory system, and their danger depends on their chemical composition and size. Thus, larger particles are normally filtered at the level of the nose and upper respiratory tract, which may be related to irritation and hypersecretion of the mucous membranes. Smaller particles, with an aerodynamic diameter of $10\text{ }\mu\text{m}$ or less (PM10) are usually more harmful as they are deposited at the level of the functional units of the respiratory system [1, 4].

Respirable particles present a greater danger to human health as they remain suspended in the air for a longer time. When inspired, they can reach the lower portions of the respiratory tract where the pulmonary alveoli are located. The constituents of particulate matter can reach the blood stream, spreading through the body, reaching the cells of living organisms, causing various deleterious effects [11]. Exposure to small particles may increase morbidity and mortality, at the pulmonary and cardiovascular levels, whose first manifestations may be restricted to changes in the interaction of the sympathetic/parasympathetic systems [20]. The American Conference of Governmental Industrial Hygienists (ACGIH) is convinced that even biologically inert, insoluble, or poorly soluble particles can cause adverse effects and recommends that their concentrations in air should be kept below 3 mg/m^3 for respirable and 10 mg/m^3 for inhalable particles, until an exposure limit value (ELV) is established for a given substance (Norma Portuguesa NP 1796/2014, 2014). The health problems caused by particles result from inhalation and penetration of particles into the lungs and blood system, causing respiratory, cardiovascular and immunological problems [19].

Dust with a diameter of less than $10\text{ }\mu\text{m}$ is therefore extremely important for the health of workers and the population of the surrounding areas, and its propagation is enhanced by atmospheric factors in dry weather conditions and windy periods [3]. Thus, and the smaller the particle, the greater the probability of penetration into the deeper parts of the respiratory system, thus leaving the individual exposed to higher levels of trace elements and toxins [7]. The release of dust, fibers or fumes in the workplace leads to the appearance of respiratory diseases. Common examples such as: pneumoconiosis, occupational asthma, benign pneumoconiosis, asbestosis, silicosis, beryllium, black lung, among others, are examples of typical diseases contracted by workers. It is therefore important that workers are aware of the types of products they handle and to which they are exposed [13].

In view of the above, the main objective of the present study is to evaluate the occupational exposure to inhalable and respirable particles in a Quarry, and how they affect or can affect health, considering the atmospheric conditions.

2 Materials and Methods

This was an observational, level II study, analytical control and transversal in nature, where occupational exposure to particles was evaluated and how they affect the health of workers in a Quarry (Fig. 1), located in the Central Region of Portugal, of limestone extraction. The sample consisted of 7 workers.

The type of sampling was non-probabilistic, and the sampling technique was either for convenience or accidental.

The data collection period took place in 2 the months (May and June). Data collection consisted of two investigation moments, the first moment being the evaluation of inhalable and respirable particles, in which measurements were carried out by dosimetry, using the SidePak™ Personal Aerosol Monitor AM510 equipment, TSI brand. The second moment, the application of a questionnaire to the seven workers included in the study.

With regard to the first moment of investigation, the assessment of inhalable and respirable particles took place through dosimetry measurements to seven workers in a quarry, corresponding to seven jobs (exploration area rotating machine; transport of aggregates—dumper machine 1; concrete area—cabin worker; loading area—loader machine; primary area—cabin worker; workshop and aggregate transport—dumper 2), where samples were taken from minute to minute. Although the study site had more jobs, only seven jobs were evaluated, as these were the ones that could reveal greater amounts of inhalable and respirable particles during the working period. Measurements were carried out for five days for each of the parameters, and divided into two different periods, that is, the morning work period, between 7 am and 12 pm, and the afternoon work period, between 1:30 pm and 5:30 pm. The measuring equipment was placed at a height corresponding to the respiratory tract of each worker, and each worker used two equipment simultaneously so that samples of inhalable and respirable particles were collected in the same period. In addition to the measurements carried out, the weather conditions of each of the measurement days were also recorded, whether the windows or doors of the workstations/equipment were closed or open during the working period, whether the air conditioning was on or not, if one of the machines is in operation, if the workers in question were wearing a protective mask, the number of occupants in the areas to be evaluated, as there



Fig. 1 Photograph of some of the quarry's workstations

could be the possibility of having more than one worker in the fixed workstations with cabin and if the quarry was operating normally.

With regard to the second moment of investigation, a questionnaire was applied, which was divided into two fundamental parts: the first addressed the sociobiographical characterization; the second was intended to obtain data on the work environment, information and training related to the activity performed, that is, if they had information and training regarding the activity performed, if they were aware of the risk assessment of their work position, and the existence of safety procedures appropriate to the hazards of work in quarries, of which they used personal protective equipment and how often they were used, what were the factors by which they are affected during the performance of tasks and how often, if there were symptoms or signs that could be related to the activity performed and, finally, information about smoking habits.

It was considered as a reference for the ELV of 10 mg/m^3 for inhalable particles and 3 mg/m^3 for respirable particles, as referred to in the Portuguese Standard (PS) 1796:2014 (Norma Portuguesa NP 1796/2014, 2014).

The statistical treatment of the data was performed using the IBM SPSS software, version 28.0. Statistical analysis consisted of descriptive statistics, through measures of central tendency (mean), dispersion (standard deviation), crossing of variables and presentation in frequency tables (absolute and relative). At the level of statistical inference, a previous assessment of the assumptions of the metric variables (parametric or non-parametric) was used. In terms of hypothesis tests, the following tests were used: *t*-Student test for 1 sample, ANOVA test, test of multiple comparisons Least Significant Difference (LSD). Data interpretation considered a 95% confidence level for a maximum random error of up to 5%.

The measurements and questionnaires were carried out with the written consent of the company responsible for the quarry and the workers, after a previous clarification of the objectives of the research, being maintained the anonymity and confidentiality of the data collected for the study.

3 Results

The sample of this study consisted of seven workers who worked in seven jobs in a quarry located in the Central Region of Portugal. It should be noted that all workers surveyed were male, aged between 26 and 68 years, with an average age of 48 years. Have been in the profession for a maximum of 40 years and a minimum of 1 year. As for the time they were working in the company under study, the minimum time was 1 year, and the maximum time was 41 years.

In Table 1, the average values of the inhalable particle concentrations at each workstation were compared with the legal reference value.

It was found that the mean values of concentrations of inhalable particles were below the ELV, 10 mg/m^3 . Using the ANOVA test for independent samples ($F = 349.155$; $df_1 = 6$; $df_2 = 16,248$; $p < 0.0001$), we recorded the presence of

Table 1 Average inhalable particulate concentrations at the different workstations

Inhalable particles (mg/m ³)							
Workstation	No	A	SD	T	gl	p-Value	AD
Exploration zone—Rotating machine	2284	0.662	0.810	−551.1	2283	<0.0001	−9.338
Transport of aggregates— <i>Dumper machine 1</i>	2350	0.321	0.744	−630.7	2349	<0.0001	−9.679
Loading zones-shovel/loader machine	2260	0.098	0.231	−2038.0	2259	<0.0001	−9.902
Concrete area—cabin worker	2388	0.206	0.458	−1044.3	2387	<0.0001	−9.794
Primary zone—cabin worker	2318	0.858	1.212	−363.2	2317	<0.0001	−9.142
Workshop	2233	0.234	0.572	−807.3	2232	<0.0001	−9.766
Aggregate transport— <i>Dumper Machine 2</i>	2422	0.269	0.497	−964.3	2421	<0.0001	−9.731

A, Average; SD, Standard deviation; AD, average difference.

t-Student test for 1 sample with Exposure Limit Value of 10 mg/m³

statistically significant differences in the values of inhalable particles between the different workstations. Through the application of the statistical test of multiple comparisons LSD, it was verified that the workstation “Exploration zone—Rotating machine”, revealed significantly higher values of inhalable particles in relation to all the workstations under analysis ($p < 0, 0001$), except for the “primary zone—cabin worker” location. This revealed, on average, values of inhalable particles significantly higher ($p < 0.0001$) compared to other jobs. When analyzing the values of significant differences, all jobs show significant differences.

The workstation “transport of aggregates—dumper 1” showed significantly higher values of inhalable particles compared to the workstations “transport of aggregates—dumper 2”, “workshop”, “concrete area—worker cabin” and “loading area—shovel/loader”. Exceptionally, the “primary zone—cabin worker” and “exploration zone—rotating machine” sites, on average, showed significantly higher values of inhalable particles ($p < 0.0001$). As the analysis of the values of significant differences showed that all stations showed significant differences ($p < 0.0001$), despite the location “transport of aggregates—dumper 2” having average values of exposure very close to the location “transport of aggregates—dumper 1”.

Taking into account the “loading area—shovel/loader machine” workstation, this turned out to be the workstation with significantly lower values of inhalable particles ($p < 0.0001$), in relation to the remaining jobs. This revealed, on average, significantly lower particle values compared to other jobs. When we analyzed the values of significant differences ($p < 0.0001$), all jobs showed significant differences.

The “concrete zone—cabin worker” was the one that showed significantly higher values of inhalable particles compared to the “Exploration zone—Rotating machine” ($p < 0.0001$), and in relation to the remaining jobs, the values of inhalable particles were significantly lower. It should be noted that it only did not present values of

significant differences in relation to the “workshop” job ($p < 0.177$), revealing values of significant differences ($p < 0.0001$) compared to the remaining jobs. Since the “transport of aggregates—dumper 2” presented very similar average exposure values, even so, they were below the p-value of less than 0.05.

Comparing the “primary-cabin worker” zone, it was found that this showed significantly higher values of inhalable particles in relation to the remaining jobs ($p < 0.0001$), and revealed, on average, values of inhalable particles significantly higher ($p < 0.0001$). When the values of significant differences were analyzed, all the jobs presented values of significant differences in relation to this one.

In turn, the “workshop” revealed significantly higher values of inhalable particles than the “concrete area—cabin worker” and “cargo area—shovel/loader” ($p < 0.0001$). And, on average, it showed significantly higher particulate values, compared to the jobs mentioned above. When the significance values were analyzed, it was found that there were significant differences in relation to the posts “loading area—shovel/loader machine”, “aggregate transport—dumper 1”, “loading area—shovel/loader machine” and “area primary—cabin worker” ($p < 0.0001$). In turn, the “concrete area—cabin worker” and “aggregate transport—dumper 2” jobs did not show significant differences, with p-value greater than 5%.

The “aggregate transport—dumper 2” workstation revealed significantly higher values of inhalable particles when compared to the “workshop”, “concrete area—cabin worker” and “cargo area—shovel/loader machine workstations”. In exception, it revealed significantly lower values of inhalable particles than the other stations. This job revealed no significant differences compared to the “workshop” job, as they have a significance value greater than 5%. In relation to the remaining posts, it revealed values of significant differences.

In Table 2, the average values of respirable particulate matter concentrations at each workstation were compared with the legal reference value.

It was found that the mean values of concentrations of respirable particles were below the ELV, 3 mg/m³. Using the ANOVA test for independent samples ($F = 469.992$; $df\ 1 = 6$; $df\ 2 = 16,249$; $p < 0.0001$), we recorded the presence of statistically significant differences in values of respirable particles between the different workstations. Through the application of the statistical test of multiple comparisons LSD, it was found that the workstation “Exploration zone—Rotating machine”, presented significantly lower values of respirable particles compared to all the workstation under analysis ($p < 0.0001$), with the exception of the “cabin worker—concrete zone” site. This revealed, on average, significantly higher values of respirable particles ($p < 0.0001$). When the significance values were analyzed, it revealed significant differences compared to all jobs, except for the location “concrete zone—cabin worker” as it presented a significance value greater than 5%.

The workstation “transport of aggregates—dumper 1” showed significantly lower values of respirable particles compared to the workstation “loading area—shovel/loader machine”, and exposure values significantly higher than the others posts.

Considering the workstation “loading area—shovel/loader machine”, this revealed significantly higher values of respirable particles when compared to all

Table 2 Average inhalable particulate concentrations at the different workstations

Respirable particles (mg/m ³)							
Workstation	No	A	SD	t	gl	p-Value	AD Rotating machine
Exploration zone	2284	0.142	0.216	−631.3	2283	<0.0001	−2.858
Transport of aggregates— <i>Dumper machine 1</i>	2350	1.174	1.497	−59.1	2349	<0.0001	−1.826
Loading zones—shovel/loader machine	2260	1.387	1.910	−40.1	2259	<0.0001	−1.613
Concrete area—cabin worker	2388	0.097	0.165	−858.3	2387	<0.0001	−2.903
Primary Zone—cabin	2318	0.502	0.847	−142.0	2317	<0.0001	−2.498
Workshop	2233	0.866	1.482	−68.0	2232	<0.0001	−2.134
Aggregate Transport— <i>Dumper Machine 2</i>	2422	0.298	0.553	−240.5	2421	<0.0001	−2.702

A, Average; SD, Standard deviation; AD, average difference.

t-Student test for 1 sample with Exposure Limit Value of 3 mg/m³.

jobs under analysis ($p < 0.0001$). When the significance values were analyzed, it showed significant differences in relation to all jobs ($p < 0.0001$).

Taking into account the “concrete zone—cabin worker” workstation, it revealed significantly lower values of respirable particles compared to all the workstations under analysis ($p < 0.0001$). When the significance values were analyzed, it showed significant differences in relation to all jobs, with the exception of the location “exploration zone—rotating machine” which did not show significant differences.

The “primary area—cabin worker” workstation showed significantly lower values of respirable particles than the “loading area—shovel/loader machine”, “workshop” and “aggregate transport—dumper 1”. When the significance values were analyzed, this revealed significant differences in relation to all jobs.

The “workshop” showed significantly lower values of respirable particles compared to the “loading area—shovel/loader” and “aggregate transport—dumper 1” ($p < 0.0001$). When analyzing the values of significant differences, this job revealed significant differences in all jobs.

Considering the “aggregate transport—dumper 2” job, it revealed significantly higher values of respirable particles in relation to the “exploration zone—rotating machine” and “concrete area—cabin worker”, in turn, showed significantly lower values of respirable particles in relation to the remaining jobs under analysis ($p < 0.0001$). When the values of significant differences were analyzed, this showed significant differences in all jobs.

Afterwards, the concentrations of inhalable and respirable particles were analyzed taking into account the measurement period and, subsequently, compared between the various evaluated workstations. It was found that the mean concentration values

of inhalable particles were below the exposure limit value ($ELV = 10 \text{ mg/m}^3$) considering the measurement period, and on average, the mean values of inhalable particles were higher in the afternoon significantly ($p < 0.0001$).

All the workstations presented values of significant differences in relation to the measurement period (morning and afternoon). The workplace that showed significantly higher values of inhalable particles was the “primary-cabin worker” zone ($p < 0.0001$), both in the morning and in the afternoon.

It was found that the mean concentration values of respirable particles were below the exposure limit value ($ELV = 3 \text{ mg/m}^3$) considering the measurement period, and, on average, the highest values of respirable particles were recorded in the morning of ($p < 0.0001$).

Then, we tried to analyze the behavior of respirable particles in relation to the Exposure Limit Value during the morning and afternoon periods adjusted by workstation. The workstation that showed significantly higher values of respirable particles was the “transport of aggregates—dumper 1”, both in the morning and in the afternoon, and the “cargo area—shovel/loader machine” also revealed values significantly higher levels of respirable particles in the morning ($p < 0.0001$). All the workstations presented values of significant differences in relation to the measurement period (morning and afternoon).

Next up, the average values of the concentrations of inhalable particles were compared, considering the different climatic conditions (Table 3).

It was found that the average concentration values of inhalable particles were below the exposure limit value ($ELV = 10 \text{ mg/m}^3$) considering the climatic conditions, and on average, it revealed higher values of inhalable particles in the climatic condition “Slightly cloudy” significantly ($p < 0.0001$).

Through the application of the statistical test of multiple comparisons LSD, it is noticeable that the weather condition “Sun” compared to “Slightly cloudy” revealed significantly lower values of inhalable particles ($p < 0.0001$) and presented significantly higher values of inhalable particles than the remaining weather conditions ($p < 0.0001$). When we analyzed the values of significant differences, it revealed significant differences in relation to all weather conditions, except for the “Cloudy” condition, which does not present significant differences when compared to “Sun”. Regarding the “Low Cloudy” weather condition, it revealed significantly higher

Table 3 Mean concentrations of inhalable particles in different climatic conditions

Inhalable particles (mg/m^3)					
Meteorology	No	Average	Standard deviation	Minimum	Maximum
Sun	4278	0.366	0.755	0.000	8.928
Little cloudy	9862	0.399	0.776	0.000	8.745
Cloudy	1852	0.327	0.656	0.000	8.490
Showers	263	0.148	0.133	0.030	0.576

Test ANOVA $F = 14.080$; $g1 = 4$; $g2 = 16,250$, $p < 0.0001$.

values of inhalable particles compared to the others ($p < 0.0001$) and revealed values of significant differences in relation to all other conditions ($p < 0.0001$).

The weather condition “Cloudy” revealed significantly lower values of inhalable particles for all weather conditions ($p < 0.0001$), except for the “Shower” condition. This, on average, revealed significantly higher values of inhalable particles ($p < 0.0001$). When the values of significant differences were analyzed, it just did not reveal significant differences when compared with the weather condition “Sun”.

Considering the condition “Showers”, it revealed significantly lower values of inhalable particles compared to the other climatic conditions ($p < 0.0001$). And, when we analyzed the significance values, it presented values of significant differences comparing with all climatic conditions.

In Table 4, the average values of concentrations of respirable particles were compared, considering the different climatic conditions.

It was found that the average concentration values of respirable particles were below the exposure limit value ($ELV = 3 \text{ mg/m}^3$) taking into account the climatic conditions and, on average, higher values of inhalable particles were found in the weather condition “Shower” significantly ($p < 0.0001$).

Through the application of the statistical test of multiple comparisons LSD, the weather condition “Sun” compared to the condition “Low Cloudy” revealed significantly higher values of respirable particles ($p < 0.0001$). When we analyzed the values of significant differences, it showed significant differences in relation to all weather conditions ($p < 0.0001$).

Regarding the weather condition “Low Cloudy”, it revealed significantly lower values of respirable particles for all weather conditions ($p < 0.0001$) and revealed values of significant differences in relation to all weather conditions ($p < 0.0001$).

The “Cloudy” condition showed significantly higher values of respirable particles in all weather conditions, except for the “Shower” condition ($p < 0.0001$), recording, on average, significantly lower values of respirable particles ($p < 0.0001$). When we analyzed the values of significant differences, it presented significant differences in relation to all weather conditions.

Considering the “Showers”, this revealed significantly higher values of respirable particles compared to other climatic conditions ($p < 0.0001$). When we analyzed the values of significant differences, it showed significant differences in relation to all weather conditions.

Table 4 Mean concentration of respirable particles in different weather conditions

Respirable Particles (mg/m^3)					
Meteorology	No	Average	Standard deviation	Minimum	Maximum
Sun	4278	0.605	1.109	0.000	8.049
Little cloudy	9862	0.550	1.145	0.000	16.749
Cloudy	1852	0.807	1.508	0.000	6.613
Showers	264	2,869	1.727	0.000	4.864

Test ANOVA $F = 338.270$; $gl1 = 3$; $gl2 = 16,252$; $p < 0.0001$.

With regard to the “functions they provide” in the company, 4 workers were machine operators/maneuvers, 1 was a concrete plant operator, 1 was a second-class mason, and finally, 1 was a quality controller in the workshop. Thus, we can verify that the same worker can occupy more than one job, considering the operators/manufacturers of machines, that is, four of the seven workers can occupy more than one task. The workers who occupied the job at the concrete plant, the second-class mason and the quality controller at the workshop only occupied their jobs. When asked about the “number of hours worked” during the day, everyone responded that they worked around 9 h.

Regarding the knowledge of workers about the “release of particles during the activity carried out”, of the 7 workers, 5 said they had knowledge. Subsequently, in relation to the knowledge of workers about the “risk assessment at the workplace and the existence of safety procedures appropriate to the dangers of work in quarries”, only one of the 7 workers said they had no knowledge, and all workers said comply with the “safety procedures” required in the quarries. When asked about the “knowledge of the existence of work accidents in their jobs”, 4 of the 7 workers said they had knowledge, thus mentioning two work accidents: head fracture and foot/boot squeezing. Taking into account the “type of work”, workers were asked if “they had ever received training or information on risk assessment and prevention and protection measures for the activity(ies) they perform”, to which only one worker stated that he had never received training or information in the area.

Regarding the use of “Individual Protection Equipment (IPE)”, namely, “protective mask, glasses and visor, ear protectors, protective footwear, helmet”, all workers mentioned their use. Subsequently, they were asked about the “frequency of using IPE”. Regarding the “protection mask”, 2 workers said they used it rarely, 2 said they used it sometimes, 2 others used it frequently and 1 never or almost never used it. 3 workers said they rarely used “glasses and visor”, 2 said they used them sometimes, and only 2 workers used them frequently. As for the use of “ear protectors”, 3 workers said they never or almost never use them, 2 said they only use them sometimes, 1 said they used them rarely and another worker said they used them often. Regarding the use of “protective helmets” by workers, 4 said they sometimes use it, when the work requires it, 1 said they never or almost never use it, another used it often and finally, 1 said they rarely use it. In general, all workers wore protective footwear.

Taking into account the question, “if you have ever suffered or suffer from any symptoms, such as respiratory problems, heart problems and skin problems”. Of the 7 workers, 4 stated that they “never” or “almost never” suffered the symptoms. Two workers claimed to have “frequently” symptoms, with one worker claiming to have “breathing problems” and the other worker claiming to have “heart problems”, taking medication regularly for the heart. One of the 7 workers claimed to “rarely” have skin problems. The 7 workers were also asked, “if they currently suffer from any of the signs/symptoms, such as headache, fatigue, irritability and difficulty concentrating, dizziness, difficulty breathing, itching, burning sensation or eye irritation, sneezing, runny or stuffy nose, dry, rough throat, cough, digestive problems, allergies, wheezing/whistling, asthma/chronic bronchitis, and irritation of the mucous membranes and/or dryness of the skin, and how often they suffer from these signs/

symptoms". About "symptoms, sneezing crisis, runny nose or stuffy nose, digestive problems, wheezing/whistling, irritation of the mucous membranes and /or dryness of the skin", all said they "never" or "almost never" had these symptoms. Considering the signs/symptoms, "difficulty in breathing and allergies", 6 of the 7 workers answered "never" or "almost never" having suffered and only one worker stated that he had "sometimes" these signs/symptoms. The signs/symptoms, "dry and rough throat and coughing", were mentioned by 5 as having "never" or "almost never" suffered them, with only two workers stating that they "sometimes" had these signs/symptoms. Regarding the signs/symptoms, "fatigue and itching, sensation of burning or irritation of the eyes", 4 workers said they "never" or "almost never" had these symptoms, 2 workers said they "sometimes" suffered, and only one worker said they "rarely" suffer these symptoms. Regarding the symptoms, "irritability and difficulty concentrating, and dizziness", 5 workers said they "never" or "almost never" suffer these symptoms, one worker said he "rarely" suffers from these symptoms, and another said he suffers "sometimes" these symptoms. Considering the symptom, "headache, only one of the workers said they "never" or "almost never" had this symptom, with 4 workers saying they suffered "sometimes" and 2 said they suffered "rarely". Finally, we can say that only one of the 7 workers reported suffering from "chronic asthma/bronchitis". In the question, "if the symptoms tend to worsen in some season of the year", 3 workers answered in the "winter", 2 workers answered in the "spring" and 2 workers answered in the "summer". As for "smoking habits", only 2 of the 7 workers revealed to be smokers.

4 Discussion

Occupational dust exposure is one, if not the main, health risk in quarries and mines. At all stages of the production process, dust is produced [18].

Taking into account the particulate matter, for inhalable particles, there is a legislated value of 10 mg/m^3 , and the average concentrations of the same were compared between the different workstations. It should be noted that there are relatively high values in some jobs when compared to the others, although all values are below the exposure limit value. Thus, the job with the highest average values was the "primary zone—cabin worker" (0.858 mg/m^3) and the one with the lowest values was the "Loading Zones—Shovel/Loader Machine" (0.098 mg/m^3). The fundamental causes of the formation of particulate matter are: industrial processes, mainly by the dragging of materials in transfer, resuspension of dust from the soil, combustion processes, and reactions that occur in the atmosphere [12].

Long-term exposure to high concentrations of particulate matter can increase the risk of lung cancer, Chronic Obstructive Respiratory Diseases (COPD), and arteriosclerosis, and short-term exposure can cause exacerbation of other respiratory

diseases, including bronchitis and asthma., as well as changes in heart rate variability [5]. Analysis of particulate matter are very important, as it is estimated that approximately 3% of deaths from cardiopulmonary diseases and 5% of deaths from lung cancer are due to particles [23].

The same study method was used for respirable particles and the gap between workstations was also verified, although these concentration values were all below the exposure limit value, 3 mg/m³ (NP1796, 2014). Noteworthy is the station with the highest average values, “Loading Zones—Shovel/Loader Machine” (1.387 mg/m³), and the station with the lowest average values, “Concrete area—cabin worker” (0.097 mg/m³). At each load, the loader machine operator has a moment when he opens the door to sign the authorization for the truck to load, which exposes him to a greater concentration of dust that remains in the air due to the unloading of stocks onto the trucks, and the movement of the loader itself, as indicated in the study developed by Catarina Pinto [18].

Regarding the measurement periods, it was found that the concentration of inhalable particles had a higher prevalence in the afternoon, with the workstation “primary zone—cabin worker” (0.978 mg/m³), the one that recorded the highest concentration value. In the case of respirable particles, the period with the highest prevalence was the morning. It was the “loading area—shovel/loader machine” (1.882 mg/m³) that had the highest average value.

The severity of the effect on human health of exposure to particulate matter depends on several factors. The geographical situation, atmospheric conditions, emission sources (distance from the source), chemical composition, concentration of particulate matter, physical characteristics of particulate matter (size, mass, shape and area), type and parameters of the handling of the material and intrinsic aspects of the worker are differentiating factors in particle toxicity [15].

By analysing the concentrations of inhalable particles in different weather conditions, it was found that the highest average values were recorded with the weather condition “lightly cloudy” (0.399 mg/m³). About the concentration of respirable particles, the highest average values were recorded with the weather condition “Shower” (2.869 mg/m³). Weather conditions are factors that affect the concentration of particulate matter, namely the concentration of particulate matter in the winter months is lower than in the summer months. The inverse effect also exists, as for example, particulate matter increases or decreases the reflectivity of clouds leading to cooling or heating effects and influencing precipitation or droughts [15]. The dry period is the most critical for air quality, due to a reduction in the pluviometry index, low relative humidity and average temperature reduction, being the factors that directly contribute to the average increase in the concentration of particulate matter [21].

The employer is responsible for reducing the concentration of dust in the different workstations evaluated, which must carry out a detailed analysis of each of these workstations and take specific measures in order to reduce the risk of exposure of these workers. It is very important to raise the awareness of the employer for prevention, as well as training and information to workers about the risks to which they are exposed. In this sense, prevention has a fundamental role, acting primarily through

the control of the source of pollution, with the alteration of the production process, use of different equipment or in the minimization of the dispersion of dust. Given the existence of dust, the possibility of using means of controlling the dispersion of dust, using water sprinklers or cistern tractors, in the different paths/zones of the quarry, with greater incidence in hot and dry periods, must be evaluated.

If the application of these measures does not allow the dust concentration to be reduced to the desired values, the use of IPE should be used [18]. Most dust enters the human body through the respiratory tract by inhalation, being by far the most important form of human-dust interaction. In the workplace, the 3 forms of contamination are closely associated and in most cases occur simultaneously, although with different degrees of extension, depending on the nature of the dust and the activities carried out [13].

Occupational health has defined some fractions of particulate matter for use in protecting human health. This system classifies particulate matter according to its entry into various fractions of the respiratory system. Inhalable particulate matter is potentially dangerous when deposited in any region of the respiratory tract, thoracic particulate matter, in turn, is potentially dangerous when deposited in the region of the pulmonary channels and in the gas exchange zone. Finally, respirable particulate matter is a subgroup of thoracic particulate matter, which penetrates into the deepest parts of the lungs and is potentially dangerous when deposited in the region of gas exchange [14].

In this study, the most prevalent symptoms reported by workers were headache, followed by fatigue and itching, burning sensation or eye irritation. Most workers stated that the symptoms tend to get worse in the “winter” season. In the season of the year, winter, there is a greater worsening of respiratory compromise and functional disability, due to the decrease in humidity and temperature, making the respiratory tract more exposed to changes, causing bronchial hyperreactivity, which induces chronic inflammation and increases respiratory symptoms. In addition, some viruses exhibit highly seasonal behaviour, with greater frequency in the cold period. These viruses are frequent causes of respiratory infections, mainly of the upper airways [2]. We can say that workers who had been working for the longest time were those who had more symptoms, namely respiratory problems (asthma) and heart problems. Occupational respiratory diseases are, therefore, diseases of the respiratory system caused by work, in which the worker, because he is professionally exposed to certain substances, becomes ill. The work environment can negatively influence the health of the worker through the respiratory system in several ways. The work can have as a consequence the worsening of the disease that the worker has. For example, a worker with allergic asthma, if he works in environments with substances that cause bronchial irritation, may have more attacks than he would have if his work environment were free from this exposure. The most dangerous characteristic of occupational diseases of the respiratory system is that they are diseases that can take decades to manifest, such as lung cancer, which can manifest itself even after occupational exposure has ended. Occupational asthma and other diseases in which the body’s defense system is also involved are now a growing concern and not exclusively in workers prone to allergies [18].

5 Conclusions

The management and monitoring of air quality is essential to ensure the safety of workers, aiming to reduce future health problems that may arise.

With the results obtained in this study, it was possible to observe that both the concentration values of inhalable particles and respirable particles presented values below the legally established values. Although these values are below the exposure limit value, it is advisable that the employer continues to carry out frequent monitoring to prevent the health of workers, as particulate matter can, in the long term, cause occupational diseases at the respiratory level. The importance of having water sprinklers that can operate sporadically throughout the working day is also important, so that there is not so much dispersion of dust and particles in the air. Mainly, with greater incidence in hot and dry periods and in workstations where there tends to be a greater production of dust and particles, as in the case of the primary cabin area and in the loading and unloading carried out by the shovel/loader machine. If the workstation is inside one of the machines, the windows must always be closed and the air conditioning must be checked to see if it works correctly, namely by checking the filters and carrying out other maintenance operations, to avoid the entry of dust and particles into your machine's compartment. When the worker has to travel within the quarry, he must resort to the use of PPE, such as, for example, the use of a protective mask with an FFP3 particle filter.

It would be necessary and extremely important to conduct further studies in this area, in order to establish a monitoring of exposure to particulate matter in quarries in Portugal, thus contributing to the prevention of adverse health effects, both to workers and to the populations surrounding quarries, induced by the release of particulate matter arising from the production processes.

In short, monitoring and evaluating the existence of particles in the work environment is crucial for the health of workers, influencing the well-being, productivity, and safety of workers. The identification of the sources of origin of the particles, as well as the application of preventive measures are important in any decision making about the quality of the work environment.

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Snapshot Assessment to Fungal Load in Wood Departments from “Do It Yourself” (DIY) Stores



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Abstract Workers are exposed to airborne dust at various phases of the wood-working and manufacturing processes, beginning with the tree-felling stage and varying in particle size, concentration, and composition. Fungi are the most well-known microorganisms present in this setting, which, under the correct circumstances, can flourish on wood products that have been stored. Woodworkers who were exposed to wood dust contaminated with fungi have reported cases of allergic alveolitis and asthma. The aim of this study was to perform a snapshot assessment regarding exposure of woodworking employees to fungal load identifying the most critical workstations in local DIY stores. The sampling campaign was conducted between December 2022 and February 2023 in 8 DIY stores located in Lisbon Metropolitan Area. An active sampling method was applied (device MAS–100), collecting 200L at a flow rate of 140 L/min. The higher counts were obtained in the wood exhibition and checkout areas. These results corroborate the employed

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sampling approach as a first step to obtain a snapshot assessment regarding fungal load in a DIY store. It was also possible to predict the spreading of the fungal load through the store, highlighting the importance of One Health approach in this specific setting.

Keywords Woodworkers • Fungi • Occupational exposure

1 Introduction

The main techniques used to work with wood are debarking, sawing, sanding, milling, lathing, drilling, veneer cutting, chipping, and mechanical defibrating. Workers are exposed to airborne dust at various phases of the woodworking and manufacturing processes, beginning with the tree-felling stage and varying in particle size, concentration, and composition [5]. In addition to wood derivatives (such as terpenes and resin acids) and microorganisms that grow on wood (eg.: fungus) and their products (mycotoxins), workers in the wood sector may be exposed to allergic, carcinogenic, and immunotoxic chemicals [7, 11]. Reduced lung function, hyperresponsiveness of the bronchial tubes, and a number of diseases, including organic dust toxic syndrome (ODTS), allergic alveolitis, asthma, chronic bronchitis, rhinitis, mucous membrane irritation (MMI), contact dermatitis, and nasal cancer [4, 7, 12], can all be the health outcomes due to exposure. Indeed, exposure to wood dust is recognized to trigger the induction of several pro-inflammatory responses [28]. Fungi are the most well-known microorganisms present in this setting, which, under the correct circumstances, can flourish on wood products (planks, chips) that have been stored [7, 12]. Indeed, woodworkers who were exposed to wood dust heavily infested with fungi during logging, debarking, and sawing duties have reported cases of allergic alveolitis and asthma [7, 12]. The World Health Organization (WHO), recently published a fungal priority pathogens list (WHO FPPL) which prioritizes fungal pathogens, considering their unmet research and development needs and perceived public health importance, and it's divided into three categories: critical, high, and medium priority (WHO, 2022). This list is crucial for the exposure evaluation in this environment since some of the species of this list, including species with critical priority, are commonly found in sawmills such as *Aspergillus* section *Fumigati* [7, 18, 28]. Most of these In Do it Yourself (DIY) stores do not have a physical separation between the wood cutting area and the rest of the store, which enables the spreading of the wood dust affecting not only workers, but also costumers. Furthermore, costumers take wood pieces for different uses (eg. Diy furniture, agriculture, etc.) which, depending on their final purpose, can influence animals' health or even the environment. To our knowledge, there has been no research on the exposure of woodworking professionals to fungal load in DIY. Thus, the aim of this study was to perform a snapshot assessment regarding exposure of wood-working employees to fungal load identifying the most critical workstations in local DIY stores.

2 Materials and Methods

This study is part of an enlarge exploratory study aiming to access microbial occupational exposure in Portuguese sawmills and DIY stores with wood cutting sections. The sampling campaign was conducted between December 2022 and February 2023 in 8 DIY stores located in Lisbon Metropolitan Area. An active sampling method was applied through the device MAS-100 that was used to collect 200 L of indoor air at a flow rate of 140 L/min. Sampling areas comprised three different locations (wood cutting service area (Fig. 1), wood exhibition area (Fig. 2) and checkout area (Fig. 3). In the wood cutting service two samples were collected in two different moments, one before any cut being made, and another during/after wood cutting. One outdoor air sample in each store was collected to be used as reference [30]. All stores had mechanical ventilation and inside the wood cutting area the machine has a specific extraction system. Additionally, although personal protective devices (PPE) are mandatory in the wood cutting area (hearing protection, gloves, mask, steel-toed safety shoes, etc.) according to the health and safety technician, the only PPE used by all workers from all stores was the hearing protection, and the steel-toed safety shoes. It is important to highlight that 7 out of 8 stores did not have any physical separation between the wood cutting area and the rest of the store.

Air samples were collected onto two standard culture media, namely, malt extract agar (MEA) supplemented with chloramphenicol (0.05%) and dichloran glycerol

Fig. 1 Checkout area



Fig. 2 Wood exhibition area**Fig. 3** Wood cutting area

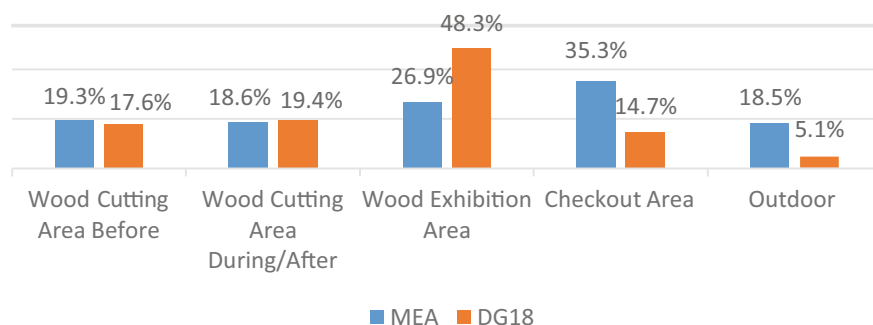


Fig. 4 Fungal (MEA; DG18) distribution from air samples (%)

(DG18) agar supplemented with chloramphenicol (0.01%) [32]. After incubation of MEA and DG18 at 27 °C for 5–7 days, fungal densities (colony-forming units, CFU.m-3) were calculated.

3 Results

Regarding the fungal load, in the wood cutting area, the prevalence was similar before and after/during wood cutting, in both culture media (Before: 19.3% MEA; 17.6% DG18; After/during: 18.6% MEA; 19.4% DG18). The wood exhibition area presented higher load on DG18 (48.3%) than on MEA (26.9%), while on the Checkout Area, MEA presented higher counts (35.3 %) than DG18 (14.7%) (Fig. 4).

Comparing the indoor and outdoor environments, indoor load obtained on MEA exceeded ($I/O > 1$) outdoor load before cutting in the wood cutting area (1.04, > 4%); wood exhibition area (1.45, > 45%), and checkout area (1.90, > 90%). On DG18, indoor exceeded outdoor load in all the sampled areas (before cutting: 3.45, > 245%; during/after cutting: 3.80, > 280%; wood exhibition: 9.45, > 845%; Checkout area: 2.88, > 188%) (Fig. 5).

4 Discussion

Air sampling for microbial assessment, may be developed using several devices. In this study, an impaction device was selected due to the well-known recovery effectiveness of microorganisms, having better results when compared to other sampling methods [27], in what concerns fungal contamination diversity [7, 8, 16, 18, 29, 31]. Although inhalation exposure can be quantified by personal or stationary sampling of bio- aerosols, some environmental factors, such as seasonal variation and ventilation [13, 31, 35], the number of occupants [24, 30], the physical layout of the

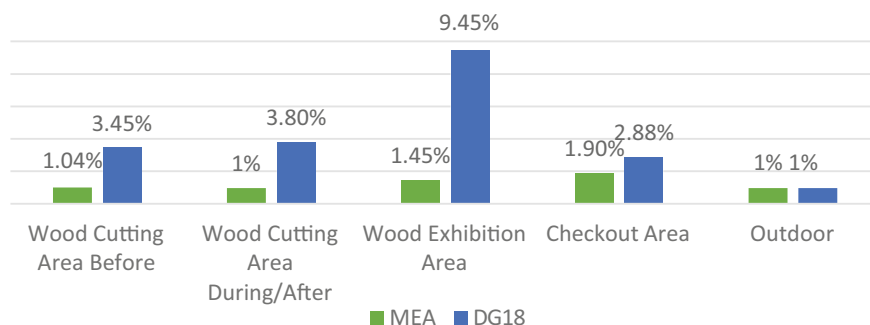


Fig. 5 Indoor/outdoor contamination ratio in all the sampling sites

building, procedures for cleaning and products used, may have a significant impact on inhalation exposure [9, 30]. Thus, besides active sampling methods, there are also several passive sampling methods that allows the collection of contamination over a longer period of time comprising the needed information regarding all the variables mentioned before [1, 23, 28, 33, 35]. Therefore, in order to achieve a more accurate assessment of occupational exposure to fungal contamination, passive and active sampling techniques should always work in parallel to overcome each methods drawbacks [21, 30, 31]. The results of this study, corroborate the employed sampling approach as a first step to obtain a snapshot assessment regarding fungal load in a DIY store, with which it was also possible to conclude that the higher counts obtained were in the wood exhibition and check-out areas.

Workers may be exposed to a wide range of microbial agents in occupational environments [10]. However, due to the wide variety of potential health impacts and microbial diversity, it is still challenging to perform risk assessment [17]. Furthermore, depending on individual susceptibility, different microorganisms may have different health impacts [27]. The development of occupational exposure limits is hampered by the absence of knowledge about the whole spectrum of exposures and of (quantitative) data on the association between exposure and the corresponding health effects (the exposure-effect relationship) (OELs). The recommendations in the literature generally considered the microbial counts without bearing in mind the potential health impact that specific microorganisms may have on workers' health [17].

As a result, there is a discrepancy in the human dose-response following exposure to microbiological contaminants [17].

Some scientific proposed limits are often used as guidance [6], such as the ratios between Indoor/Outdoor ([19] that suggests an acceptable indoor environment when the results are below 1 [6]. For quantitative analysis, there is also a stipulated limit for maximum indoor load (150 CFU.m^{-3}) proposed by WHO (2009), followed by a qualitative assessment, identifying species as indicators of harmful fungal contamination [32], such *Aspergillus* sections *Fumigati*, *Nidulantes*, *Flavi* e *Circumdati* [29]. Some countries defined their own limits like Germany that is the only country that has a technical control value for spores of mesophilic moulds in the workplace air

of waste handling facilities of 5×10^4 spores per m^3 of respiratory air [2]. Or even Scandinavia where the Nordic Expert Group studied the health impacts of hazardous molds and determined that the level of mold spores in the air at which non-sensitized workers begin to feel effects is approximately 10^5 spores/ m^3 of air (Eduard 2006, 2009). It is also important to highlight that there is no safe level of exposure to pathogenic microorganisms and the cut-off should be 0 CFU/ m^3 [14]. In this study, the limit used as a guidance was the ratio between Indoor/Outdoor which suggests an acceptable indoor environment when the results are below 1. In this case, considering the obtained results, indoor load obtained on MEA exceeded ($\text{I/O} > 1$) outdoor load in three sampling sites: before cutting in the wood cutting area, in wood exhibition area, and in checkout area. On DG18, indoor exceeded outdoor load in all the sampled areas suggesting the need to implement measures aiming the risk control. Although there are no well-defined values for dose- response to microbial agents associated with work shift, there are numerous options for employees to reduce workers risk of exposure to these biohazards. It is also important to highlight that there are numerous suggestions for employees who are or may be exposed to biohazards, notwithstanding the lack of well-defined values for dose-response to microbiological agents during work shifts [3, 22]. However, comprehensive data on exposure sources and all factors that may affect exposure are necessary in order to properly assess the possible health effects of occupational exposure to microbial contamination [7]. In fact, an interesting factor that was observed during the sampling campaign is that only one out of eight stores had physical separation between the wood cutting section and the actual store where customers are. Therefore, this can justify the fact that wood exhibition area was the sampling site with the highest contamination in DG18, which means that the fungal load may be spreading all over the store, or at least the nearby places. Thus, it is affecting not only workers but also customers highlighting the importance of One Health approach in this specific setting. Also, there is the possibility of antimicrobial resistance development in this occupational setting. In this specific environment, antimicrobial resistance may occur due to environmental pressure on potentially pathogenic microbial present in wood, and the use of wood azole treatment with hazardous potential for human health [14]. Depending on the type of timber being processed and the production technology, the airborne microflora in sawmill departments can differ greatly [7, 11, 16, 20]. Azole fungicides are used to preserve spruce and pine fields during wood processing, preservation, and maintenance [7, 16, 28]. Additionally, it has already been reported that this environment is a hot spot for azole resistant fungi, and more specifically for *Aspergillus* section *Fumigati* [18, 28]. While some fungi have an innate resilience to azoles, acquired azole resistance has been observed in fungi from occupational settings, such as sawmills, where azole fungicides (14- α demethylase inhibitors, DMI) used to preserve wood may put some selection pressure on microbial populations [28]. Aiming to obtain a more accurate scenario regarding exposure to fungal contamination a multi-approach concerning sampling methods, combining active and passive sampling methods, and assays aiming the fungal characterization and screening of susceptibility to azoles, is reinforced by the use of azole fungicides to protect the wood and it should be the trend to follow [7].

5 Conclusions

This study allowed to conclude that wood exhibition area is the sampling site with the highest fungal load. The active sampling method was effective in identifying the most critical workstation in this specific occupational environment. The out-comes of this approach also corroborate the necessity of a more thorough characterization of the microbial exposure risk, in order to help prioritize efforts for its eradication or reduction.

It was also possible to predict the spreading of the fungal load through the store. However, it is well known that active sampling methods should be used combined with passive methods to assess occupational exposure to microbial contamination indoors, since they provide information from a longer period. The combination of active and passive sampling methods, along with species identification and detection, to ensure a better risk characterization and management, is something to look forward to in future studies from this enlarged exploratory study aiming the proposal of a refined protocol. Finally, in order to ensure the workers' and customers' safety a One Health approach should be considered.

Acknowledgements This research was funded by national funds through the FCT—Fundação para a Ciência e Tecnologia, I.P., within the scope of the PhD Grant UI/BD/151431/2021. H&TRC authors gratefully acknowledge the FCT/MCTES national support through the UIDB/05608/2020 and UIDP/05608/2020.

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Thermal Comfort Assessment in a Food Industry (SIA)–Case Study



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Abstract Control of thermal comfort is a very important factor in the work- place. If this control is lacking, workers' concentration levels can be affected, which has a direct impact on their performance and productivity. Temperature and humidity in the workplace, as well as in communal facilities, must be suitable for the human body, taking into account the working methods, the clothing used and the physical limitations of workers, in order to ensure comfort and protect health. **Aims:** Evaluate the environmental variables and the individual variables, using the PMV and PPD indices to assess whether thermal comfort is present in workplaces in a food industry. **Material and Methods:** For the analytical evaluation, the Delta Ohm device was used, whose model was HD 32.1 Thermal Microclimate, and measurements were taken in 7 work areas of a food industry. **Results:** In this study, all the places where the measurements were made did not have thermal comfort, and in some workplaces a very hot thermal sensation was reached by most of the workers.

Keywords Food industry · Physical risks · Thermal environment · Thermal comfort

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1 Introduction

Every occupational activity poses risks to workers, risks that are divided into chemical, biological, physical, ergonomic and mechanical, all of which are found in a wide variety of work environments.

The thermal environment, a central fact in the approach of this study, is closely related to the other environmental risk factors, as the spread and contamination of other agents (chemical and biological) is largely determined by the variables of temperature and humidity. This is true not only for the indoor climate, but especially for the outdoor climate [7].

Although it is recognised that workers in an industrial context may face hot or cold thermal environments, i.e. outside the thermal comfort zone, it is considered that the main reason for thermal environment studies is to ensure that a greater number of people feel comfortable in a given workplace, in order to avoid possible occupational accidents, health problems and other issues that the discomfort may cause. In view of this, work performance and productivity will generally increase [3].

The perception of thermal comfort is determined by transmission processes that take place between the individual and the environment and depend both on environmental factors such as air temperature, average radiant temperature, relative humidity and air velocity, and on individual factors such as activity and thermal resistance of clothing, but also on the physiological differences that are characteristic of each individual, since ideal conditions for thermal comfort can hardly be achieved for all individuals working in a given place [2].

The study of thermal comfort is crucial for creating more comfortable, safe and productive environments. In an industrial context, the study of thermal comfort aims to create a positive relationship between employees and their working environment, which is necessary for good performance [5].

In an industrial environment, it is difficult and often impractical to strive for thermal comfort. This is due to the production processes that sometimes introduce large amounts of radiant heat into the industrial buildings, the operating procedures or even the lack of structural measures to reduce the impact of outdoor temperature fluctuations in the industrial buildings. In these situations, it is common to calculate indices that characterise warmer thermal environments and provide an estimate of the thermal sensation of workers [3].

Currently, there is a growing need for indoor space assessment, as an environment with good thermal comfort significantly improves people's health, well-being and productivity. Although thermal comfort is of great importance to occupants, buildings must not only be prepared to provide comfort to their occupants, but also to operate efficiently, as buildings are responsible for about one third of the world's total energy consumption [6].

Over time, human comfort has been an important driver for the development of new technologies not only in the workplace, but also in industry, transport and commerce, favouring thermal comfort-driven performance and enabling workers in general to improve their quality of life [2].

The PMV (Predicted Mean Vote) is a thermal comfort index that gives an average value for a large group of people exposed to the same environment. This index of thermal comfort was proposed in 1970 by P.O. Fanger and is used to assess thermal sensation in temperate environments (Xavier 2020).

The PPD (Predicted Percentage of Dissatisfied), an index of predicted quantitative value that indicates the percentage of people who are dissatisfied with the thermal conditions of an environment, i.e. who perceive the environment as too hot or too cold. Taking into account the parameters of PMV, mathematical formulas are used to infer the comfort conditions of a given space [4].

For thermal comfort to exist, the numerical values of PMV must vary between -0.5 and $+0.5$, and estimated values greater than ± 0.5 denote thermal discomfort due to cold or heat, depending on the environment assessed [2].

The poor quality of the indoor environment in activities performed outside the thermal comfort zone in certain workplaces can affect job satisfaction. If the air quality, air conditioning and lighting system of the workplace in question are poor, effects such as fatigue, headaches, among others, can lead to workers' productivity being affected. In addition, dry skin, dry eyes and throat, itchy eyes, among others, cause thermal discomfort caused by extreme heat or cold [2].

The human organism uses several mechanisms to promote the body's heat balance. During cold weather, the organism can speed up the mechanism to produce more energy in the form of heat.

High temperatures have a very big impact on humans. When going beyond the comfort zone, the person feels dissatisfied and uncomfortable in the space he is in. The diseases he may be carrying tend to get worse. During physical work in hot ambient temperature, the internal body temperature rises above normal. When the heat that the organism gives off to the environment is less than the heat it receives or produces through the whole metabolism, the organism tends to increase its temperature and, to avoid this, hyperthermia—*increase in body temperature* [2].

Daily/prolonged exposure to high temperatures leads not only to skin ageing, skin lesions and premature loss of skin elasticity, but also to stress, reduced muscle capacity and performance with altered mental activity, sensorimotor coordination disorders, fainting and even brain damage—*stroke* [2].

During physical work in cold ambient temperature, the internal body temperature tends to be lower than the normal value. When the heat released to the environment is greater than the heat absorbed or generated by the basal metabolic rate /work due to the physical activity performed, the body tends to cool down and, to avoid this, hypothermia—a *drop in body temperature* [2].

For the purposes of the study, an objective method, the thermal comfort indices (PMV and PPD), was selected as an assessment tool that ensures an ideal approximation to statistically real thermal comfort and is derived from ISO 7730:2005—*Ergonomics of the thermal environment; Analytical determination and interpretation of thermal comfort by calculation of PMV and PPD*.

Clothing represents an element of great importance for thermal comfort, as it directly affects it by regulating the exchange of energy in the form of heat, such as the sweat mass of the human body, with the environment [8].

Since thermal comfort is a feeling and not a physical or mathematical parameter that can be precisely quantified, the definition of thermal comfort is very subjective depending on the individual. This definition may even vary for the same person depending on their state of health and/or psychological condition. Under these circumstances, it is impossible to create a universal neutral thermal environment for all individuals [8].

2 Materials and Methods

2.1 Study Design

This study was classified as observational, descriptive, cross-sectional type. The place chosen for the study was the food industry Sociedade Industrial De Aperitivos, S.A—SIA, where a quantitative assessment was carried out to evaluate thermal comfort in this industry.

2.2 Population and Sample

The target population of this study was food industry employees—SIA—with a sample of 280 workers. The sampling method used was non-probabilistic and as far as the technique is concerned, it is for convenience. In order to integrate the study, the sample included as inclusion criteria the workers of the workplaces where the measurements were made. The exclusion criteria were all workers not working full time in the industry.

In June 2022, measurements were taken at 7 different workplaces: Raw goods reception; potato cutter; fryer area; potato storage; packaging zone; palletising zone; loading/unloading zone—warehouse.

2.3 Instruments and Data Collection

For the present study, the Delta Ohm device was used for the analytical evaluation, the model of which was the HD 32.1 Thermal Microclimate. After the system had stabilised at the worker's workstation for 20–30 min, data collection began by measuring environmental variables (air temperature, relative humidity, air velocity and radiant temperature) at 15–15 s intervals.

The data collected by Delta Ohm was then transferred to a computer for analysis and data processing, and the PMV and PPD indices were calculated. Deltalog10 software was used to visualise the results.

2.4 Statistical Analysis

To better interpret the results obtained, measures of central tendency (average), dispersion (standard deviation), maximum and minimum values were used with the help of the programme Deltalog10. Subsequently, the software IBM SPSS Statistics (version 27.0) was used to match the ambient temperature/relative humidity data and the indices of PMV-PPD in the 7 locations studied with the legally recommended values for the protection of workers in your working environment.

3 Results

The results on environmental parameters (air temperature, relative humidity, radiant temperature, air velocity, predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) at the 7 study sites were summarised in tables for better interpretation.

It is important to note that during our measurements the outdoor temperatures were hot.

After analysing the results (Table 1), it was found that the value of the variable T_a (ambient temperature) was higher in the potato storage area than in the other locations. It had a maximum value of 33.8 °C, a minimum value of 28.7 °C and an average value of 32.9 °C.

As for relative humidity (RH), the highest value was obtained in the raw material reception area, with a maximum value of 80.9%, a minimum value of 78.4% and an average value of 79.4%.

As for the variable T_r (radiant temperature), a maximum value of 34.2 °C was obtained in the potato storage area, a minimum value of 29.8 °C and an average value of 32.2 °C.

As far as the variable V_a (air velocity) is concerned, a maximum value of 0.63 m/s, a minimum value of 0.01 m/s and an average value of 0.22 m/s were determined in the raw material reception area.

As far as the thermal comfort indices PMV and PPD are concerned, an average value of 2.81 and 97.41% respectively was obtained in the potato storage area. As it can be seen, it can be concluded that there is no thermal comfort in any of the studied places as the average PMV is > 0.5 and the PPD has an average percentage of 77.24% ($< 10\%$), i.e. 77.24% of the company's employees are dissatisfied with the perceived thermal environment in their workplace.

As for the individual parameters of the company's employees, the thermal resistance of their clothing is 0.75 clo (underwear, shirt, trousers, socks, shoes) and a metabolic heat energy of about 144.8 w/m². At the workplace in the loading and unloading area, the employees have a higher metabolic heat energy with a value of about 184.9 w/m².

Table 1 Measurement of thermal comfort parameters in the reception of raw materials

Work station 1—Reception of raw materials							
	At (°C)	RH (%)	Rt (°C)	Av (m/s)	PMV	PPD (%)	Thermal sensation
Average	21,50	79,40	22,90	0,22	1,26	38,53	Uncomfortable for most occupants—Slightly warm
SD	0,12	0,59	0,70	0,15	0,11	5,64	
Work station 2—Potato cutters							
Average	26,20	68,30	25,50	0,12	1,91	72,18	Uncomfortable for most occupants—Hot
Standard deviation	0,45	1,91	1,43	0,06	0,11	5,61	
Work station 3—Fryer zone							
Average	29,30	58,20	31,30	0,12	2,54	93,68	Uncomfortable for most occupants—Very hot
	−0,38	1,76	1,79	0,08	0,15	3,41	
Work station 4—Potato accumulators							
Average	32,90	44,20	32,20	0,01	2,81	97,41	Uncomfortable for most occupants—Very hot
Standard deviation	1,24	3,31	1,53	0,01	0,18	1,99	
Work station 5—Packing zone							
Average	26,50	59,10	28,60	0,06	2,13	81,63	Uncomfortable for most occupants—Hot
Standard deviation	0,73	2,27	1,85	0,051	0,18	6,57	
Work station 6—Palletizing zone							
Average	24,70	63,00	25,40	0,01	1,79	66,38	Uncomfortable for most occupants—Hot
Standard deviation	0,13	0,36	0,34	0,04	0,03	1,74	
Work station 7—Loading/unloading zone							
Average	26,20	60,50	26,02	0,07	2,4	90,73	Uncomfortable for most occupants—Hot
Standard deviation	0,57	2,19	1,41	0,08	0,12	3,33	

4 Discussion

Workplaces, as well as communal facilities, must provide good temperature and humidity conditions to protect the well-being and health of workers.

In this study, established reference criteria were sought. For example, according to Legal Framework No. 53/71 of 23 February, it is recommended that the temperature in workplaces should be between 18 °C and 22 °C and the humidity between 50 and 70%.

Although there are no reference criteria for air velocity and radiant temperature, they affect the thermal comfort of the worker, so it is recommended that reference values be established to control these parameters in the workplace.

In view of the values obtained in the measurements carried out and the criteria for protecting the health of workers exposed to the thermal environment in their work-place, it was found that there were situations in which their health could be at risk.

At site 1, the recommended exposure limits were not reached at ambient temperature. However, a maximum value of 21.8 °C was reached, which is very close to the limit value (22 °C). The data collected at ambient temperature was crossed with the legally recommended values and it was found that the results of 100% of the measurements taken at this site were within the recommended range. Relative humidity at this workplace, on the other hand, was found to have a maximum value of 80.9%, exceeding the recommended limit of 70%. Considering the thermal comfort indices (PMV and PPD) at this location, it can be said that 38.53% of the workers are dissatisfied with the thermal environment as they have an uncomfortable thermal feeling, for most workers—slightly hot.

At site 2, the potato cutter area, an average ambient temperature of 26.2 °C was measured and 100% of the measurements taken at this site exceeded the exposure limits. For perceived relative humidity, the values were 68.7%, with 17.1% of the measurements exceeding the recommended occupational exposure limits for relative humidity. Taking into account the location and the values of the thermal comfort indices (PMV and PPD), it can be concluded that 72.18% of the workers in this area are dissatisfied with the thermal environment, with most workers having an uncomfortable thermal sensation. Workers—Hot.

At site 3, the average ambient temperature is 29.3 °C, which is above the maximum recommended by law. As for relative humidity, the values are within the recommended limits. Considering the values of the thermal comfort indices (PMV and PPD) in the area of the fryers, we find that 93.68% of the workers in this location are dissatisfied with the thermal environment, putting their health at risk. The thermal environment in the fryer area is uncomfortable for most occupants—too hot.

For the workers at the 4th study site, the recommended limits for ambient temperature were exceeded (32.9 °C) and those for relative humidity were below the recommended values (44.2%). As for the values of the thermal comfort indices (PMV and PPD) in the area, it can be said that 97.41% of the workers are dissatisfied with the thermal environment in their workplace. The thermal environment in the potato storage area is uncomfortable for most of the occupants—very hot.

At site 5, workers are exposed to an ambient temperature of 26.5 °C, which is above the recommended levels. The relative humidity values recorded were reasonable as they are within the recommended limits. Regarding the thermal comfort indices (PPD and PMV), it was found that about 81.63% of the workers were dissatisfied with the thermal environment in their work area. The thermal environment in the packing zone is uncomfortable, for most occupants—hot.

For the studied site 6, an average value of 24.7 °C was determined for the ambient temperature, which is above the legally recommended limit (22 °C). As for relative

humidity, the values were reasonable and within the recommended values. As for the thermal comfort indices PMV and PPD, we can see that 66.38% of the workers in the study are dissatisfied with the thermal environment in the palletising zone. The thermal sensation in this place is uncomfortable, for most workers—hot.

In the last location studied, workers do not meet the recommended conditions in terms of exposure to ambient temperature (26.2 °C). As for the perceived relative humidity in this area, the values are favourable, so it has an average value of 60.5%. Taking into account the location and the PMV and PPD values, it can be concluded that 90.73% of workers are dissatisfied with the thermal environment in their work- place. The thermal environment in the loading and unloading zone is uncomfortable—hot—for most occupants.

5 Conclusions

Thermal comfort is essentially a subjective response or state of mind in which a person expresses satisfaction with the thermal environment. Thermal sensation varies greatly from person to person and depends on environmental factors, clothing insulation and the person's acclimatisation, which is due to endocrine adaptations that occur over a long period of time. Full acclimatisation is achieved on average after 30 days and by the end of this period comfort preferences should have changed. Thermal comfort assessment is not one of the most frequently requested occupational safety and health (OSH) services. Health, satisfaction, safety and productivity are requirements directly related to a healthy working environment.

Considering the values found and taking into account the values recommended by law in Legal Framework No. 53/71 of 23 February and in ISO 7730:2005—Ergonomics of the thermal environment; Analytical determination and interpretation of thermal comfort based on the calculation of the PMV and PPD, we can say that in all the places studied there are situations that endanger the health of workers in this sector, focusing on the area of deep fryers and the area of potato accumulators.

High temperatures have a very big impact on people. Workers exposed to this type of risk feel uncomfortable and unhappy in the space they are in. This can affect their productivity and put their health at risk, with possible symptoms such as weakness, fatigue, increased body temperature, thirst and headaches, among others.

It should be noted that high values were found in the measurements studied, underlining the need to reduce not only these values but also the time they are exposed. In this study we have applied a methodology that focuses on the use of measuring devices to assess thermal comfort. However, it is also possible to assess thermal comfort by directly interviewing workers, using the same thermal comfort indices (PMV and PPD), in order to obtain your responses and to know your opinion on the thermal environment. We therefore propose that the thermal comfort assessment should also be carried out in this way in the future, so that the two methods can be compared to see if they do indeed reach similar conclusions or if there is a dissonance

between these two methods. It is important to continue this objective by pointing out a knowledge that is urgently needed to better understand the exposure levels of people working in this food industry by complementing this study with research on possible consequences for the health of the employees of this company.

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Evaluation of Workers' Exposure to Occupational Noise in the Textile Industry (Case Study)



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Abstract *Introduction*: Today's society is more developed and industrialized, which has multiplied the sources of noise and, consequently, the increase in sound levels, becoming one of the main threatening causes for the physical, psychological, physiological and social health of workers. Noise can have consequences for human health, productivity and work performance. *Objectives*: to evaluate workers' exposure to occupational noise in the textile industry. *Material and Methods*: In a first phase, an individual and anonymous survey was made to the workers, and in a second phase, the levels of exposure of factory workers to noise were evaluated and we carried out the selection of ear protectors in accordance with the legal assumptions. *Results*: The study made it possible to verify that most of the evaluated jobs were above the legal values of lower and higher share value. No worker used hearing protection during work activity. Workers reveal some symptomatology associated with continuous exposure to occupational noise, such as tinnitus, and perceive a decrease in hearing equity associated with the number of years they were exposed in the textile industry.

Keywords Noise pollution · Hearing protection · Tinnitus · Occupational noise · Professional deafness

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1 Introduction

Noise is known as one of the main risk factors for the health of workers in the industrial environment [1, 2]. This sound—Noise—is defined as being unpleasant or undesirable [3], whose intensity is measured in decibels (dB(A)) [4]. The exposure of workers to industrial noise can be controlled, with minimal costs and without any technical obstacles. The main objective of industrial noise control is to eliminate or reduce noise at its source [3].

One of the largest and most important national business sectors is the textile industry, which is one of the oldest and most traditional Portuguese industries. With the industrial revolution, which began in the late 18th and mid-nineteenth centuries, industrialization expanded. The revolution promoted the origin of textile production [5]. The rapid development of industrialization has become one of the main threatening causes for the physical and psychological health of workers. In numerous industrial workstations and work-places, workers are exposed to different risk factors, such as lighting, vibration, radiation, noise, among others, which can have consequences for human health, productivity and work performance. Within these risk factors, noise is classified as one of the most influential and harmful physical agents in the work environment [6].

In Portugal, the number of workers detected with occupational diseases is quite high, with professional deafness being one of the most frequent occupational diseases. Noise-driven hearing loss is the most common occupational disease in the European Union [3, 7]. According to the European Agency for Safety and Health at Work, the reduction in hearing capacity caused by noise was recognized as the most prevalent irreversible occupational disease. Noise affects human beings simultaneously in physical, physiological, psychological and social aspects [3, 2].

Several studies show that loud noise is associated with hearing loss—irreversible deafness, as well as associated with stress, discomfort, drowsiness, hypertension, cardiovascular diseases, reduced cognitive performance and concentration, reaction speed and memory, as well as other factors less obvious, such as bad mood and discomfort [1, 8–10].

The main objective of this study was to evaluate workers' exposure to occupational noise in a textile industry and to determine workers' exposure risk.

2 Methods and Materials

2.1 Study Design, Population and Sample

The study was observational with a cross-sectional time line. With regard to the level of knowledge, it was classified as level II (descriptive-correlational). Sampling was non-probabilistic and, in terms of technique, for convenience. The study population

focused on workers in a textile industry located in the central region of Portugal, in the district of Coimbra, municipality of Lousã (Industrial Zone).

As inclusion criteria in the selection, it was assumed that workers exposed to factory noise and that they covered all work sections were included. As exclusion criteria, workers with congenital hearing problems and workers from departments who were not directly exposed to the company's work activity were not included. As for the sample size (number of workers), it consisted of 8 employees, one for each work section (dyeing and centrifuge room, packaging areas, forming room, labeling room, looms area and Sewing).

2.2 *Instuments and Data Collection*

First, an individual and anonymous survey was applied. It comprised 21 questions, divided into 6 sections: socio-biographical information, history of pathologies; workers' perception of their exposure to noise and its classification in terms of intensity; Disturbance signs/symptoms associated with noise at work at the end of the working day (eg memory lapses, temporary hearing loss, tinnitus, etc.); Perception of hearing loss due to the noise to which they were exposed in their workplace; Aptitude sheet; training in Occupational Health and Safety; Conducting health examinations; Individual protection practices at the auditory level.

In a second phase, the collection of analytical data was carried out, namely the quantitative assessment of the levels of daily personal exposure to noise ($L_{EX,8H}$), the peak sound pressure levels (L_{Cpeak}) and the frequencies in Octave Bands (63, 125, 250, 500, 1, 2, 4, 8 kHz). Of the 8 workstations, 1 worker was selected for each position and the measuring instrument was placed there, providing the survey simultaneously. 3 measurements were performed with a sampling time of 20 min to 1 h, at each workstation. In this way, a total of 24 measurements were performed. Measurements were performed with the aid of CESVA DC112 dosimeters. The calibration of these devices was carried out, in accordance with legal requirements, using the CESVA Acoustic Calibrator equipment. Taking into account the great mobility of employees, the measuring instruments were applied in such a way that our study did not disturb the normal development of work activity.

The dosimeters were placed on the participant's belt. The microphone was placed at a height equivalent to the factory operator's ear, so that the sound levels that reached the microphone were similar to those received by the worker's ear.

After collecting data with the measuring instrument, they were transferred to a personal computer using a software characteristic of the "CESVA Capture Studio" equipment, version 9.14.0. We had as support, for analysis and evaluation, the Decree-Law n.182/2006, of September 6, which establishes the exposure limit values and the upper and lower action values (Table 1), with regard to exposure worker's daily personal and peak sound pressure level: Lower Action Value: $L_{EX,8H} = 80$ dB(A) and $L_{Cpeak} = 135$ dB(C); Upper Action Value: $L_{EX,8H} = 85$ dB(A) and $L_{Cpeak} = 137$ dB(C); Exposure Limit Value: $L_{EX,8H} = 87$ dB(A) and $L_{Cpeak} = 140$ dB(C).

2.3 Statistical Analysis

The data obtained were treated statistically using the IBM SPSS Statistics software, version 27. At the level of this case study, specific descriptive statistics measures were applied (mean, standard deviation, median) and graphic measures (bar diagram and diagram of extremes and quartiles).

3 Results

The study was carried out with 8 factory workers, where they performed daytime work, had fixed jobs. They work 5 days a week and 8 h a day (8:30 am–5 pm). Most were female and aged between 35 and 64 years. With regard to academic qualifications, most had completed the 3rd cycle. They indicated working in the industrial sector between 11 and 30 years old.

Regarding the question, *“Have you ever had any pathology that led to hearing loss?”* All workers responded negatively. All employees answered affirmatively to the question *“Do you think your workplace is exposed to noise?”* As for the perception of the noise intensity to which they were exposed, most workers considered it *“moderate”*. According to the question *“At the end of your working day, have you ever left your workplace upset due to noise?”* a positive response was observed. None of the workers experienced or ever experienced noise-associated memory lapses or temporary hearing loss. However, 3 already felt tinnitus at the end of the work day. *“Over the years, do you feel that you are losing your hearing due to the noise you are exposed to in your workplace?”* only 2 workers said yes. As for training in Health and Safety, most responded that the issue of noise was addressed. Also with regard to health surveillance, most respondents underwent tests and all had the aptitude form.

None of the workers used hearing protectors, however most answered that personal protective equipment should be part of their job, despite finding it a nuisance.

To have a better perception of jobs according to $L_{EX,8H}$, in view of the legislated values, look at Fig. 1 (diagram of extremes and quartiles) and Table 1 with the respective octave bands:

After observing the behavior of the $L_{EX,8H}$ in each workstation, and comparing it with the values legislated by Decree-Law n° 182/2006, it was possible to verify that, out of 8 workstations, 7 were the values that were presented in yellow and red in Table 1, require hearing protection. Since the $L_{EX,8H}$ values vary between 80 and 86 dB(A), that is, the employer has to make personal protective equipment available to the worker and the worker is the one who decides whether or not to use it (those in yellow), whereas values in red require the use of hearing protectors.

We sought to assess the noise exposure of factory workers and, if necessary, recommend hearing protection. We proposed 2 types of hearing protectors—1 plug and 1 muffler. These two types of hearing protection were suitable for the 7 jobs.

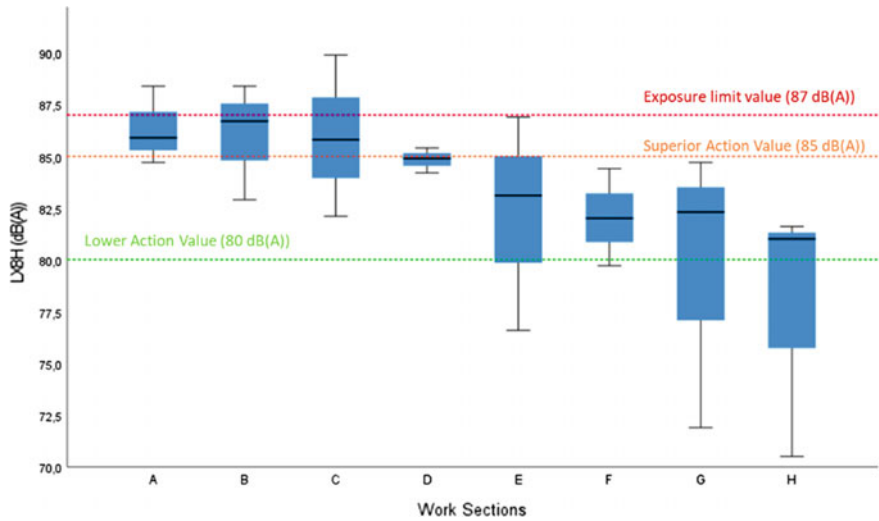


Fig. 1 Levels of L_{X8H} per work section within legal limits

Table 1 Value of $L_{EX,8H}$ and L_{Cpico} at each workstation and the respective frequencies

		Frequencies in Octave Bands – dB(A)								
	$L_{EX,8H}$ – dB(A)	L_{Cpico} – dB(C)	63HZ	125HZ	250HZ	500HZ	1KHZ	2KHZ	4KHZ	8KHZ
A	86,3	138,5	49,8	61,9	72,6	81,0	82,3	79,3	73,6	66,3
G	79,6	121,5	70	62,3	70,6	77,1	76,6	70,2	60,0	62,8
E	82,2	122,1	52,3	57	67,8	76,1	78,4	74,5	71,8	70,6
F	82,0	120,1	71,3	71,4	75,4	78,3	78,3	74,0	71,1	69,4
C	85,9	134,1	44,4	61,6	74,3	81,7	80,8	76,2	71,7	70,0
B	86,0	124,5	58,8	62,9	75,0	79,5	81,1	79,4	77,8	75,4
H	77,7	129,8	42,8	52,5	70,0	72,6	71,7	68,3	63,7	59,5
D	84,8	122,2	51,2	67,2	74,7	80,3	80,3	75,8	71,0	66,5

Subtitle: (A) Dyeing room and Centrifuge; (B) Looms; (C) Seam Zone 1; (D) Seam Zone 2; (E) Labeling; (F) Forming; (G) Packaging 1; (H) Packaging 2. Red Color: 85 dB(A) to 87 dB(A)—Worststations where hearing protectors are recommended, employers must provide EPI’s and the workers decide whether to use it or not. Color yellow: 80 dB(A) to 85 dB(A)—Workplaces where hearing protectors are recommended, the employer must make PPE available, and the workers are the ones who decide whether to use it or not. Blue Color: L_{Cpeak} value higher than the upper action value (137 dB(A)).

According to NP EN 458, the ideal exposure value, already with hearing protectors, must be between 65 and 75 dB(A) — $L_{EX,8H}$ effective. Let’s look at Tables 2 and 3.

After the calculation, to propose hearing protectors, we obtained ideal values according to NP EN 458 ($L_{EX,8H}$ effective 65 dB(A) –75 dB(A)). The ideal external hearing protector found was the “Ear Ultra” as well as “Bilsom”.

Table 2 Frequencies in octave bands and value of $L_{EX,8H}$ in each workstation

Damper (Ear Ultra)	63HZ	125HZ	250HZ	500HZ	1KHZ	2KHZ	4KHZ	8KHZ	
AP	-26,3	-27,7	-26,4	-28,2	-26,3	-31,2	-36,2	-40,2	
DP	6,4	7,9	8,2	7,6	5,6	5,5	7,5	5,9	$L_{EX,8H}$ effective
A	36,3	50,0	62,6	68,0	67,2	59,1	52,4	37,9	71,6
G	56,5	50,4	60,6	64,1	61,5	50,0	38,8	34,4	67,6
E	38,8	45,1	57,8	63,1	63,3	54,3	50,6	42,2	67,2
F	57,8	59,5	65,4	65,3	63,2	53,8	49,9	41,0	70,3
C	30,9	49,7	64,3	68,7	65,7	56,0	50,5	41,6	71,6
B	45,3	51,0	65,0	66,5	66,0	59,2	56,6	47,0	71,2
D	37,7	55,3	64,7	67,3	65,2	55,6	49,8	38,1	70,9

Subtitle: AP=Protector attenuation average; DP=Standard Deviation; (A) Dyeing room and Centrifuge; (B) Looms; (C) Seam Zone 1; (D) Seam Zone 2; (E) Labeling; (F) Forming; (G) Packaging 1

Green color: Values of $L_{EX,8H}$ effective, that is, the workstations already with the hearing protector recommendation

Table 3 Frequencies in octave bands and value of $L_{EX,8H}$ in each workstation

Headphone (Bilsom)	63HZ	125HZ	250HZ	500HZ	1KHZ	2KHZ	4KHZ	8KHZ	
AP	-26,3	-27,7	-26,4	-28,2	-26,3	-31,2	-36,2	-40,2	
DP	6,4	7,9	8,2	7,6	5,6	5,5	7,5	5,9	$L_{EX,8H}$ effective
A	36,3	50,0	62,6	68,0	67,2	59,1	52,4	37,9	71,6
G	56,5	50,4	60,6	64,1	61,5	50,0	38,8	34,4	67,6
E	38,8	45,1	57,8	63,1	63,3	54,3	50,6	42,2	67,2
F	57,8	59,5	65,4	65,3	63,2	53,8	49,9	41,0	70,3
C	30,9	49,7	64,3	68,7	65,7	56,0	50,5	41,6	71,6
B	45,3	51,0	65,0	66,5	66,0	59,2	56,6	47,0	71,2
D	37,7	55,3	64,7	67,3	65,2	55,6	49,8	38,1	70,9

Subtitle: AP=Protector attenuation average; DP=Standard Deviation; (A) Dyeing room and Centrifuge; (B) Looms; (C) Seam Zone 1; (D) Seam Zone 2; (E) Labeling; (F) Forming; (G) Packaging 1

Green color: Values of $L_{EX,8H}$ effective, that is, the workstations already with the hearing protector recommendation

4 Discussion

As we can see, the age of the workers ranged from 35 to 64 years old, this characteristic being a determining factor of hearing loss [11]. When we associate work activity, with special emphasis on the textile industry, the work of machines, in the production sector, produces undesirable noise that may have an impact on the general health of workers [12, 7] and in a way manifested by the study participants.

According to [1] one of the manifestation characteristics of changes in hearing after exposure to occupational noise is the occurrence of a continuous ringing in the ears (tinnitus), although temporary. In a way, 3 workers reported feeling tinnitus after leaving the workplace. This symptomatology can also be quite uncomfortable in people with noise-induced hearing loss [13].

To the question “*Over the years, do you feel that you are losing your hearing due to the noise you are exposed to in your workplace?*” 2 employees said yes, and according to the Portuguese Security Association (APSEI), it reveals that prolonged exposure to noise can cause permanent hearing loss [3]. According to our workers, we could see that most of the workers who took part in this study have been working in this field for many years (industrial sector) and that this same time (years) of contact with noise work may be associated, in their perception, with a decrease in hearing capacity [14, 15].

The use of personal protective equipment, specifically hearing protection, is very important to protect workers from future problems. As referred by APSEI and other studies, companies (managers) must ensure the availability of individual hearing protection equipment, whenever one of the lower action values is exceeded, and ensure its effective use, whenever the level of exposure to noise reach or exceed higher action values [3, 16]. With the results obtained, it was possible to verify that there are 7 workstations in which at least the lower action value of 80 dB(A) is reached, however, and according to the survey carried out to the workers, it was possible to verify that no worker in this manufacturing unit used or had hearing protection available. However, most workers reported having had training in safety and health at work, more specifically, on the subject of occupational noise.

In terms of health surveillance, and in accordance with the Security Portuguese Association, companies must ensure adequate medical surveillance of workers when there is exposure to occupational noise. This type of surveillance is associated with the objective of early detection of possible hearing loss in workers and taking measures to preserve their hearing capacity. Thus, the employer must guarantee the medical surveillance of workers with the following periodicity: Annual (or less if the doctor so decides) for workers who have been exposed to noise levels higher than the higher action values ($L_{EX,8H} = 85$ dB (A) and $L_{Cpeak} = 137$ dB(C)). And every two years (or less if the doctor decides so) for workers who have been exposed to noise levels higher than the lower action values ($L_{EX,8H} = 80$ dB(A) and $L_{Cpeak} = 135$ dB(C)) [3]. And as it was possible to find out, all employees had an aptitude form and most underwent health examinations.

The value of $L_{EX,8H}$ fluctuated depending on the job. Of the 8 jobs evaluated, 7 of these had higher values, as was the example of the dyeing room and centrifuge 86.3 dB(A), the two cooking zones (sewing): Sewing the toe of the sock 85.9 dB (A), and Sewing make tights 84.8 dB(A), and looms (weaving) 86.0 dB(A). These values are partly confirmed by what was presented in the sectoral action plan for the improvement of hygiene and safety conditions at work in the “textile and clothing sector” of Citeve, where it revealed that the weaving sector of this industry were normally superior to 90.0 dB(A) [17, 18]. In the cooking area, the noise value can be between 80 dB(A) and 87 dB(A).

In terms of hearing protection, hearing protectors were recommended for the 7 jobs that needed these elements. For the recommendation of hearing protection, we used NP EN 458 [19] as a basis, which states that the ideal value with hearing protection must vary between 65 and 75 dB(A) of effective $L_{EX,8H}$. That said, and by collecting the different frequencies in each job, it was possible to identify the internal and external hearing protectors that would be more favorable to workers.

5 Conclusions

With this study and as main objective, it was intended to evaluate the noise levels to which factory workers were exposed. After data collection and analysis, it was possible to verify that many of the stations had levels higher than the lower and/or higher action values. Through direct observation of the worker and analysis of the answers given to the survey, it was possible to verify that no worker used hearing protection. And as a secondary objective of this study, it was to recommend, if necessary, hearing protection for workers and we reached the conclusion that the hearing protector that best adapted to all the necessary jobs was identified. This strategy allowed the employer, when purchasing a single type of external and internal hearing protector, to be more practical in distributing PPE to the sections that needed it. We also highlight the need to carry out a specific analysis of the origin of the existing noise in the workplace where the LC_{peak} value exceeds the upper action level, with the objective of finding prevention/control methodologies for this risk factor.

As suggestions for future research, this type of study could be carried out in other manufacturing units with a similar profile in order to be able to compare results and also to evaluate workers' exposure to noise and simultaneously their hearing capacity, in order to be able to understand the reflection of this exposure in the hearing of workers. collaborators, performing auxiliary diagnostic exams to see whether or not there are alterations in auditory acuity.

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Diagnosis of Occupational Diseases in the Northern Region of Portugal: 2019–2021



Ana Silva  and Maria de Lurdes Dinis 

Abstract An occupational disease is considered to be a disease caused by exposure at work to a risk factor of a physical, organisational, chemical or biological nature or a combination of these factors. Musculoskeletal disorders (MSDs) are the most common health problem in the European Union, affecting all sectors of activity and occupations. A total of 9915 occupational diseases recognised by Social Security for workers in the Northern region of mainland Portugal between 2019 and 2021 were analysed. For data processing, SPSS software was used to calculate occupational disease incidence and prevalence rates, group occupational diseases by major disease groups, and categorise occupational diseases by activity sectors in the Northern Region. The study found that the number and incidence of occupational diseases increase with age and are higher in women. The highest incidence rate per 100000 workers of occupational diseases was recorded in industrialised municipalities in the district of Aveiro, such as Castelo de Paiva, Vale de Cambra and Oliveira de Azeméis. It is also verified that in the Northern Region of Portugal, 69% of certified occupational diseases between 2019–2021 correspond to musculoskeletal diseases, such as Epicondylitis, Periarthritis and Tenosynovitis. The activity sector that most contributed to these diseases was the clothing industry (24%), followed by the extractive industry (quarries) and the footwear industry, with 6%, respectively.

Keywords Occupational diseases · Musculoskeletal disorders · Ergonomics · Incidence

1 Introduction

An occupational disease is, by definition, caused by exposure at work to a physical, organisational, chemical or biological risk factor or a combination of these factors (Law N° 98/2009, September 4th and Decree Law N° 503/99, of November 20).

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The European Commission Recommendation 2003/670/CE of September 25 (2003), adopts the European schedule of occupational diseases, which is organised into five chapters: (i) Diseases caused by chemical agents, (ii) Skin diseases, (iii) Diseases caused by inhalation of substances, (iv) Infectious and parasitic diseases and (v) Diseases caused by physical agents. The Regulatory Decree N.º 76/2007, of July 17, changes the list of occupational diseases approved by Regulatory Decree N.º 6/2001, of May 5, also organised into five chapters: (i) Diseases caused by chemical agents, (ii) Respiratory system diseases, (iii) Skin diseases and others, (iv) Diseases caused by physical agents and (v) Infectious and parasitic diseases.

The European Agency for Safety and Health at Work (EU-OSHA) has competence in the field of occupational diseases, namely to provide a basis for prevention and to provide policies in occupational safety and health to achieve a better overview of the burden of diseases at work [6, 22].

Workplace accidents have decreased by about 25% in the last ten years. However, work-related injuries and illnesses result in the loss of 3.9% of all working years globally and 3.3% of those in the EU, equating to a cost of approximately 2,680 billion and 476 billion, respectively [21, 32, 38]. On the other hand, circulatory system diseases are the highest death cause globally. Moreover, the circulatory system diseases have the highest DALYs (Years of Life Lost or Years of Life with Disability). In the European Union (EU), cancer is the highest dead cause and also has the highest DALY (years of life lost or years of life with disability) in the EU [38].

Musculoskeletal disorders (MSDs) are the most common health problem in the EU, affecting all sectors of activity and occupations [7, 9, 14, 34–36]. Apart from the effects of these MSDs on the worker, they lead to high costs for economics and society [10, 28]. The National Institute for Occupational Safety and Health (NIOSH) defines MSD as a disorder and injury that affects a part of the body's musculoskeletal system, which includes bones, nerves, tendons, ligaments, joints, cartilage, blood vessels and spinal discs, that, therefore, recommends that the design of tasks, workspaces, controls, tools, lighting, and equipment should be adapted to the physical capabilities and limitations of the workers [39].

The percentage of all work-related DALYs from musculoskeletal disorders represents 15% globally and 16% in the European Union [37]. About three out of five workers in the EU-28 report MSD complaints, the most common being back pain and muscle pain in the upper limbs [11, 13]. The prevalence of MSDs is highest in health and social work activities and least reported in financial, technical and scientific activities, education, arts and entertainment [15].

The Strategic Framework for Health and Safety at Work 2014–2020 defines MSDs as one of the main challenges to be faced in the near future due to repeated exposure to ergonomic risk factors, especially in women [12].

In this sense, the risk of workers suffering from musculoskeletal disorders should be prevented. Promoting musculoskeletal health throughout people working life, and contributing to addressing the effects of demographic ageing, became not only an occupational health challenge but also a public health, demographic and social issue as well [17, 19, 23, 24, 26].

The certification of an occupational disease is an important tool for the epidemiological surveillance of occupational morbidity, ensures that workers and their families are given redress, facilitates the collection of information/data of great usefulness and relevance for the company/employer and for national, regional and local Occupational Health Services, which are fundamental for the design or improvement of an effective preventive strategy. In Portugal, occupational diseases are confirmed by the Social Security Institute (SSI), which annually sends the file identifying these diseases to the respective Regional Health Administration (RHA). In view of the certification of occupational diseases and in accordance with Regulatory Decree No. 14/2012 of January 26, public health units are responsible for: (i) diagnosing and epidemiological surveillance of occupational diseases, (ii) conducting an epidemiological survey of each occupational disease; (iii) identifying the economic activities/professions in their region that trigger more occupational diseases and proposing measures; (iv) monitoring the organisation and operation of occupational health services in companies.

This study aims to make a diagnostic of the prevalence of occupational diseases in the Northern Region of Portugal between 2019–2021, the latest data sent to Regional Health Administration Northem, alerting the competent entities to actions that can be implemented to prevent or minimise the exposure of other workers to similar occupational risk factors.

2 Materials and Methods

This study analysed all occupational diseases recognised by Social Security for workers in the Northern region of mainland Portugal between 2019 and 2021. The Planning and Management Control Unit—Planning and Strategy Office of the Social Security Institute provided the data. The period under analysis corresponds to the last data sent to the Regional Health Administration of the Northem after the COVID-19 pandemic. These data are treated for epidemiological monitoring purposes.

Between 2019 and 2021, a total of 9915 occupational diseases were analysed in the Northern region of mainland Portugal: 1966 in 2019, 3414 in 2020 and 4535 in 2021.

The Northem Region integrates eight sub-regions NUTS III (Nomenclature of Territorial Units for Statistical Purposes defined according to population, administrative and geographical criteria), Alto Minho, Cávado, Ave, Metropolitan Area of Porto, Alto Tâmega, Tâmega e Sousa, Douro and Terras de Trás-os-Montes - an area of about 21 278 km². It has an estimated active population of 1833.6 thousand people (35% of the continental population) and around 38% of the young national population (0–14 years old). The Northem of Portugal comprises 86 councils and 1426 parishes [1].

Occupational diseases were analysed according to the socio-demographic characteristics of the workers, the municipality where the occupational disease was registered and the economic activity sector. As in previous studies [30], this study

considered six groups of occupational illnesses: musculoskeletal illnesses, paralysis, hypoacusis, respiratory illnesses, skin diseases and other illnesses (meningitis, Lyme disease, Measles, malignant tumours, among others).

For data processing, SPSS software was used to calculate occupational disease incidence rates prevalence rates, group occupational diseases by major disease groups, and categorise occupational diseases by activity sectors in the Northern Region. A correlation analysis was performed between occupational disease certification and age using a two-dimensional correlation matrix.

3 Results and Discussion

Between 2019 and 2021, 9915 occupational diseases were registered in workers in the Northern Region of mainland Portugal between the ages of 15 and 64.

The number and incidence of occupational diseases increase with age and are higher among women. The incidence rate per 100000 workers is much higher among women than men, with the highest rate (1091,7/100000) among women aged 50 or over (Fig. 1).

In Portugal, there is also a tendency for the number and incidence of occupational diseases to increase with age, especially among women [30]. However, the incidence rate per 100000 workers in women is lower in the Northern Region (218,0/100000) [30]. The gender difference in the frequency of occupational disease may be partially explained by the fact that most certified illnesses consist of disorders, musculoskeletal

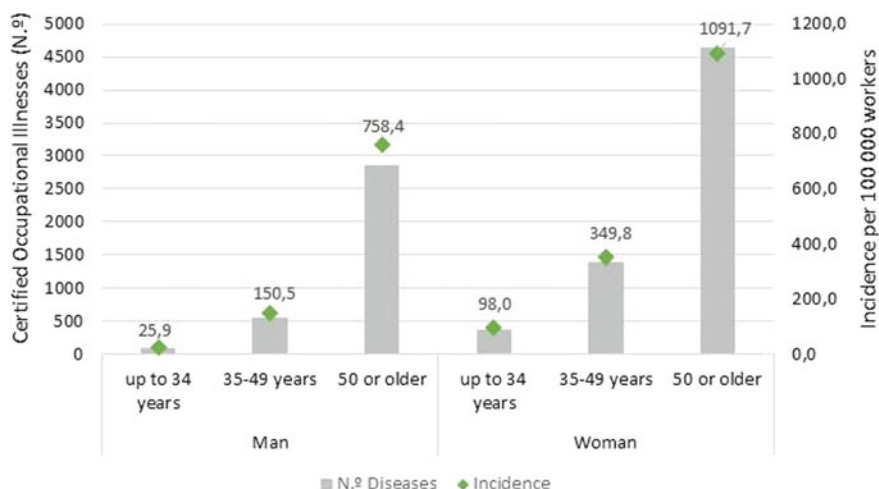


Fig. 1 Number and prevalence rate per 100000 workers of certified occupational diseases by age (15 - 64 years) and gender

disorders and paralysis that include carpal tunnel syndrome, nosological entities predominant in females [30].

The literature suggests that men and women have different exposures to occupational risks and that these differences are not only due to the gender distribution of the workforce [2, 3]. Some studies report a higher prevalence in men for exposure to biomechanical and ergonomic hazards, which include repetitive tasks, awkward postures, and sitting or standing in prolonged work [5, 16, 18]. Other studies report a higher prevalence in men for noise exposure [8, 29], vibration [29, 33], ultraviolet radiation from sun exposure [4, 31]. However, one study reported that women are more likely to experience sexual violence than men, although both genders were likely to experience physical violence at work [27].

The highest incidence rate per 100000 workers of occupational diseases was recorded in the municipalities of Castelo de Paiva (2654,63/100000), Vale de Cambra (2555,27/100000), and Oliveira de Azeméis (2321,95/100000), all located in the district of Aveiro (Table 1). This high incidence rate of occupational diseases can be explained by the fact that the municipality of Aveiro is one of the most industrialised municipalities in mainland Portugal.

The lowest incidence rate of occupational diseases was found in the municipalities of Tarouca, Chaves e Valpaços, 30,65/100000, 36,67/100000 and 37,53/100000, respectively (Table 1), explained by the fact that they have fewer inhabitants and fewer industries.

However, in the municipalities of Boticas, Freixo de Espada à Cinta, Mesão Frio, Mogadouro, Ribeira de Pena, Santa Marta de Penaguião, Vila Flor and Vila Nova de Foz Côa there were no occupational diseases registered between 2019 and 2021 (Table 1).

In the Tâmega e Sousa region, the prevalence of occupational diseases per 100000 workers was the highest (394,09), followed by the Metropolitan Area of Porto (348,21). In the Tâmega e Sousa region, the high prevalence of occupational diseases is due to highly industrialised municipalities such as the municipality of Felgueiras (549 occupational diseases) and in the municipality of Penafiel due to the high number of cases of silicosis, explained by the fact that in this region there are a high number of quarries. The region with the lowest prevalence rate of occupational diseases per 100000 workers was Alto Tâmega e Barroso (22,25), explained by the non-existence of occupational diseases in municipalities such as Boticas and Ribeira de Pena. The municipality with the highest number of occupational diseases was Vila Pouca de Aguiar (9).

In Portugal, the Lisbon metropolitan area and the Northern Region are the the regions where the higher number of occupational disease certified, 110,5 cases and 83,6 per 100000 workers, respectively [30].

In the European Union, the prevalence of work-related diseases for all groups per 100000 inhabitants (above 16 years) decreases slightly from 997 (2000) to 973 (2016) [38]. The same trend has been observed in Portugal, however, with a sharper decline in prevalence rate from 1128/100000 (2000) to 930/100000 (2006) [38].

In the Northern Region of Mainland Portugal, 69% of the certified occupational diseases were musculoskeletal diseases, mostly Epichondylitis, Periarthritis and

Table 1 Incidence rate per 100000 workers of certified occupational diseases per municipality

Municipality	Number of certified diseases	Active population	Incidence rate per 100000 workers	Resident Population 15–64 years old	Incidence Population 15–64 years old
Alijó	2	4521	44,24	10,527	19,00
Amarante	107	25,104	426,23	52,877	202,36
Amares	18	8477	212,34	18,090	99,50
Arcos de Valdevez	39	7859	496,25	20,785	187,64
Armamar	1	2420	41,32	5716	17,49
Arouca	119	9954	1195,50	20,609	577,42
Baião	12	8156	147,13	18,575	64,60
Barcelos	217	59,734	362,28	115,589	187,73
Braga	599	94,411	634,46	182,924	327,46
Bragança	37	15,411	240,09	33,441	110,64
Boticas	0	1975	0	4 926	0
Cabeceiras de Basto	3	6758	44,39	15,526	19,32
Caminha	16	7209	221,94	15,787	101,35
Carrazeda de Ansiães	1	2134	46,86	5610	17,83
Castelo de Paiva	197	7421	2654,63	15,303	1287,33
Celorico de Basto	19	8227	230,95	18,904	100,51
Chaves	6	16,363	36,67	39,198	15,31
Cinfães	24	7598	315,87	18,001	133,33
Espinho	133	14,611	910,27	29,425	452,00
Esposende	49	17,023	287,85	34,170	143,40
Fafe	44	23,345	188,48	47,741	92,16
Felgueiras	549	29,795	1842,59	56,128	978,12
Freixo de Espada à Cinta	0	1298	0	3612	0
Gondomar	324	83,941	385,99	165,700	195,53
Guimarães	161	81,191	198,30	151,621	106,19
Lamego	20	11,874	168,44	24,756	80,79
Lousada	111	23,995	462,60	46,580	238,30
Macedo de Cavaleiros	6	5901	101,68	14,419	41,61
Maia	264	71,047	371,59	139,641	189,06

(continued)

Tabel 1 (continued)

Municipality	Number of certified diseases	Active population	Incidence rate per 100000 workers	Resident Population 15–64 years old	Incidence Population 15–64 years old	
Marco de Canaveses	172	23,665	726,81	51,253	335,59	
Matosinhos	361	88,326	408,71	175,556	205,63	
Melgaço	1	2903	34,45	7991	12,51	
Mesão Frio	0	1817	0	3547	0	
Mogadouro	0	3497	0	8301	0	
Miranda do douro	3	2889	103,84	6763	44,36	
Mirandela	4	9716	41,17	21,587	18,53	
Moimenta da Beira	2	3873	51,64	9713	20,59	
Monção	4	7227	41,17	17,727	22,56	
Mondim de Basto	17	2729	622,94	6880	247,09	
Montalegre	2	3485	57,39	8882	22,52	
Murça	1	2097	47,69	5399	18,52	
Oliveira de Azeméis	803	34,583	2321,95	65,751	1221,27	
Paços de Ferreira	89	29,075	306,10	56,547	157,39	
Paredes	215	43,272	496,86	85,880	250,35	
Paredes de Coura	19	3764	504,78	8472	224,27	
Penafiel	346	34,228	1010,87	69,419	498,42	
Penedono	1	1069	93,54	2572	38,88	
Peso da Régua	4	7447	53,71	15,687	25,50	
Ponte da Barca	22	4570	481,40	11,098	198,23	
Ponte de Lima		84	18,780	447,28	41,058	204,59
Porto		279	107,331	259,94	216,887	128,64
Póvoa de Lanhoso		11	9413	116,86	21,480	51,21
Póvoa de Varzim		73	30,871	236,47	62,785	116,27
Resende		4	3909	102,33	10,022	39,91
Ribeira de Pena		0	2465	0	5884	0

(continued)

Tabel 1 (continued)

Ponte de Lima	84	18,780	447,28	41,058	204,59
Sabrosa	1	2448	40,85	5882	17,00
Santa Maria da Feira	1328	70,154	1892,98	138,434	959,30
Santa Marta de Penagão	0	2938	0	6100	0
Santo Tirso	129	35,784	360,50	67,600	190,83
São João da Madeira	145	11,170	1298,12	22,061	657,27
São João da Pesqueira	4	3153	126,86	7060	56,66
Sernancelhe	4	2114	189,21	5375	74,42
Tabuaço	3	2317	129,48	6020	49,83
Tarouca	1	3263	30,65	7821	12,79
Terras de Bouro	2	2696	74,18	6315	31,67
Torre de Moncorvo	3	3117	96,25	7607	39,44
Trofa	174	20,289	857,61	38,462	452,39
Vale de Cambra	267	10,449	2555,27	21,207	1259,02
Valença	22	6079	361,90	13,193	166,76
Valongo	310	48,070	644,89	97,797	316,98
Valpaços	2	5329	37,53	14,647	13,65
Viana do Castelo	373	41,585	896,96	84,055	443,76
Vieira do Minho	4	4767	83,91	11,786	33,94
Vila do Conde	178	39,981	445,21	79,961	222,61
Vila Flor	0	2570	0	6050	0
Vila Nova de Cerveira	20	4148	482,16	8900	224,72
Vila Nova de Famalicão	298	68,616	434,30	131,292	226,97
Vila Nova de Foz Côa	0	2671	0	6304	0
Vila Nova de Gaia	876	152,560	574,20	300,018	291,98

(continued)

Tabel 1 (continued)

Ponte de Lima	84	18,780	447,28	41,058	204,59
Vila Pouca de Aguiar	9	4847	185,68	11,858	75,90
Vila Real	26	24,130	107,75	49,875	52,13
Vila Verde	50	21,240	235,40	46,772	106,90
Vimioso	1	1541	64,89	3958	25,27
Vinhais	3	2683	111,82	7609	39,43
Vizela	22	12,680	173,50	23,898	92,06

Tendonosynovitis, followed by respiratory diseases (17%), which includes Asthma, Tuberculosis and COVID-19 (Fig. 2).

Regarding the musculoskeletal diseases group (6764), 60% of the certified diseases concern Periarthritis (4078), 37% Epicondylitis (2274), 4.4% Tendonovitis (300), 1% Tendonitis (73), and 1% Myotendonovitis, Arthrosis, and Bursitis. Regarding the incidence rate per 100000 workers of the disease Periarthritis, 77% of these diseases originate from industry (3102), 8% from commerce, restaurants and hotels, 2% from health and transportation, and 1% from public administration, civil construction and education. In the case of Epicondylitis, 79% of the diseases originate in industry, 8% are related to the trade, restaurant and hotel sector, 2% to health and public administration, and 1% are related to construction, education and transport. Most Tendonovitis is also associated with the industry (75%), followed by commerce, restaurants and hotels (10%), health (4%), education (2%) and public

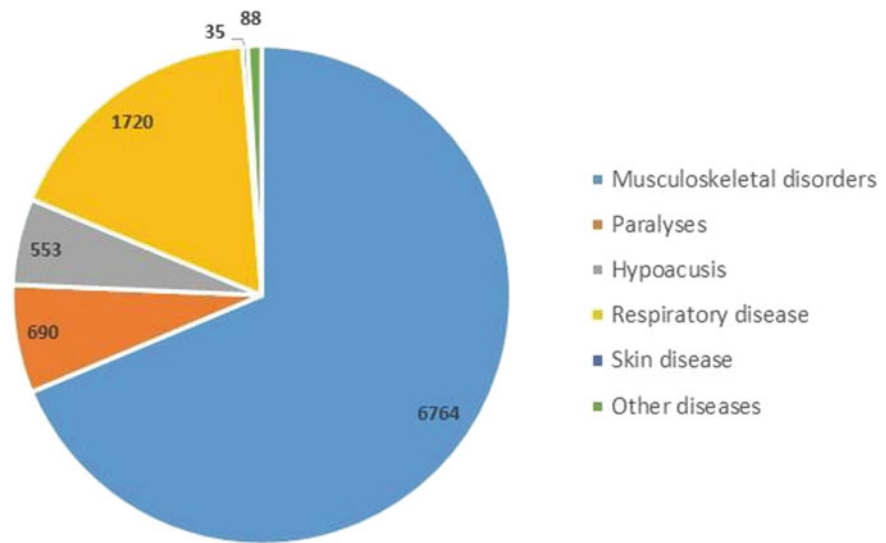


Fig. 2 Number of occupational diseases registered by disease group, 15 to 64 years

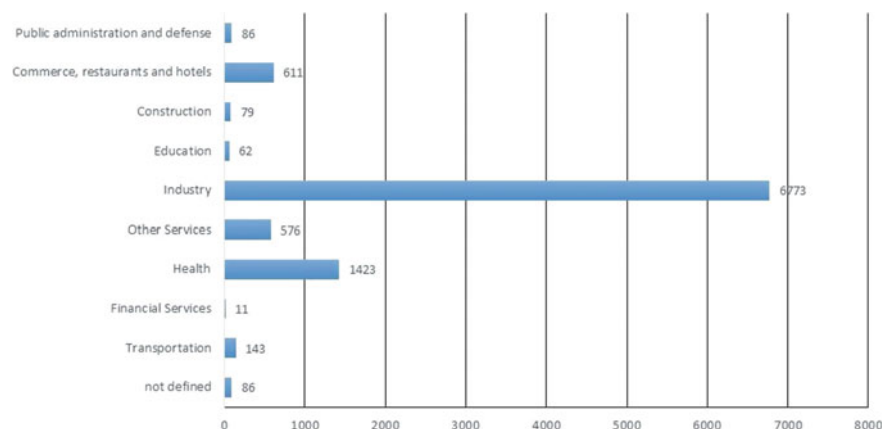


Fig. 3 Number of certified occupational diseases by economic activity, 15 to 64 years old

administration (1%). Concerning tendonitis, 81% of the certified diseases come from industry and 7% from commerce.

Some studies highlight that musculoskeletal disorders are twice as likely as other chronic diseases and that employers do not give them the due attention since they are rarely fatal but irreversible [6, 26, 28, 34], (Hartvigsen et al., 2018).

The industry sector presents the highest number of certified occupational diseases (68%), followed by the health sector with 14.4% (Fig. 3). In the health sector, the most certified occupational disease, during the considered period was COVID-19.

In the industry sector, 24% of occupational diseases originate in the clothing industry, and 6% of occupational diseases originate in quarrying and footwear. The Northern region of Portugal follows the trend in Portugal, where the high incidence of occupational disease in the industry sector stands out (240.6 cases per 100,000 workers) [30]. The reason for these results is that the tertiary sector employs the most people in mainland Portugal [20].

The applied Pearson's correlation test, showed that the occupational diseases have a moderate negative correlation (-0.577) with age, for a significance level of 0.01. Similar to what has been observed in other European populations, the ageing of the working population in Portugal is significative. On the other hand, the under-representation of young people in the labour market tends to decrease as a result of the extension of academic life, posing a number of challenges related to the increase in the average age of the labour force. In this sense, a decline in physical, sensory and/or cognitive abilities, as well as the risk of work-related health problems, can be expected [30].

4 Conclusions

This study concluded that the number and incidence of occupational diseases increase with age and are higher in women. The highest incidence rate per 100000 workers of occupational diseases was recorded in municipalities in the district of Aveiro, such as Castelo de Paiva, Vale de Cambra and Oliveira de Azeméis, due to the fact that this district is highly industrialised. It is also verified that in the Northern Region of Portugal, 69% of the occupational diseases certified between 2019–2021 correspond to musculoskeletal diseases, such as Epichondylitis, Periarthritis and Tenosynovitis.

The activity sector that most contributed to these diseases was the clothing industry (24%), followed by the extractive industry (quarries) and the footwear industry, with 6%, respectively.

In this situation, it is important for employees and occupational health and safety technicians to take some preventive measures, namely: changing the layout of the workplace, fitting ergonomic equipment, changing work methods or tools and avoiding work repetitiveness. On the other hand, consultation with workers and their active participation is essential to select the necessary measures to be adopted at their workplace and implementing them successfully.

This study had some limitations, such as access to a larger database of occupational diseases, which made it impossible to perform a more comprehensive statistical study. In the future, we intend to carry out a broader study, namely a diagnosis and characterisation of occupational disease cases in ARS Norte between 2000 and 2021.

5 Acknowledgements

This work was financially supported by Base Funding–UIDB/04028/2020 and Programmatic Funding–UIDP/04028/2020 of the Research Center for Natural Resources and Environment–CERENA–funded by national funds through the FCT/MCTES (PIDDAC).

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Indoor Air Quality at Portuguese Firehouses



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Abstract This work assessed firefighters' exposure to gases pollutants in non- fire work settings during the pre-fire season as a baseline for the respective occupational exposure characterization. Indoor air sampling (total volatile organic compounds—TVOCs, ozone- O_3 , and carbon di oxide- CO_2) was conducted for two weeks in the pre-fire season of 2021 in seven firehouses (FH1–FH7) situated in the north-interior of Portugal. The result showed that across all FH, TVOCs highly varied with observed levels of $180 \mu g m^{-3}$ and $11.5 mg m^{-3}$ (overall median of $1.86 mg m^{-3}$). Furthermore, at all FH, the observed levels highly exceeded (1.5–6.6 times) the Portuguese protective thresholds of $600 \mu g m^{-3}$ for indoor air quality in public buildings. On the contrary, the indoor ozone concentrations (range: $23\text{--}80 \mu g m^{-3}$; median $60 \mu g m^{-3}$) and CO_2 (range $800\text{--}1160 mg m^{-3}$; median $924 mg m^{-3}$) were relatively low and in accordance with existing national standards. While the associations between the

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pollutants were low—moderate ($|r_{\text{rs}}| = 0.030\text{--}0.679$) to better identify the respective indoor emission sources, quantification of specific VOC compounds/classes is required in future studies.

Keywords IAQ · Occupational exposure · Firefighters · TVOCs · Legislation

1 Introduction

In the last decades, the occurrences of forest fires have been increasing [1] with longer fire seasons, a higher number of fire events and more severe incidents. These fires cause serious ecological, economic, and social consequences in the affected areas and lead to an annual loss of €140.8 million [2]. Forest fires are undeniably linked with global temperature warming, leading to climate change and some extreme weather consequences (such as droughts, heat waves, temperature abnormalities, winds, etc.). However, it must be emphasized that increasing deforestation (due to growing urbanization and/or higher demand for forest products) and land loss of forest biodiversity add additional complexity to this problem. Portugal (among other Mediterranean European) is one of the countries the most affected by forest fires [3], with North and Centre regions being the high-risk zones. Nevertheless, the European Environmental Agency (EEA) estimates suggest that weather-driven forest fires may become a great public and environmental risk in most EU countries [1, 4].

The smoke and health-hazardous gases (volatile organic compounds, carbon monoxide, polycyclic aromatic hydrocarbons, etc.) represent a risk for the occupationally exposed workers. Exposure to fire emissions has been associated with increased morbidity and mortality in firefighter populations [5–8] as well as various cancer risks (namely bladder, pulmonary, testicular, kidney, skin melanoma, etc.) [8–11]. Given the negative health consequences of the respective exposure, International Agency on Research on Cancer (IARC) recently classified firefighting as carcinogenic to humans (i.e., group 1) [12, 13]. While exposure monitoring the fire combat is rather challenging [14, 15] due to the predictability of the respective environment, a correct characterization requires, first of all, an understanding of the levels of exposure. In that view, this work aimed to study the exposure of firefighters to selected gas pollutants in non-fire work settings during the pre-fire season, determining a baseline for the respective occupational exposure characterizations.

2 Materials and Methods

2.1 Sampling

The indoor air quality (IAQ) monitoring was performed in seven firehouses (FH1–FH7) during two weeks in spring (i.e., pre-fire season) 2021. All seven firehouses were in the Bragança district (north interior of Portugal), which represents one of the highest risk zones for forest fire hazards [3]. This region (area 6599 km²; 7% of the total Portuguese territory; [16]), has a climate with long and cold winters (absolute minimum temperatures below 0 °C); the summers are hot (annual mean of 19 °C) and dry (precipitation of 684.6 mm), with absolute maximum temperatures often above 30 °C [17].

FH was situated in the central zones of each small city (urban-background), characteristically with direct or quick access to the main/national roadways.

Overall, the building design and architectural organization between the FH largely varied. All FH were naturally ventilated, but the level of building sophistication, indoor design, and available spaces greatly depended on each “in-house” management and administrative condition of each fire corporation. In general, the functional organization of all FH was composed of three main parts: (i) the administrative section; (ii) the operational centre with auxiliary technical sectors; and (iii) private quarters. The administration part included offices for management staff necessary for regular station operations, a general room (i.e., joint office/area for the field workers) and/or study rooms. The operational section included the control centre and auxiliary technical spaces, which consisted of various storages (for protective gear and equipment), functional places for repairs (equipment and car), and garages and vehicle bays. In some FH, truck bays were directly connected to the control centre; in others, these spaces were separated. Finally, private spaces consisted of sex-specific bedrooms and showers, in some cases also of kitchenettes. Apart from these, some FH utilities included canteens or coffee houses, and an auditorium.

The indoor air sampling was conducted continuously during 8–10 h in each FH in the general room. This room was selected as it was where the fighters spent the majority of their indoor time (when waiting on call). Gaseous (TVOCs, CO₂, CO, O₃) and physical parameters (T, RH) were monitored by GrayWolf Sensing Solutions probe (model IQ-610, GrayWolf Sensing Solutions LLC, USA) with a data acquisition interval of 1 min. Before the sampling campaign, all equipment was calibrated at the manufacturer and re-checked daily during the sampling. Detailed characterization of all indoor and outdoor spaces (layout, size, area, design, used material, age and reconstruction, equipment, outdoor surroundings, etc.) was obtained; potential emission sources, occupants’ activities and patterns, and other relevant occurrences for the air sampling were registered. The observed levels were compared with protective thresholds as established in Ordinance No. 138-G/2021 [18].

2.2 Statistical Treatment

All statistical analyses were conducted in SPSS (IBM Statistics 27). Data (means and distributions) were compared through the Kruskal–Wallis test since normal distributions were not verified (Shapiro–Wilk test). Spearman correlation coefficients (r_s) were used to evaluate the possible relations among indoor pollutants. Statistical significance was defined as $p \leq 0.05$.

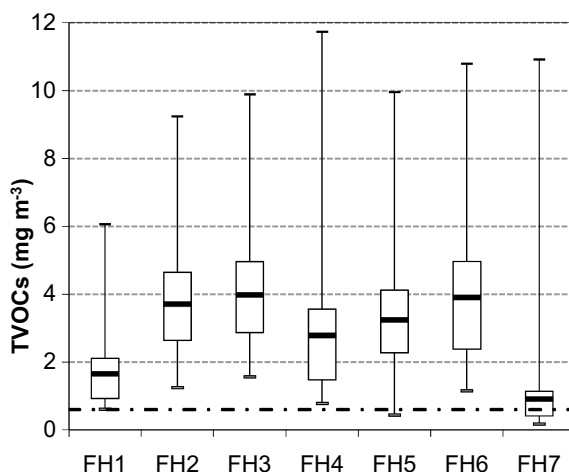
3 Results

3.1 Gaseous Pollutants

The overall statistics for TVOC levels at seven fire corporations are presented in Fig. 1. The results showed that TVOCs mean and distributions were significantly different ($p < 0.05$) across all seven FH, with a wide range of concentrations ($180 \mu\text{g m}^{-3}$ and 11.5 mg m^{-3}); overall median of 1.86 mg m^{-3} . Considering means per each FC, TVOCs ranged between 0.907 – and 3.90 mg m^{-3} . The corresponding indoor medians ranged between 0.700 and 3.58 mg m^{-3} .

In Portugal, the IAQ in public buildings is encompassed in Ordinance No. 138- G/ 2021 [18], which establishes the specific requirements for the assessment of indoor air quality in commercial and service buildings, including the protection thresholds, reference conditions and compliance criteria, and the respective methodology for measuring pollutants and for monitoring compliance with approved standards. Volatile organic compounds are expressed as total content (i.e., TVOCs), with a limit

Fig. 1 TVOCs (■ mean, □ 25–75%, ▮ range) in the indoor air of seven fire houses (FH1–FH7)



value of $600 \mu\text{g m}^{-3}$ (as 8 h mean). As shown in Fig. 1, in all FH1-FH7, the mean concentrations highly exceeded (1.5–6.6 times) the protective threshold.

The horizontal lines represent the Portuguese protective threshold for TVOCs ($600 \mu\text{g m}^{-3}$) as established in Ordinance No. 138-G/2021 [18].

Furthermore, it is noteworthy that the secondary stipulation, allowing a 100% margin of tolerance for the observed indoor concentrations (i.e., $1200 \mu\text{g m}^{-3}$) was too highly exceeded (both for means and medians) in 6 out of 7 FH, thus indicating the potential for health concerns.

The overall information on VOCs levels in firehouses is relatively limited. Engelsman et al. [19] assessed VOCs in living quarters in Australian fire houses. The authors reported only very partial VOCs data in their study as low sensitivity of the quantification methods did not allow for proper analysis in indoor air; six VOCs compounds (2-methylbutane, toluene, styrene, n-pentane, 2-methylpentane, and isopropyl alcohol) were observed as above the limit of detection. In addition, limited information also exists for workers exposure to VOCs using the biomonitoring assessment [20].

In indoor air, the typical primary indoor sources of VOCs include construction materials, cleaning products, paints, [12, 21–23]. However, other factors such as building age, and occupants' activities also significantly affect VOCs emissions [24–29]. Specifically in firehouses, the VOCs sources include vehicle exhausts (due to stations layout and general connectivity between indoor spaces), off-gassing of contaminated personal protective equipment that leads to VOCs accumulation in indoor air or combustion processes (cooking, smoking) [30]. While the high levels of FH3 were most likely caused by the penetrations of smoking emissions (the smoking zone was situated directly next to the room entrance in the inner courtyards of the station complex), the majority of the VOCs most likely originated from occupants (human respiration/breath), their activities (smoking, cleaning, use personal products) as well as the building materials [31].

In addition to primary origin, secondary indoor VOCs can be formed by photochemical reactions of ozone, either with human surfaces (such as skin, hair, and clothes), or room surfaces (carpet, paints, or fabrics) [32, 33]. The levels of ozone observed in the indoor air of seven FH are summarized in Fig. 2.

The results showed that both means and distributions of O_3 were significantly different ($p < 0.05$) across the seven firehouses, with O_3 means ranging between $23 \mu\text{g m}^{-3}$ (at FH6) and $80 \mu\text{g m}^{-3}$ at FH8 (overall median of $60 \mu\text{g m}^{-3}$). Furthermore, while there were no direct indoor emissions sources of ozone in the respective sampling spaces (e.g., office equipment such as printers and photocopiers, air purifiers, etc.) [34], the results in Table 1 show negative associations between TVOCs and O_3 at all FH. However, in general, the obtained correlations were of weak-moderate strength. Therefore, in order to better identify the respective indoor emission sources of both pollutants, and to better characterize the respective associations, the identification and quantification of specific VOC compounds/classes would be precious.

Insufficient ventilation in indoor spaces can cause the accumulation of the respective pollutants in respective environments and lead to high indoor pollution levels

Fig. 2 Ozone (■ mean, □ 25–75%, ▮ range) in indoor air of seven fire houses (FH1–FH7). *Note* Ordinance No. 138-G/2021 [18] does not establish any protective threshold for ozone

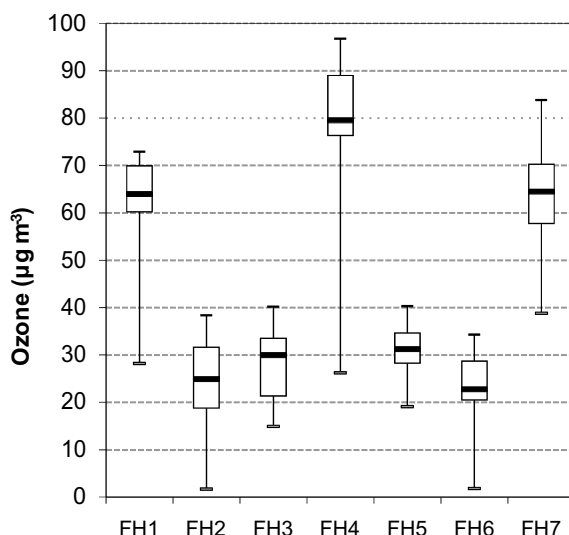


Table 1 Spearman correlation coefficient (r_s) of gaseous compounds (TVOCs, O_3 and CO_2) in indoor air of seven fire houses (FH1–FH7)

R_s	FH1	FH2	FH3	FH4	FH5	FH6	FH7
TVOCs versus O_3	−0.679	−0.587	0.609	−0.104	−0.418	−0.173	−0.179
TVOCs versus CO_2	0.064	−0.157	0.126	0.030	0.290	0.222	0.404
O_3 versus CO_2	0.451	0.264	0.351	0.202	−0.307	0.201	−0.396

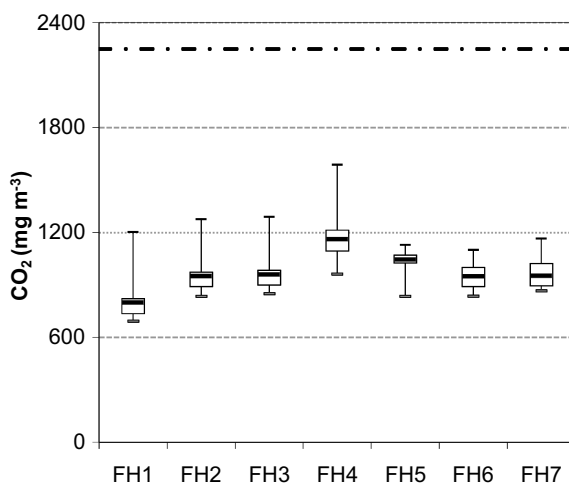
Note Values in bold indicate a significant correlation at 0.01 level

[35]. Due to its characteristic relation between human occupancy and the respective levels, CO_2 has been used as an indicator for IAQ in indoor environments [34]. The CO_2 levels observed at FH (Fig. 3) ranged between 800–1160 $mg\ m^{-3}$ (overall median of 924 $mg\ m^{-3}$). These levels were low in a comparison with previous studies that typically reported indoor CO_2 concentrations in occupied spaces commonly in a range of 2500–3000 ppm (i.e., 3600–5400 $mg\ m^{-3}$) [34]. Furthermore, it shall be emphasized that the observed levels were well below (1.9 times at FH1–2.8 times at FH4) the protective threshold (2200 $mg\ m^{-3}$ set by the Portuguese legislation. Finally, CO_2 showed weak associations with TVOCs and O_3 .

4 Conclusions

Firefighting represents one of the most hazardous occupational exposures, yet its monitoring is rather challenging. This study characterized exposure levels in non-fire settings. The obtained results indicated that the measured VOCs levels highly

Fig. 3 CO₂ (■ mean, □ 25–75%, ▮ range) in indoor air of seven fire houses (FH1–FH7). The horizontal lines represent the Portuguese protective threshold for CO₂ (2250 mg m⁻³) as established in Ordinance No. 138-G/2021 [18]. *Note* Mean and distributions were significantly different ($p < 0.05$) across all seven FH



exceeded the Portuguese protective thresholds in indoor spaces. Thus, in future studies characterization and quantification of specific VOCs compounds would be required in order to identify the respective indoor emission sources.

The extent of the present study is solely encompassed by indoor air quality monitoring. In order to fully characterize the occupational exposure of the fire-fighting population, a more comprehensive assessment is required in future, including personal exposure approaches and monitorization of other health-relevant pollutants (such as carbon monoxide and nitrogen dioxide in the personal air of firefighters), their follow-up throughout the fire season. The inclusion of the collection of biological fluids (e.g., urine, blood) may be a possible solution in the countries severely affected by forest fires, in order to better characterize and understand the risks and their direct (short- and long-term) health impact along the workers' life and to provide a comprehensive understanding of forest fires implications, both for occupational and general populations.

Acknowledgements This work was financially supported by PCIF/SSO/0017/2018 by FCT-MCTES through national funds. Additional supports include projects LA/P/0045/2020 (ALiCE), UIDB/00511/2020-UIDP/00511/2020 (LEPABE), UIDB/00690/2020-UIDP/00690/2020 (CIMO), LA/P/0007/2020 (Sus-TEC), and UIDB/50006/2020-UIDP/50006/2020 (REQUIMTE), and FCT fellowships SFRH/BPD/115/112/2016, 2020.07394.BD, and UI/BD/150783/2020.

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What, How and Where They Eat: Results from a Portuguese company's Employees



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Abstract *Background* The workplace is recognized by the World Health Organization as suitable for health promotion, as it can contribute to the reduction of harmful lifestyles, promoting the development of enterprises and, in turn, economic growth. The purpose of this study was to characterize eating habits and determinants of food consumption from a Portuguese company of employees. *Methods:* To characterize the nutritional and general health status of the employees, questionnaires previously developed and used in Portuguese employees were adapted and applied. Questionnaires include multiple choice and short answers to obtain socioeconomic, food habits and health data, namely the prevalence of chronic diseases. Statistical analysis was carried out, which allowed the study of the sample with detail, drawing some conclusions and the interconnection of different factors, such as type of food consumed for snacks, Body Mass Index (BMI), gender, and lunch place. *Results:* It was verified that some of our results did not resemble those presented in available scientific literature, such as the relationship between academic qualifications and BMI. However, were obtained some interesting and enlightening results, such as the main conditioners of the lunch place. *Conclusions:* The results show the need for greater investment

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in this area by companies' managers, both nationally and internationally, since they impact employees' health and, consequently, their productivity.

Keywords BMI · Employees · Workplace · Food habits · Chronic diseases · Food determinants

1 Introduction

Food patterns have undergone drastic changes in recent decades due to globalization. They are characterized by a reduction in the prevalence of malnutrition, with a generalized increase in the prevalence of overweight and obesity [14]. Behavior plays a prominent role in the etiology of various noncommunicable chronic diseases, including obesity, diabetes mellitus, cardiovascular diseases, among others, whose prevalence tends to be stationary or even increasing [1, 14]. These diseases have a negative impact not only on the health and quality of life of the directly affected individuals and their families, but also on the socioeconomic structure of the country where they live [18].

Employees spend most of the day at the workplace. According to the European Union, a Portuguese full-time worker is on average 8.28 hours a day at work [6], which justifies the promotion of health in these places and the development of initiatives to improve health, quality of life and productivity at work [2–5, 8, 10, 11, 9, 22].

The workplace is recognized by the World Health Organization (WHO) as suitable for health promotion [17, 21], as it can contribute to the reduction of harmful lifestyles, promoting the development of enterprises and, in turn, economic growth [17, 19, 21]. For that purpose, worksite canteens and occupational health services have a leading role on healthy eating and in the disease prevention and promotion of health [12, 16]. In order to carry out this study, there are fundamental variables to study food habits, namely the time that takes to get from home to the workplace [18], the place where people eat [12, 15], the prevalence of chronic diseases [18], 19, 20), the type of food purchased in the vending machine [16] and weight and height [18]. Thus, the main objective of this study was to characterize the eating habits of the employees and to perceive some determinant factors, enabling a more adequate intervention in the improvement of the lifestyle of the population under analysis and others similar populations.

2 Materials and Methods

2.1 Subjects

The subjects for this study were collected from an industrial company based in the central region of Portugal. The sample was composed by 69 individuals within a universe of 92 employees, which resulted in a response rate of 75%, having been hard-pressed to reach the largest number of people in the company during working hours.

2.2 Study Design

A retrospective study was carried out through an analysis of the dietary habits of the population and the prevalence of chronic diseases, considering the past.

Data were obtained through a questionnaire adapted from a previous project carried out at an institution of higher education.

This questionnaire is divided into three parts: sociodemographic questions, eating habits and lifestyle, and finally health status. The questions presented in the survey were in the form of multiple choice and free response.

Was used a questionnaire already approved by an ethics committee (CEFADE), the entities involved, the company and the authors of the questionnaire were asked for authorization. After approvals, data collection began, and the principles of the Helsinki Declaration were complied with, with informed consent being given to each participant, ensuring the anonymity and confidentiality of the data, and the voluntary nature of the collaboration. Questionnaires were applied to all employees of the company via Google Forms. Data collection was carried out in the 1st semester of 2018 and data analysis was conducted a posteriori.

2.3 Statistical Analysis

This study's database was compiled and transposed to Excel[®] and after to the software Statistical Package for the Social Sciences (IBM SPSS). Descriptive statistics were performed.

According to the normality and homogeneity of the variables, parametric or non-parametric tests were applied. To compare 3 or more groups, it was used ANOVA and Kruskal–Wallis. In the case of the nominal qualitative variables, the chi-square test was used between nominal variables. Considering a level of the critical significance of 5%.

3 Results

3.1 Sample Characterization

There is a similar distribution of genders among the evaluated employees (52% of males); the majority are married or live together (65%), although 26% of the employees are un-married. Regarding academic qualifications, the majority of employees have secondary education (42%) or 9th grade (30%), and only 18.8% have a bachelor's degree. Among the employees evaluated, 40.6% work as shop floor workers, 20.3% are maintenance workers, and the rest perform administrative functions.

Regarding the physical activity performed during working hours, it was possible to verify that 57.9% of employees are sitting most of the time or standing still, and that 42% of the employees move from side to side most of the time. In addition to the previous results, regarding the physical effort required by the work, about 65% classified their function as "Not very demanding", 27.5% as "Demanding" and only 7.2% rated it as "Very demanding".

3.2 Meals Pattern

Related to meals pattern, 94% stated that they have breakfast at home and that 1.4% did not have this meal usually. 74% have the mid-morning snack at the workplace and 16% do not have this meal. 39% have lunch at home, 32% have near the workplace and 29% have lunch at the workplace. 75% take the mid-afternoon snack at work, 12% do not snack at afternoon and 10% take it on their way to home.

When people eat at the workplace, food may come from a variety of sources, including:

- **Home**

It was remarkable that the food that was more brought from home to snack, was fruit (80%) and yogurt (60%), and it was also evident that most of them bring water (61%).

- **Vending machines**

The most acquired foods are water (15,9%), followed by sandwiches (14,5%), cakes/puff pastry (13%) and cookies (13%).

Graphic 1 represents the factors that determine the place where the lunch is held, showing that the factors which employees, of both sexes, gave more relevance were price, quality of food and location

By studying the variable Body Mass Index (BMI), based on the weight and height re-reported by the participants, it was verified that on average the employees presented an adequate weight (56.5%). There was a higher BMI in shop floor workers

and maintenance workers ($p = 0.02$), compared to employees performing administrative functions (Table 1).

Males had a higher mean BMI (26.3 kg/m^2) than females (23.8 kg/m^2), and the percentage of overweight was 61.1 and 24.3%, respectively.

Regarding the place where the employees mainly lunch, it was found that the administrative staff are those who take this meal daily at work, opting to bring food from home, comparatively shop floor workers perform mostly in restaurants near the workplace.

There is no relation between the type of job and the search for a healthy lunch option, which shows that, regardless of the type of work performed, there is no concern regarding this determinant.

As for the places where employees eat, it is verified that there is no significant difference between normal weight and overweight at any of the most frequently chosen places.



Graphic 1 Factors that determine the place where the lunch happen

Table 1 Relationship between employees' function and BMI

	Pre-Obesity	Obesity	P
Shop floor workers	12 (43%)	4 (14%)	
Mechanic	4 (29%)	2 (14%)	0,02

4 Discussion

Differences in BMI between the genders were found, with women presenting a more adequate weight than men, as was also concluded in another study [13]. In contrast to similar studies [7], there was no relationship between low academic qualifications and high BMI, and at any college degree, on average, the employees had normal weight (elementary school (6th grade)–50%; elementary school (9th grade)–43%, secondary education–55%, bachelor's degree–67%, graduation–100%). It was verified that 43% of the sample is overweight (pre-obesity or obesity), which is close to that found in another similar study performed in Portuguese population [7]. Considering the type of job, it is observed that the work-men are the group with the highest rate of over-weight, proving the existence of a relation between these variables.

As for the physical activity inherent to the type of job, it was expected that individuals who spent more time sitting or standing still had higher BMI values, which was not observed, showing that body weight is not only influenced by the type of work, therefore this variable (BMI) is a multifactorial aspect.

In order to understand if working in the commercial area is a risk factor for worse eating habits, the incidence of malnutrition (more specifically overweight) was related to the place where they eat the main meal during working hours, lunch. One of the hypotheses in question was that these employees had to resort to restaurants more often because of their role, which would force them to be far from their company and home.

The collected data that relate these variables, showed that the place where they take this meal is not directly related to nutritional status, not proving the assumption.

The administrative staff are those who have an adequate weight which can be associated to their position, since they have contact with the public, being their image important for a good performance of their function and for the fact of presenting higher health literacy, due to the high academic qualifications. This population group also indicated that they often eat lunch at the workplace, unlike the group of employees who take this meal mainly in restaurants near the company.

The determinants that condition where the lunch take place, price, quality of meals and location are considered the most important for this sample, which is corroborated by other studies [7, 13]. It is noteworthy that males are the only ones to mention the importance of the variety of the menu available. Regarding the existence of healthy options in the menu, only 29% indicated this determinant, which reflects the lack of concern about adopting a healthy diet.

About the food used to snack, results showed that there is a concern with the practice of a healthy diet since they prefer fruit, yogurt and water. In turn, when they use the vending machine, they get sandwiches, cakes/pastry, cookies and water. The frequent acquisition of bottles of water by employees can be an indicator of the need of employees to hydrate and therefore, it is important and opportune to create potable water points, thus encouraging their consumption.

The most reported pathologies are hypertension and hypercholesterolemia, although these have very low prevalence and cannot be related to other factors associated with eating habits and lifestyle.

Physical activity outside work is not considered in the research and could play an important role in the obtained results. Additionally, considering that the company under study have not a canteen or even a cafeteria, any real intervention is difficult.

5 Conclusions

The workplace is an excellent opportunity for nutrition interventions as it is where the working population eats most of the daily meals therefore can be considered a factor of interest the meals consumed during working hours, being possible to contribute to the improvement of the eating habits of the population.

In sum, the results obtained with this study are considered very useful for possible future investigations given that the theme of food in the workplace is underdeveloped, both nationally and internationally. Therefore, there is a need for further study of employees' lifestyles and from them measures should be implemented by companies to make them healthier, as it only benefits both the company and the employees, want for the economy of the country. So, to become a reality, it would be very interesting to integrate nutritionists into large business groups for the reasons given above.

Thus, our research was important to understand which factors determine food consumption during working hours, the employees' frequent consumption habits and their influence on nutritional and general health status.

Most of the results obtained agree with the few existing studies in the area. On the other hand, these results did not meet the initial perspective regarding possible factors of food consumption that could be related to nutritional status. This may have been due to the reduced sample size, making it difficult to obtain meaningful statistics; possible mis-interpretation by respondents of the questions posed, lack of consideration of some respondents when completing the questionnaires, the initial obligation to use existing questions from the survey used as a basis, and not being able to customize with questions more relevant to the characteristics of the company; lack of more robust information collection on the nutritional status of the sample (anthropometric measurements).

Considering the data obtained, the relevance of a closer monitoring of the studied population is relevant, in order to improve the detected bad habits and to regulate their health status.

Looking at other variables generally, there is no consistent evidence that working in the business area is more harmful to health compared to other employees

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Zirconium Silicate and Exposure to Ionizing Radiation in Ceramic Industry



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Abstract Zircon sands have natural radioactivity and can be found as raw materials and as a by-product of mining and processing of heavy minerals sand. This sand is used in ceramics industry, directly or incorporated in frits. So, workers exposed to ionizing radiation in their workplace should be considered a population at risk. As a general research objective, the external dose of ionizing radiation in different types of activity in a ceramic industry company is measured and this dose is, then, related with the use and/or presence of zirconium silicate. This study was observational (analytical), with a cross-sectional timeline and level of knowledge II (Descriptive—Correlational). The study was located in the glazes preparation section of a ceramic company. The study universe consisted of several workplaces in a ceramic industry company. The sampling method applied was non-probabilistic and regarding the sampling technique was for convenience. For the elaboration of this work, a bibliographic review on the subject was carried out and measurements using a portable radiometer were made in a ceramics plant. It was verified that workers could be exposed to external dose values of ionizing radiation higher than the background radiation, depending on the activity performed, for example, the load of the mill with zirconium silicate and also in the storage of raw materials with zirconium silicate. This study identified that workers in the ceramic industry, in particular those working in the glaze preparation, could be exposed to higher external doses of ionizing radiation than public in general.

Keywords External radiation dose · Zircon sands · Radiometer · Ceramic glaze

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1 Introduction

Radiation sources are used throughout the world for a wide variety of beneficial purposes within the scope of industry, medicine, research, agriculture and education, and its usefulness is indisputable.

Ionizing radiation includes electromagnetic radiation (x-rays and gamma rays) as well as corpuscular radiation of subatomic particles: protons, neutrons, electrons. Both electromagnetic and corpuscular radiation, when they come into contact with matter, have the ability, directly or indirectly, to induce ionization [1].

Many materials that are normally found in the Earth's crust contain measurable amounts of naturally occurring radioactivity. Some specific minerals contain naturally occurring radionuclides at levels much higher than those normally present in the Earth's crust, assuming particular relevance technologically enhanced natural radioactivity, due to the industrial use of raw materials that contain natural radionuclides, such as those resulting from the decay chain of uranium and thorium.

Zircon sands, from which zirconium silicate (also known as zirconia) is obtained, have high activity values, $>500 \text{ Bq} \cdot \text{kg}^{-1}$ of both ^{238}U and ^{232}Th radionuclides [2].

There are different types of sources of enhanced natural radiations: coal-fired power stations, uranium mining, phosphoric acid and fertilizers production, mineral sand processing facilities (for the production of cassiterite, rutile, ilmenite, zircon), and natural gas [2].

The ceramic production process can be briefly described by the stages of body preparation, shaping, glazing (on glazed products), firing and sorting. At different stages of the process, dust is generated, arising either from the use of powdered raw materials or from the processing of materials with generation of dust. In the preparation of glazes, raw materials in powder with different granulometries are generally used, and then wet milled to obtain an aqueous suspension that is subsequently applied to the ceramic body of the pieces.

Exposure to small particles could increase morbidity and mortality related to pulmonary and cardiovascular levels, whose first manifestations may be restricted to changes in the interaction of sympathetic/parasympathetic systems. The predominance of sympathetic activity may predispose to arterial hypertension, heart rhythm changes and development of ischemic or cerebrovascular disease. The deposition of particles in the lungs can also trigger an inflammatory process, thus changing the lung function tests significantly. The parameters that are most easily modified are the forced expiratory volume and forced vital capacity. These transitions can become permanent and/or worsen, eventually leading to chronic obstructive pulmonary disease, in the most serious cases [3].

Ceramic fibers, with good conductivity properties, lightness and ease of use, arise from the reaction, at very high temperatures, of aluminum and silica. Fibers respirable fraction has the capacity to deposit in the lungs and in vivo studies in rodents have shown that these fibers contributed to the appearance of fibrosis, lung cancer, and abdominal oncological pathologies. However, other studies argue that, in humans, only pleural plaques and respiratory symptoms (such as chronic cough,

sputum, chest pain, wheezing and, above all, dyspnea) are found and exposure to specific ceramic fibers was not associated with an increased incidence of lung cancer or mesotheliomas [3].

Chronic exposure to high levels of crystalline silica can lead to chronic bronchitis and emphysema. The individuals (within the context of the ceramics industry) most exposed to crystalline silica are workers in body preparation, dry pressing, hand finishing of dried ceramic pieces, and in general, those working with powder material or in dust generating processes.

Concerning collective protection measures, the use of closed and automated systems, adequate local ventilation, humidification, reducing the number of tasks in the most problematic areas, signs, and adequate laundry service (for uniforms) could be referred. Exposure monitoring and medical surveillance are necessary and also personal protective equipment [4].

Zirconium silicate (ZrSiO_4) is one of the most important compounds obtained from zircon sands.

It can also be synthesized by melting SiO_2 (silica) and ZrO_2 (zirconium dioxide) in an arc furnace, or by reaction of a zirconium salt with sodium silicate in an aqueous solution [3].

Zircon occurs in nature associated with quartz and other minerals, such as rutile, ilmenite, and rare earth elements phosphates [5].

Zirconium silicate is a white powder (zircon flour) that has gained a lot of visibility in several industries, for its excellent characteristics, such as high resistance to abrasion, corrosion and even fracture. The transformation in the form of molecules allows the zirconium spheres not to undergo microcracks during friction or impact, and with that, its durability increases considerably compared to other ceramic spheres, which is why zirconium silicate is widely used in milling operations [5].

Currently, Australia, South Africa, United States, Mozambique and Indonesia are the largest producers of zirconia minerals [6].

Some industrial activities use zircon sand (zircon silicate) as a raw material. This sand is ground for direct use by the ceramic industry or as an intermediate step for production of frits for use, after grinding, also in the ceramic industry, namely in the preparation of glazes.

Zirconium silicate is irritant, abrasive to skin and eyes. Dust exposure can cause lung diseases and even skin inflammation. There were not detected adverse effects for normal and accidental ingestion [7].

It should be noted that workers exposed to ionizing radiation at their workplace must be considered a population at risk, for which it is essential to pay special attention to the assessment and management of this occupational risk, which requires strict health surveillance with some specificity. It is therefore essential that workers undergo appropriate health checks before occupational exposure to ionizing radiation and, subsequently, have an adequate and continuous monitoring of health status [1].

As a general research objective, the external dose of ionizing radiation in different types of activity in a ceramic industry company is measured and this dose is, then,

related with the use and/or presence of zirconium silicate. It is intended to identify workplaces or tasks with increased exposure to ionizing radiation coming from zirconium silicate.

2 Materials and Methods

2.1 Study Design

This study was observational (analytical), with a cross-sectional timeline and level of knowledge II (Descriptive—Correlational). The place of study was a ceramics plant.

2.2 Population and Sample

The study universe consisted of several workplaces in a ceramic industry plant. The sampling method to be applied was non-probabilistic and the sampling technique was by convenience.

2.3 Instruments and Data Collection

The study was carried out in the academic year 2021/2022 and data collection was carried out during the months of March and April of 2022.

To carry out the collection of the evaluated parameters, a portable radiometer, Graetz, model GPD 100, serial no. 102631, was used, which allowed to measure the external radiation dose during the work.

The sample of this study was constituted by the measurements of the external dose of ionizing radiation in the work in the glaze preparation section of a ceramics industry plant. These measurements had the duration of 10 min at each point. The unit of measurement used was “counts per minute” (CPM), subsequently converted into dose ($\mu\text{Sv/h}$), by dividing CPM by 100, according to the protocol of equipment calibration, referenced to Cs-137.

The equivalent dose is given by the product of absorbed dose and a related quality factor with the effectiveness of radiation in causing biological damage. The SI unit for the equivalent dose is the Sievert (Sv).

2.4 Statistical Analysis

The statistical approach of the research work was carried out using specialized software to data processing (IBM SPSS Statistics version 27).

Concerning the hypothesis tests (statistical inference) the chi-square test of the adherence to the comparison of observed values against the theoretical values of workers was used.

For the variable relationship between the “type of activity” and the “presence of zirconium silicate”, the test Chisquare test of Independence, as well as the Chi-square test of Independence with Correction of Yates continuity were used.

For the external dose ($\mu\text{Sv/h}$) during the mill load with and without zirconium silicate, the test Wilcoxon-Mann-Whitney was used.

As for the extrapolation of the results to the population under study, a confidence level of 95% was assumed for a maximum random error up to 5%.

3 Results

In the following analysis, we tried to evaluate the differences in the mean and standard deviation in the different types of activity. The overall results are presented in Table 1.

According to the results presented in the previous table, it appears that there were two measurement sites with average external dose values higher than those measured in the mill loading zone. In the “Raw materials warehouse”, near the zirconium silicate storage shelves, an average value of $0.285 \pm 0.061 \mu\text{Sv/h}$ was obtained. In “Preparation of glazes section”, the radiation dose is high due to the proximity of the storage, an average value of $0.200 \pm 0.084 \mu\text{Sv/h}$ was obtained.

The mean dose of “background radiation” was measured, obtaining a value of $0.135 \pm 0.059 \mu\text{Sv/h}$, which was the lowest dose value measured. This measurement

Table 1 Table of Mean Values and Standard Deviation in Dose ($\mu\text{Sv/h}$) by work activity

External dose mean values ($\mu\text{Sv/h}$)			
Location	Average	Standard deviation	N
Background radiation	0.135	0.059	10
Preparation of glazes section (middle of section)	0.200	0.084	
Loading the mill with zirconium silicate	0.159	0.054	
Loading the mill without zirconium silicate	0.150	0.016	
Raw materials warehouse (close to zirconium containing products)	0.285	0.061	
Total	0.185	0.078	50

Test t-Student

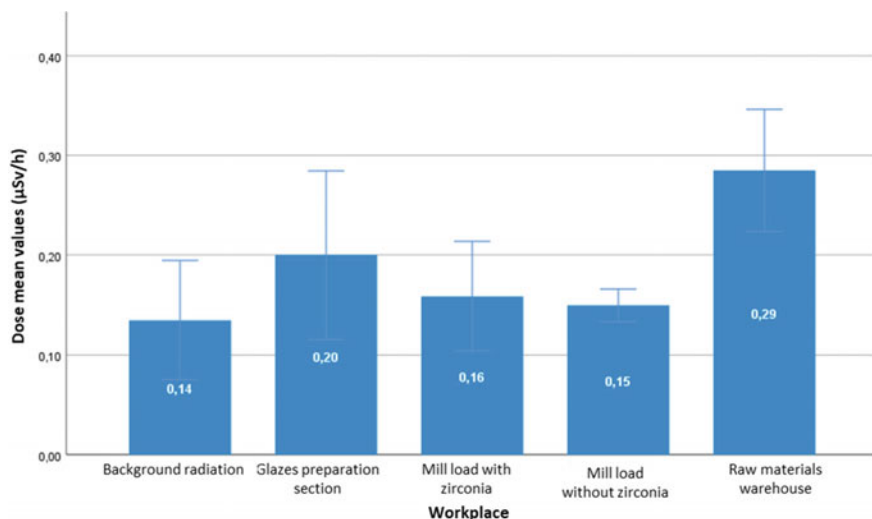


Fig. 1 Average dose values in different workplaces (T-Student test)

was carried out at the entrance to the workplaces of the plant, away from possible internal sources of ionizing radiation.

Next, the evaluation of average doses in different types of activity/sites compared with the exposure limit value was considered (see Fig. 1).

According to the results presented in Fig. 1, there was a statistically significant difference (p -value = 0.001) only with regard to the comparison of dose values between “background radiation” and the “raw materials warehouse”. In relation to the remaining measurement activities/locations, the variations observed are not statistically significant, although there is some tendency for an increase in radiation in this area of the company, compared to “background radiation”.

According to the results presented in Fig. 2, there were no significant differences (p -value = 0.446), and, being, in average, the values of the external dose of the “mill load with zirconia” with a value of 0.159 μ Sv/h higher than the dose values of the “mill load without zirconia”, with a dose value of 0.150 μ Sv/h.

Despite showing a slight difference in the values obtained, on the day of measurements at the industrial ceramic company, the mill was loaded with a composition containing ceramic frit with a content of only 7% zirconium and also 6% of zirconium silicate, hence the difference was not significant.

Then, an analysis strategy was carried out based on the average external dose for the load of the mill with and without zirconium in different phases of the task, as shown in Fig. 3, time variation, and Table 2, descriptive statistics.

It was found that, as expected, the dose values of the “mill load with zirconia” were almost always higher than the “mill load without zirconia”. On the red line, “mill loading with zirconia”, an average in the first part of the task [1–4 min] of 0.190 ± 0.008 μ Sv/h and in the 2nd part [5–10 min] an average value of 0.138 ± 0.064

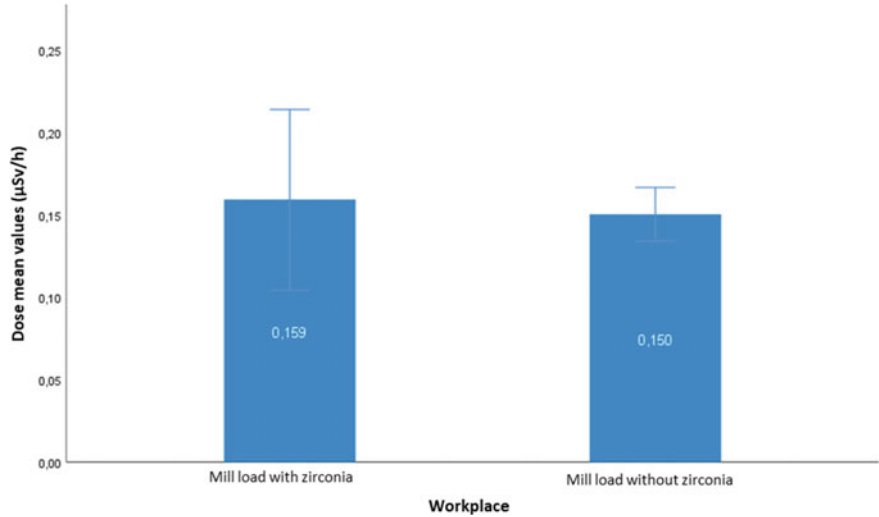


Fig. 2 Correlation of average values between mill loading, with and without zirconium silicate

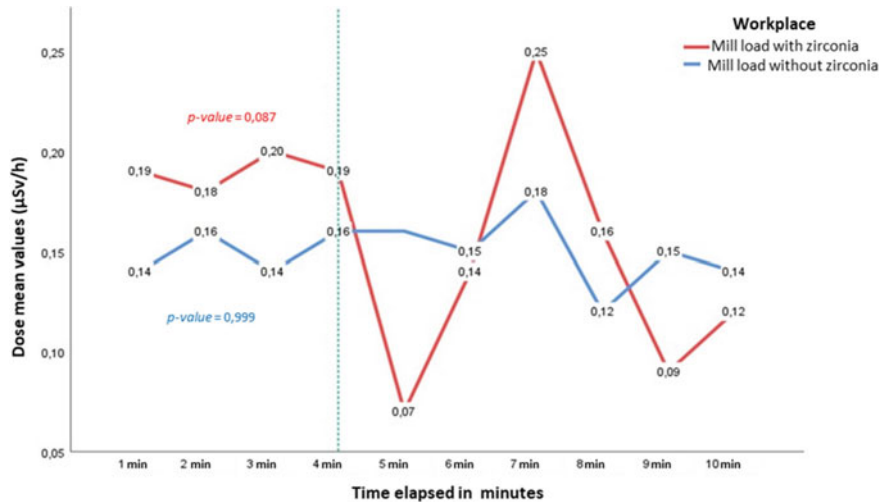


Fig. 3 External dose values (µSv/h) during mill load with and without zirconium silicate (Wilcoxon-Mann Whitney test)

µSv/h and the difference was not significant ($p - value = 0.087$), possibly due to the small amount of zirconium silicate used that day. Evidently, the values, on average, are higher up to the 4th minute, compared to the period after 5 min. Up to 4 min, the worker loaded the mill and fully charged the material at minute 4, hence at minute 5 the external dose of the red line has gone down. However, this line undergoes

Table 2 Table of average mill load values in a time interval

Zirconium silicate—Radiation Dose ($\mu\text{Sv/h}$)				Mean	Standard deviation	Median
Location	Loading the mill with zirconium silicate	Time in classes	[1–4] min	0.190	0.008	0.190
			[5–10] min	0.138	0.064	0.130
	Loading the mill without zirconium silicate	Time in classes	[1–4] min	0.150	0.012	0.150
			[5–10] min	0.150	0.020	0.150
	Total	Time in classes	[1–4] min	0.170	0.023	0.170
			[5–10] min	0.144	0.045	0.145

some changes over the 10 min of measurement of the external dose, visible in Fig. 3. Establishing the same criterion as the cut-off point, the “*mill load without zirconia*”, blue line, an average of $0.150 \pm 0.012 \mu\text{Sv/h}$ was obtained in the [1–4 min] and after the [5–10 min] an average value of $0.150 \pm 0.020 \mu\text{Sv/h}$ for a median of 0.150 for both, with no significant differences (p - value = 0.999) the trend is more or less constant over time.

With this analysis, we found that there is a tendency for a higher dose of ionizing radiation while the zirconium silicate is in the “*big-bag*” to be loaded in the mill and during the material load, in relation to the remaining operation period, while in the preparation without zirconium silicate the radiation level is constant throughout all the mill loading operation..

According to European Council Directive 96/29/EURATOM of 13 May, the effective dose limit for exposed workers is set at 20 mSv (20000 μSv) per year (100 mSV in 5 years), with the possibility to reach 50 mSv (50000 μSv) in the one year, provided that the average annual dose over the five consecutive years, including the years in which the limit was not exceeded, does not exceed 20 μSv [8].

Once the external dose of the “*mill load with zirconia*”—during the 10 min of measurement, has an average of $0.159 \mu\text{Sv/h}$, subtracting the average from the background radiation, a total of $0.024 \mu\text{Sv/h}$ was obtained. However, the total dose was $0.004 \mu\text{Sv}$ (considering 10 min of exposure). Multiplying this value by 220 working days a value of $0.88 \mu\text{Sv}$ is obtained, which is equivalent to 0.00088 mSv per year.

The same estimate was made for the “*raw materials warehouse*”, subtracting the average background radiation, during the 10 min of measurement, a value of $0.15 \mu\text{Sv/h}$ was obtained. However, the total dose had a value of $0.038 \mu\text{Sv}$ ($0.15 \mu\text{Sv} \cdot 15 \text{ min}/60 \text{ min}$, considering 15 min a day in that area of the warehouse). Multiplying

this value by 220 working days, a $8.36 \mu\text{Sv}$ dose is obtained, which is equivalent to 0.00836 mSv per year

Also, the same calculation was applied for the “*preparation of glazes*”, subtracting the average background radiation, during the 10 min of measurement, a value of $0.07 \mu\text{Sv/h}$ was obtained. The total dose obtained has a value of $0.42 \mu\text{Sv}$ (assuming a daily stay of 6 hours on site). Multiplying this value by 220 days of work, gives a value of $92.4 \mu\text{Sv}$ which is equivalent to 0.0924 mSv per year.

Adding the three partial annual doses an estimated annual dose value of 0.1012 mSv per year is obtained for the workers of glaze preparation.

4 Discussion

The work environment must provide the well-being of its workers, giving the appropriate value to human being development, creating opportunities for development, which should be the goal of any company, in order to provide a better quality of life for its employees [9].

The health surveillance program for workers exposed to radiation aims to prevent and control of possible pathologies induced by the radiation [10], and employers should consider its implementation if workers are exposed.

Going through the entire investigation and based on the inferential analysis presented, it was possible to determine a set of evidences regarding the subject under study. The risk analysis in the work environment, in this case a ceramics industry plant, is of paramount importance for the preservation of workers' health.

After analyzing the values obtained in the measurements of ionizing radiation due to zirconium silicate in the work-places, it was found that workers are exposed to radiation depending on the tasks they perform. It was found that, in “*raw materials warehouse*”, with an exposure dose value of $0.285 \pm 0.061 \mu\text{Sv/h}$ and in “*glaze preparation section*”, with an average external dose of $0.200 \pm 0.084 \mu\text{Sv/h}$, the values of the external dose of ionizing radiation are higher.

The “*mill load with zirconium silicate*” and the “*mill load without zirconium silicate*” were also compared. Although the differences were not significant, we obtained a slightly higher value in the “*mill loading with zirconium silicate*”, with a mean dose value of $0.1590 \pm 0.0546 \mu\text{Sv/h}$ during the load of the mill. It was also verified that, in the first 4 min, the external dose of ionizing radiation has values, on average, higher than in the remaining 6 min, in the case of the mill load with zirconia, and it is similar over the entire loading 10 min period for the zirconium silicate-free glaze zirconium. In this workplace, during the filling of glaze containing zirconium silicate, it is identified the activity with increased likelihood for the worker inhaling radioactive dust (internal dose), released by raw materials in powder form.

Considering the estimated annual dose value (0.1012 mSv per year), it appears that the value of the external dose of the workers, is lower than the value set in the legislation (20 mSv per year), assuming the estimated exposure times in the in each task/workplace. However, it will still be necessary to consider the internal dose,

associated with the inhalation of zirconium silicate dust, which will increase the exposure doses.

Despite differences of methods, the results obtained are in line with a previous research in Spanish ceramic tiles industry, considering the different tasks and workplaces [5].

It is important that workers use personal protective equipment (PPE) suitable for their functions, such as respiratory protection, gloves, goggles, boots and a coverall, as well, the employer providing collective protective equipment, in particular local exhaust ventilation in workplaces with zirconium silicate dust emission. Applying the dust exposure controls will reduce dust exposure and, thus, reduce internal radiation dose [5].

The external dose comes from the radioactive materials present at the site, and this dose is measured with the Geiger counter, used in this study. The internal dose results from the inhalation of gas, dust or any other radioactive chemical agent that ends up remaining inside the organism, more specifically, in the respiratory tract. This is measured by the concentration of radionuclides present in workers' respiratory zone, related to the presence of zirconium silicate airborne dust.

The main limitation of this study was the impossibility to measure the internal dose of radiation, that is, the dose due to inhalation during work with exposure to zirconium silicate dust that settles in the tissues of the respiratory tract, since analytical means for this measurement were not available.

5 Conclusions

Considering the results obtained, it was found that, despite the low external dose value, workers are always facing ionizing radiation during their work in the jobs of glazes preparation. In the *“raw materials warehouse”*, a higher external dose of radiation was found, since this is where the raw material with zirconium silicate, in quantities of a few tons is stored, followed by *“glass preparation”* and *“mill loading with zirconium silicate”*, in which the dose value is higher than the *“mill load without zirconium silicate”*.

The main occupational diseases, highlighted in bibliography, are related to the respiratory system especially silicosis and possible oncological pathology. The majority of workers in the ceramics industry do not realize the importance or intensity of health risks, leading to underestimation of some collective and/or individual protection measures. Even so, as preventive measures, it is recommended the correct planning of the activities that will be developed in work environments, in order to reduce the individual doses, and reduce the number of people exposed and the probability of accidental exposures.

The annual external radiation exposure was found below the regulatory exposure limit value but it is also necessary to consider the internal dose, related with exposure to radioactive dust. Technical, administrative and individual exposure control measures must be considered for the glaze preparation workplaces and ceramics

companies should also, reduce the amount of raw materials containing zirconium silicate in inventory.

The information presented in this study brings together, very succinctly, what the most recent publications about exposure to radioactive dust and, more specifically, the handling of zirconium silicate in ceramic industry, published in other countries. In order to provide easy access to this information for professionals in this industrial sector, it would be pertinent to motivate occupational safety and health professionals who work in the field (or will work) to investigate relevant aspects of the topic, disseminating the conclusions obtained through the publication of articles.

There is a need to develop and deepen this type of study in the future, since, in Portugal, it has not yet been made the measurement and correlation of the two doses, internal and external, in order to relate them to possible pathologies associated with exposure to zirconium silicate.

Conflicts of Interest The authors declare no conflict of interest.

Acknowledgements Authors would like to thank the Technological Center for Ceramics and Glass (CTCV) who provided the measurement equipment.

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Human Resources Practices for Managing the Ageing of the Workforce



Verónica Girão Braga, Isabel Soares Silva, and Ana Veloso

Abstract The ageing of the population has many repercussions on the labour market. It is possible to observe a rising proportion of older workers, therefore there are now workplace policies and practices aimed to help the organizations cope with the ageing of the workforce. For this present study, an online survey was used. The objective was to verify whether organizations follow the human resources practices designed to address the ageing of the labour force. The sample involves 99 Human Resources Managers from different organizations and different sectors of activity and 3 individuals delegated by the people in charge for the Human Resource in those organizations. The overall results showed that majority of the organizations follow the practices laid out to address older workers. The most used practices were related to the culture inside the companies and the work organization. Most companies have a culture based on the respect and recognition of all workers. They also promote on the job learning/training, and strongly advocate diversity concepts. The least used practices were letting older workers dictate their own work rhythm besides offering different models for going into retirement. The implications for practice of these findings are further discussed.

Keywords Population ageing · Older workers · People management · Age-friendly work

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1 Introduction

The ageing of the population is something that affects all countries of the European Union (EU), with a particular impact on Greece, Italy and Portugal [11, 14]. This phenomenon has several social, economic, and organizational repercussions (Pili-chowski et al. 2007). In terms of economic impact, the ageing of the population will lead to an increase of the total age-related dependency rate (relationship between the elderly and working-age population) in the EU countries, where it is expected to almost double by 2100 [5, 15]. In order to rectify the situation and as part of the definition of preventive strategies to face the challenges resulting from the ageing of the population, most EU countries raised the official retirement age and imposed restrictions on early retirement [10, 16]. In addition, several countries have been taking different steps to encourage active ageing and late retirement, as well as to promote lifelong employability [10–12]. Thus, there has been a significant growth of the older age groups that make up the workforce [6]. From 2005 to 2020, in the EU27, it was possible to see a growth of 7.3% of the working population in the age group from 55 to 64 years [13].

Faced with the prospect of the increasing number of active workers in increasingly older age classes, there are already organizations around the world that have invested in “ageing-friendly” Human Resource (HR) policies and practices [23]. These policies and practices aim to increase the performance of organizations in the context of an ageing workforce with an explicit focus on the demands and characteristics of older workers [7, 22].

This research aims, through the answers given by the HR managers of several organizations, to understand whether they use the HR management policies and practices identified in the literature directed to the ageing working population. Although there is no consensual definition of the concept of what is an older worker (Czaja 2020), considering the systematic review conducted by [17] and the guidelines of [4], in the present research those aged 55 years or above are considered older worker.

2 Materials and Methods

2.1 Sample

The participants of this study were HR Managers from different private sector organizations in Portugal. After data collection, the sample resulted in 99 HR representatives (e.g. “Human Resources Director”, “Human Resources Manager”) from 99 different organizations and 3 individuals delegated by the people in charge of HR in those 3 organizations to fulfill the questionnaire. These 3 individuals occupy the roles of: “personal assistant”; “secretary” and “administrative” within the organization.

Regarding the level of education, most participants have a bachelor’s degree (52.9%) as an academic qualification, followed by 42.2% having a master’s degree,

and 3.9% having the 12th grade. 1 of the participants selected the “other” option. Considering the time the participants have been working in that organization, the majority revealed that they have been working in that organization for a period between 1 and 5 years, corresponding to 40.2% of the sample, 23.5% reported working in the organization for more than 10 years, 21.6% worked for less than 1 year, and 14.7% have been working in the organization for an approximate period between 6 and 10 years.

Within the 102 participants, 72.5% work in the tertiary sector, 22.5% in the secondary sector, and only 4.9% work in the primary sector. In relation to the geographical location where participants work, the sample is divided as follows: 44.1% participants belong to the northern region of the country; 31.4% participants belong to the central region; 12.7% participants belong to the south; and 11.8% participants belong to the islands (Madeira and Azores). In relation to the size of the organizations where the participants work, the majority are working in large companies, corresponding to 41.2% of the sample, followed by 27.5% who work in medium-sized companies, 20.6% work in small companies, and only 10.8% work in microcompanies.

As far as the number of older workers (workers aged ≥ 55 years) working in the organizations that the sample belongs, 51 participants work in organizations with 0–20% of aged workers, 27 participants work in an organization with a percentage between 21 and 40% of aged workers, 18 participants of the sample belong to an organization with a percentage between 41 and 60% of aged workers, 3 of the HR Managers work in an organization with 61–80% of aged workers, and 3 participants work in an organization with a percentage between 81 and 100%. Considering the type of work that older workers are allocated in the organizations that the participants work, 43.1% of the cases are allocated to “both physical and cognitive work”, 30.4% of older workers are working in places with tasks that are “predominantly cognitive/intellectual”, and 26.5% of older workers have a sort of work that is “predominantly manual/physical”.

2.2 Research Instrument

The present study uses the survey as the research instrument, more specifically the online questionnaire. This methodology is becoming very common in the scientific world because it allows money and time saving in a very effective way. This methodology also facilitates data collection in different geographical areas [20, 27]. Therefore, it seemed the most suitable research instrument for the objectives of the study. Nevertheless, the fact that the design of this study was developed during the pandemic time also contributed to the choice of this research instrument.

The research protocol includes 7 questions about sample characterization (e.g., sector of activity of the organization, geographic location of the organization, time working in the organization, “percentage of workers in the organization aged

≥55 years”, etc.). 26 were items adapted from the “Checklist to identify the need for action in companies in terms of the age structure” [8].

The European Network for Workplace Health Promotion (ENWHP) has published a report with measures and tools that can be taken to improve the status of older workers. For this study, it was decided to use one of the tools presented in this report as a guideline for the research instrument. The original checklist from which the 26 questions were adapted, as the authors [8] refer, is an instrument of free access and self-completion, addressed to any HR representative. The purpose of this checklist is to help get a perspective on which are the steps to take within the organization to cope with the ageing of the workforce [8]. The 26 items refer to different HR management policies that are grouped into different fields of action: (i) Training and qualification (e.g. we actively support our older workers so that they take part in further training courses); (ii) Work organisation (e.g. we organise work and group tasks in such a way that they are relevant to learning and therefore permit on-the-job training); (iii) Staff development plans (e.g. we ensure that workers are relocated to workplaces suitable for their age); (iv) Workplace health promotion and integration (e.g. we collect sufficient information on the state of health of the work-force and possible approaches to promote health at the company); (v) Know-how transfer (e.g. we specifically form work groups of mixed ages in order to promote the exchange of knowledge between the generations); (vi) Organisation of working hours (e.g. we enable our employees to organise their working time flexibly); and (vii) Corporate culture (e.g. diversity concepts are discussed and promoted at our company).

2.3 Procedures

In the initial stage, the authors proceeded with the development of the questionnaire, using as a guideline the checklist mentioned above. The translation of the questions from English to Portuguese was the first step to start. Next, 26 questions were selected from a total of 46, where the fundamental concern of this selection was to choose HR management practices and policies directly related to the older workers. One example of a question that was excluded is: “Our employees of middle age and older master new technologies just as competently as our younger employees”. Afterwards, it was necessary to decide which response scale was more in accordance with the research objectives. The original version of the checklist has only two response options: “Yes/No”. In the survey used for the present investigation, the answer options that were given are “We Use/We Don’t use.”

The last stage of the questionnaire design was to develop the introductory part, informed consent, and sample characterization questions. Upon completion, we used Google Forms to transpose the questionnaire to its online version. Then, a pretest was performed with one HR Manager to understand whether the language and content of the survey were clear. Given the feedback obtained, it was decided to add the answer option “Not applicable (N/A)”. It was agreed that adding that option was important

so that the participants could have an option to choose when any of the items was not suitable in their organization (e. g. some organizations don't work in shifts).

To make filling out the questionnaire easier, the items were divided into three tables (Radio buttons were used on google forms so the participants could only choose one option per line). To avoid item non-response bias [20], it was required that respondents answer all the questions.

Data collection started on 4th July 2021 and ended on 7th September 2021. Participants were asked to complete the online questionnaire, which was disseminated through various forms. Initially, the institutional email and personal contacts were used to ask the participants to answer the survey. The emails were sent to different private sector organizations. These organizations are in a free access database, available on the internet. At the later stage, the questionnaire was disseminated through publications and private messages on LinkedIn to ask different HR Managers to answer the questionnaire. Both emails and contact made through private messages on LinkedIn were personalized, with the intention of boosting the number of responses. To avoid data duplication, the introduction part of the survey asked that if the participant has already filled out the questionnaire, he or she should not do it again.

2.4 Data Analysis

For the data analysis, IBM SPSS Statistics version 28.0.0.0 was used to make a frequency analysis of the questionnaire responses.

3 Results

The response frequency for each of the 26 HR management policies and practices to deal with the ageing of the workforce is shown in Tables 1 and 2. The results show that the practices and policies used the most in the organizations that the participants belong are: (i) having a culture based on the respect and recognition of all workers with 92.2% of responses saying that practice is used in their organizations; (ii) 85.3% organize work and tasks in a way that is relevant to learning and allows on-the-job training; (iii) 85.3% have a diversity based organizational culture; (iv) 82.4% make sure that their older workers participate in their training plans; (v) 79.4% recognize the importance of the empirical knowledge of older workers to maintain their companies work process; (vi) 76.5% have mixed age working teams in order to promote knowledge transfer; (vii) 75.5% reduce the exposure of older workers to risk factors (e.g. through the implementation of ergonomic workspaces); (viii) 75.5% have health promotion measures; and (ix) 73.5% make sure that their older workers participate in in-house training programs just as frequently as the younger workers.

In contrast, the results show that the least used HR management policies and practices to deal with the ageing of the workforce are: (i) 36.3% of the organizations

Table 1 Frequency analysis (N = 102)

We use		We don't use	N/A
Frequency (%)		Frequency (%)	Frequency (%)
<i>Training and qualifications</i>			
1-We regularly examine whether our older workers participate in in-house further training programmes just as frequently as the younger workers	73,5	16,7	9,8
2-We actively support our older workers so that they take part in further training courses	82,4	8,8	8,8
3-We use teaching methods in in-house further training courses which suit older and adult workers	54,9	25,5	19,6
<i>Work organisation</i>			
4-We make sure that our workers frequently change their work activities and workplace and therefore train their learning skills	36,3	38,2	25,5
5-We organise work and group tasks in such a way that they are relevant to learning and therefore permit on-the-job training	85,3	9,8	4,9
<i>Staff development plans</i>			
6-We support the strategy of our employees actively planning their further careers and wesupport them in this	62,7	25,5	11,8
7-We promote the employees working in different areas and fields in the company over the course of their working lives so that they can further develop their vocational skills	54,9	33,3	11,8
8-We define age-appropriate workplaces and use these selectively for the deployment of older workers	44,1	32,4	23,5
9-We intentionally make sure that our employees do not perform routine work over prolonged periods (10 years and longer)	32,4	44,1	23,5
10-We pay attention to a "limited staying time" of employees in age-critical work areas and offer them the opportunity of changing to physically and mentally less demanding workplaces after pursuing one activity for a long time	32,4	40,2	27,5

Table 2 Cont. Frequency analysis (N = 102)

We use		We don't use	N/A
Frequency (%)		Frequency (%)	Frequency (%)
<i>Workplace health promotion and integration</i>			
11-We take positive action to reduce working exposures of the employees (e.g. ergonomic workplace design)	75,5	14,7	9,8
12-We take positive action to promote the health of the employees (e.g. organisation of health workshops)	75,5	19,6	4,9
13- We enable older workers, after doing night shift for many years, to stop working shifts	21,6	20,6	57,8
14- We organise the shift work to create as little impact on health as possible	34,3	14,7	51
15-We organise the workflows and work deployment in such a way that older workers schedule their work themselves and can therefore largely dictate their work rhythm themselves (planning of shift sequences, location, duration and distribution of the working time)	31,4	36,3	32,4
16-We collect sufficient information on the state of health of the workforce and possible approaches to promote health at the company	69,6	16,7	13,7
<i>Know-how transfer</i>			
17-We recognize that our older employees have specific (empirical) knowledge which is essential for maintaining the company work processes	79,4	5,9	14,7
18-We specifically form work groups of mixed ages in order to promote the exchange of knowledge between the generations	76,5	13,7	9,8
19-We maintain special systems for transferring knowledge between the generations (e.g. sponsoring systems, mentoring, tandems or mixed-age project teams)	64,7	18,6	16,7
20-We promote models of sliding transition into retirement in order to maintain the efficiency of our older workers and support the handover of knowledge from old to young		43,1	28,4
			28,4

(continued)

Table 2 (continued)

<i>Organisation of working hours</i>			
21-We enable our employees to organise their working time flexibly	45,1	43,1	11,8
22-We offer the older workers different models for going into retirement (e.g. working up to the statutory age limit, part-time, flexible transition into retirement)	22,5	45,1	32,4
<i>Corporate culture</i>			
23-We have strategies to counteract prejudices about a generally poorer efficiency of older employees in the company	57,8	27,5	14,7
24-We make sure that older employees as well as younger ones experience recognition and respect in their work	92,2	3,9	3,9
25-We have developed corporate guidelines for an inter-generational HR policy	66,7	20,6	12,7
26-Diversity concepts are discussed and promoted at our company	85,3	6,9	7,8

that the participant belong make sure that their workers frequently change their work activities and workplace, so they train their learning skills; (ii) 32.4% make sure that their employees don't perform routine work over prolonged periods; (iii) 32.4% pay attention to a "limited staying time" of employees in age-critical work and offer them the opportunity of changing to less physically and mentally demanding workplaces; (iv) 31.4% organize the workflows and work deployment in a way that older workers can schedule and dictate their work rhythm themselves; and (v) 22.5% offer the older workers different models for going into retirement (e.g. working up to the statutory age limit, part-time, and flexible transition into retirement).

4 Discussion

Based on the result of this study, it is possible to concluded that among the organizations that were a part of this study and according to the perspective of the HR Managers, most of the organizations use the practices identified in the literature to deal with the ageing of the workforce. Some exceptions are for example "job rotation" and "ensuring that employees do not stay too many years doing the same tasks". These two practices are related and the literature suggests that the organizations should not keep their workers performing routine work or doing the same tasks over prolonged periods, instead they should provide opportunities for training and development of their workers. It is important that employees can change roles and perform different tasks so that they can use their learning skills [3, 8] and get more vocational skills [4], especially given that workplace demands change and require constant skill updating

[2]. This can avoid the cognitive decline that is normally associated to the ageing process [15, 18] and help keep older workers productive and engaged [2]. The fact that most of the organizations in the present study don't allow their workers to go into less demanding jobs is a negative practice for managing a workforce that is ageing. Organizations should accommodate older workers' needs by considering job reassignment to less demanding jobs [25]. Switching to less physically demanding jobs can avoid some physical decline that might come with age and less mentally demanding jobs may encourage workers to work longer [24, 26]. Having health and safety measures at work is also very important and can avoid some physical decline and physical complications, which will result in a best performance and productivity from older workers [27].

In the study conducted by [1], it was possible to find that in general, aged and retired workers felt that organizations were not truly committed to HR measures to better adjust to their needs. In this manner, it would be interesting in future studies to try to understand, from the perspective of aged workers, whether they feel that organizations follow the HR measures guidelines to deal with the ageing of their workers. HR policies that promote the active ageing are crucial to face the challenges that come with the ageing of the population [9] and it will only succeed if they are taken seriously and rely on the commitment of different agents within organizations [21]. It is estimated that giving older employees greater opportunities to work could raise GDP per capita by 19% over the next three decades [9].

The low response rate achieved in the primary sector is a limitation in this study, because statistics indicate that the primary sector is a sector with a high number of aged population [6]. However, given the fact that this is probably a sector with little access or use of the internet, this can be one of the reasons that justifies a low response rate from this group, which highlights a limitation in the methodology used [20] and reflects a typical coverage error of this methodology [20]. Nevertheless, according to [19], only 5% of the Portuguese population was working in the primary sector in 2019, so this factor may also have contributed to the low number of responses in this sector. Thus, it would be interesting in future studies to try to collect a sample from this specific sector.

Acknowledgements The authors would like to thank the study participants and the reviewers of the paper for helping to make it better. The authors would also like to thank their families for all the support at all times.

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Occupational and Environmental Safety

Cooperation Between the Employer and Employees in Developing Safety, Health and Well-Being in Small and Medium Sized Enterprises



Sari Tappura , Susanna Mattila , and Elli Karttunen

Abstract Small and medium-sized enterprises (SMEs) are major sources of economic activity and employment due to their volume of business. Improving SMEs' working conditions and the occupational safety, health, and well-being (SHW) of their employees is important for not only businesses but also their employees' work ability and productivity. SMEs are more often characterised by higher injury rates and severe injury types than large enterprises. They often lack the resources and competence needed to effectively manage and develop SHW. Thus, more research into practices that help SMEs in developing occupational SHW is needed. The aim of this study was to investigate the development needs and practical measures for developing SHW in SMEs. The data were collected during company-specific development processes in nine SMEs in which the employers and employees cooperatively created a development plan with an accurate schedule and assigned responsibilities. Several job resources were highlighted, including a positive work climate, support from colleagues and good work-related equipment. The most common development needs were related to communication, community spirit, the flow of information and order and tidiness. Related development activities were suggested. This study emphasises the need for cooperation between employer and employees to enhance SHW, productivity, and organisational performance.

Keywords Occupational safety · Injury · Psychosocial hazard · Productivity · Employee engagement

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1 Introduction

Small and medium-sized enterprises (SMEs) are major sources of economic activity and employment due to the volume of business they generate [8]. Improving SMEs' working conditions and developing the occupational safety, health, and well-being (SHW) of their employees is important for not only such businesses and their brands but also their employees' work ability and productivity [34]. This view is supported in Goal 8 (Decent work and economic growth) of the Sustainable Development Goals, which aims to promote 'inclusive and sustainable economic growth, employment and decent work for all' [32] and in the Vision Zero approach of addressing prevention culture to achieve excellence in SHW [17]. Currently, responsibility is also emphasized, and companies should consider ethical duties that extend beyond their legal compliance with regard to SHW [18].

At the same time, SMEs are more often characterised by higher injury rates and more severe injury types than large enterprises [10, 13, 14, 25]. Moreover, they often lack the resources and competences needed to effectively manage and develop SHW [3, 7, 24, 29, 33]. The orientation and training of new employees should be emphasised, particularly in small enterprises [14]. However, research conducted in SMEs is underrepresented in the field of occupational safety and health (OSH) [11].

Based on previous studies, job design, the organisation of work and the work environment have effects on accident frequency [9, 10, 28, 35]. These are the main themes with regard to psychosocial hazards, and they may cause injury and ill health and reduce well-being at work [16]. Accidents can be prevented by simply modifying the working environment, such as the workplace layout, and taking basic protective actions [10]. Increasing management commitment and engaging employees in continuous improvement are suggested to be effective actions, especially in SMEs [3, 31]. Thus, elementary measures may serve as a basis for developing SHW in SMEs.

Currently, organisational practices tend to be more focused on occupational safety than health and wellbeing at work [19, 38]. The effective integration of traditional OSH and workplace health promotion is needed [18, 22]. This integration is also emphasized in the recent OHS management standard ISO 45003, as it supports the better management of psychosocial risks [16]. Developing SHW jointly emphasises the fact that working conditions can both mitigate threats to employees' safety and health and enhance their overall well-being. Moreover, the components of SHW have a great deal in common with one another because each involves valuing people and undergirds both organisational and prevention culture [36, 37], which are both important from an SME's point of view.

The OSH legislation regulates managing OSH and emphasises the employer's role in improving working conditions and the working environment in cooperation with employees [5, 27]. The global Vision Zero approach emphasises integrating SHW and developing it in cooperation with the employer and employees [17, 38]. OSH management standards also emphasise such cooperation [15, 16]. Therefore, SHW

should be developed simultaneously and in close collaboration with the employer and employees.

Nevertheless, many SME managers are still unaware of their duties of care and ignore their OSH responsibilities [33]. Because external resources are often limited, SME managers require support in carrying out participatory development processes in which employees and managers work in cooperation to improve SHW in the workplace. Thus, more research into practices that help SMEs in developing occupational SHW in cooperation with their employees is needed.

The aim of this study was to investigate the development needs and practical measures for developing occupational SHW in SMEs. The study discusses integrating SHW perspectives and provides examples of SHW development actions which are relevant for facilitating the implementation of SHW initiatives in SMEs. The study emphasises cooperation between employer and employees in developing SHW. In addition to promoting SHW, creating a positive work climate and facilitating communication may improve employees' quality of work, productivity, and organisational performance [12].

2 Materials and Methods

The data were gathered during company-specific SHW development processes, specifically company-specific interviews and workshops in nine SMEs representing manufacturing industry and industrial services in Finland (see Table 1). The authors facilitated the development processes and analysed the results. A preceding risk assessment e-survey was carried out and reported in a corresponding study [1].

The companies participating the study were selected based on their willingness to develop employees' SHW and interest in participating company-specific development process. Both employer and employee representatives participated in the development process. The managers of the companies appointed employees to participate in the interviews and workshops.

The focus of the semi-structured group interviews was in SHW resources and stress factors. The interviewees were asked to freely express their perceptions on the themes related to work, work community, and employee by using qualitative methods, which is valid as regards qualitative research [30]. The interviews were based on a theoretical framework of concepts of structural and psychological empowerment [20, 23]. The aim of the interviews was to figure out how employees and management representatives perceive the SHW and factors influencing it. Between six and 14 interviewees per company participated in the interviews. The interviewees were selected based on their availability and consent.

The aim of the workshop was to discuss development needs in SHW, engage the management and employees in developing SHW, and commit themselves to related development activities. Workshops had between eight and 15 participants, which is useful when the number of participants in one company is not available. The workshop participants were selected based on their availability and consent.

Table 1 Participating companies' and employees' background information

Company	Industry	No of employees	No of interviewees	No of participants in workshop
1	Manufacturing	88	8 (1/7)*	15 (1/14)*
2	Manufacturing	130	8 (1/7)*	9 (1/8)*
3	Manufacturing	102	10 (1/9)*	11 (2/9)*
4	Manufacturing	32	8 (1/7)*	9 (1/8)*
5	Manufacturing	30	13 (1/12)*	12 (1/11)*
6	Manufacturing	196	14 (3/11)*	9 (3/6)*
7	Manufacturing	20	8 (2/6)*	9 (3/6)*
8	Administrative and support service activities	19	8 (1/7)*	8 (2/6)*
9	Water supply; sewerage, waste management and remediation activities	39	6 (0/6)*	n/a (video work-shop)

*Gender distribution (female/male)

Based on the interview results and workshop discussions, the development needs that emerged were prioritised, and an action plan, with a timetable and responsibilities for developing SHW, was co-created. The follow-up on the action plan was the companies' management's responsibility and beyond the scope of this study. The results were thematically analysed and categorised in three themes deductively [2]: (1) the content and organisation of the work, (2) the work community, and (3) the work environment and equipment. Illustrative examples were given of each theme.

The research has been conducted by following the ethical research guidelines [21]. The study has received a positive review statement from the human Sciences ethics committee of the Helsinki Region Universities of Applied Sciences. An informed consent was asked from every

participant. The rigor and validity of the study were improved by selecting sufficient number and quality of representatives from different companies, by closely interaction with them, and by using two researchers to analyse the data [6, 30].

3 Results

The interview results showed that there were several resources supporting the SHW of the employees (see Table 2). Related to the content and organisation of work, the most important resources were wide-ranging work tasks and achieved competence. The results also support the importance of other resources, namely employees' ability

to control their own work and ways of working. Moreover, flexible working hours and tasks were mentioned as a resource.

With regard to the work community, fellow workers and their support were found to be very important SHW resource in all companies. In line with this, good community spirit and equality were also mentioned in several companies. Good work-related and personal protective equipment were highlighted as SHW resources regarding the work environment and equipment category. Moreover, good, proactive service and maintenance on work equipment and cars were emphasised.

In the workshops, the interview results were discussed and major development areas for SHW were identified and agreed upon. Development actions were suggested in three categories (see Table 3). Related to the content and organisation of the work, improving the flow of information and parts, prioritising tasks of great urgency, and developing the orientation and training of employees were found to be of great importance. Moreover, in jobs that require travel, such as installation jobs, procedures to support smoother operations were suggested.

Improving community spirit, information flow and work ability activities were suggested as major SHW development actions related to the work community category. These can be supported by, for example, collective events and informing employees about the progress made on their development suggestions.

Regarding the work environment and equipment, improving tidiness and orderliness was highlighted in almost all companies. Suggested actions were related to both daily cleaning and regular thorough cleaning. Development activities were also suggested related to improving workspaces and passages, such as minimising extra parts waiting for operation. Moreover, the better availability and usage of tools was emphasised, and procedures for inventing, storing, and handling tools were suggested.

In addition to the identification of development activities, they were prioritised. Moreover, a schedule and responsible person were decided upon on each of the activities to ensure the continuity of SHW development. Based on the feedback from the workshops, the employees felt that the workshops were interactive, and they were engaged in SHW development.

Table 2 Categorisation and examples of SHW resources

SHW category	Examples of SHW resources
Content and organisation of the work	Wide-ranging work tasks and competence Influencing over one's own ways of working Flexible working hours and tasks Control over one's own work
Work community	Fellow workers and their support Equality Good community spirit
Work environment and equipment	Good work equipment Good personal protective equipment Good and proactive maintenance of the work equipment

Table 3 Categorisation and examples of SHW development actions

SHW category	SHW subcategory	Examples of SHW development actions
Content and organisation of the work	Improving the flow of information	Regular meetings and provision of information (e.g., weekly meetings, information screens and/or e-mails)
	Prioritising tasks of great urgency	Cooperation and cross-training between departments, the training of substitutes
	Improving flow of parts and related information from one stage of work to the next	Developing information system, entrusting employees at the previous stage of work to take care of moving the parts to the next stage
	Developing orientation of new employees	Keeping the orientation instructions up to date, nominating an orienting person, arranging orientation training and allocating time for orientation
	Developing training	Compiling training plan for employees
	Reducing the burden of jobs that involve travel, specifically installation work	Ordering and listing installation materials, informing the project manager, agreeing on residual material and having discussion with the customer to gather feedback
Work community	Improving community spirit	Increasing communication and collective events (e.g., spring cleaning and company outings)
	Informing employees of progress on issues brought out by these employees	Informing employees of progress (e.g., an information board or screen) and providing more resources to maintenance
	Developing work ability activities	Activating employee well-being agents, implementing ergonomics enquiries and carrying out work ability activities
Work environment and equipment	Improving tidiness and orderliness	Determining the tidiness and orderliness level, arranging a larger annual spring cleaning, taking daily cleaning as part of a routine, tidying up after oneself and arranging machine-specific dust extraction
	Improving workspaces	Developing setting times for parts, considering the order amounts for purchased products, scrutinising the un-rotating final products and improving the staff room
	Improving passages	Removing useless things from corridors, reviving 5S method use, marking the passages and forbidding loading at the personnel gate
	Improving availability and usability of tools	Taking an inventory of tools, assigning responsibilities for tools, arranging one's own places for tools and organising a lending system for tools

4 Discussion

This study provides information on current SHW development needs and related practical measures in SMEs. Based on the company-specific development processes, all the participating companies identified several SHW resources and development needs. The resources serve as a good measure via which to sustain employees' SHW and productivity during hectic or uncertain times. The integration of the SHW supported comprehensive development of OSH within psychosocial perspective, which often receives less attention [19, 22, 38].

Most of the identified development actions, such as improving communication and cleaning, were quite simple and easy to carry out in line with [10, 13]. Moreover, the workshops initiated small improvements right away. This is important for SMEs' because they often lack resources [3, 24, 29, 33]. Because SMEs may limit investments in prevention and often save on safety measures for economic reasons [4, 10, 26], it is important to highlight small and profitable development actions providing immediate return to the business. The cooperative development process itself promoted management commitment and employee engagement in development, which are suggested to be especially effective in SMEs [3, 31].

Several SHW resources were highlighted, such as versatile and flexible work, fellow workers and their support and good work equipment. However, improving community spirit was suggested also as a development action, even though the work community was found to be a resource in all companies. Therefore, it should be constantly emphasised. The other suggested development actions were related to communication, training, the flow of information and parts, tidiness and orderliness, and the workspace and tools. Related practical measures were suggested, and action plans were co-created with employees and management in each participating company.

This study contributes to OSH research in SMEs, which is often underrepresented [11]. The study emphasises cooperation between employer and employees in developing SHW. In addition to promoting SHW, creating a positive working climate and facilitating communication may improve employees' quality of work, productivity, and organisational performance [12]. Moreover, it adds on the current discussion on integrating traditional OSH perspectives and well-being at work [18, 22] by emphasising that they should be developed jointly. It provides practical measures suitable for SMEs because the measures developed for large companies cannot be simply transferred to SMEs [4, 25]. Moreover, this encourages SMEs to engage employees in continuous development to improve their well-being and productivity.

This study has certain limitations. The number of the participating SMEs was quite low, and the included SMEs represented only a few industries. Thus, the results may not be extrapolated to other industries. Nevertheless, the quality of the study was improved by appointing both employer and employee representatives of each company, by using qualitative methods, and by engaging several researchers in the development process and analysis [6, 30]. Future studies should focus on means of supporting SMEs in their SHW development. More research is also needed

regarding the integration of SHW and combining traditional OSH and workplace health promotion [18, 38].

Acknowledgements The authors acknowledge the European Social Fund for funding this study.

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Occupational Safety and Health Risks of Gig Workers in Finland



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Abstract Temporary work and work through temporary agency, i.e. gig work, have been associated with adverse effects on occupational safety and health (OSH). About 15% of employees in the European Union work temporarily. The objective of this study was to identify the main OSH risks for gig workers. A total of 164 gig workers responded to an e-survey covering 25 risk assessment sections. Most of the respondents worked in health care and social services. The main risks were awkward work postures, work breaks and pace of work, and inappropriate behaviour. Only 28% of the respondents thought that gig workers are aware of their OSH responsibilities and duties. The lack of knowledge of OSH responsibilities and duties can also constitute an OSH risk. To ensure that gig workers know their responsibilities and duties and are aware of risks at work, gig workers should receive better orientation and become involved in risk assessment in the workplace. From a management point of view, knowing the risks is a prerequisite to proactively improving the OSH of gig workers.

Keywords Temporary work · Non-standard employment · Incident · Hazard · Risk assessment

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1 Introduction

Non-standard employment has increased over the past few decades [11]. Before the COVID-19 pandemic, in the European Union in 2018, 15.5% of employees had temporary contracts [6], and 2.1% worked for temporary work agencies [7]. In this study, gig workers are defined as employees working in temporary (or fixed-term) employment or as temporary agency workers.

Despite its flexibility, non-standard work may have adverse effects on occupational safety and health (OSH); for example, it may increase the risk of accidents [9, 15]. Job (in)security is related to both the physical and psychological health of gig workers [3, 8]. Reference [2] showed that employees in temporary agency work and fixed-term employment face a higher risk of mortality compared to permanent employees. This could be due to factors such as insufficient training, more hazardous work tasks, provision of poor-quality personal protective equipment, or inadequate OSH management [10]. Gig workers are often young and inexperienced workers, and they typically suffer accidents more commonly than other employees [12, 19]. Therefore, young and inexperienced workers should be introduced to safe work practices from the very beginning of their careers [12].

On the other hand, according to [20], fixed-term workers do not have more occupational injuries than permanent workers. Full-time health care workers have an even higher occupational injury risk than part-time and casual workers [1]. Reference [4] found part-time work to be a preventive factor for back injuries among nursing personnel.

The OSH regulations state the basis for managing OSH and preventing risks in the workplace by emphasising the employer's role in continuously improving working conditions, managing risks, providing adequate instruction and guidance, and advancing cooperation between employers and employees [5, 14]. However, these requirements may be neglected [17]. The risk management process may also need improvement—for example, by strengthening the utilisation of risk assessment results in training and orientation [13, 16]. Therefore, more emphasis must be placed on identifying, assessing, and managing OSH risks among gig workers alongside permanent employees.

The objective of this study was to determine the main OSH risks for gig workers. Assessing the risks is a prerequisite to managing them and proactively improving the OSH of gig workers.

2 Materials and Methods

Data was gathered through an e-survey filled out by gig workers in Finland. This sample of convenience was collected in 2020–2022. The survey consisted of background questions, questions about OSH organisation and responsibilities, and 25 risk assessment sections. Risks were related to the physical work environment (five

sections); physical, chemical, and biological hazards (eight sections); physical strain (five sections); and psychosocial strain (seven sections). The respondents evaluated the risks according to the following scale:

- Risk exists, meaning that the hazard has been acknowledged and that eliminating it or reducing its risk to a manageable level requires action
- Risk is under control, meaning that the hazard has been acknowledged and its risk is under control
- No risk, meaning that the hazard does not exist in the workplace

The respondents were also asked to describe any incidents and hazards they had observed. Terms “hazard” and “risk” were not defined.

In total, 164 gig workers responded to the survey. Most (59%) worked in the health care and social services (HCSS) sector (Table 1). The others (41%) worked in accommodation and food service activities; wholesale and retail trade, including repair of motor vehicles and motorcycles; arts, entertainment, and recreation; transportation and storage; construction; manufacturing; water supply, sewage, and waste management and remediation activities; or other industries. About one-fourth (26%) had worked as gig workers for less than a year. Most of the respondents (64%) were women, 75% of whom worked in HCSS. The proportion of young workers less than 26 years old was 38%.

Statistical analysis of the results was conducted using MS Excel. Descriptive statistics were used to determine the proportions of variable values as frequency tables and charts. In comparisons, $p < 0.05$ (two-tailed) was accepted as a statistically significant threshold. Values were calculated using a two-sample z-test for proportions. Open answers were qualitatively analysed, and representative quotes were selected.

Table 1 Number and percentage of respondents by work sector, work experience as gig workers, gender, and age

Demographics		n	%
Work sector	Health care and social services	97	59
	Other	67	41
Work experience as a gig worker	Less than a year	42	26
	At least one year	104	63
	No answer	18	11
Gender	Female	105	64
	Male	54	33
	No answer	5	3
Age	Under 26 years	62	38
	26–45 years	79	48
	Over 45 years	23	14

3 Results

3.1 Knowledge of OSH Organisation and Responsibilities

Only 22% of all respondents knew who the occupational safety officer was at their workplace, and 29% knew the occupational safety representative (Fig. 1). Only 13% of respondents working in HCSS knew who the occupational safety officer was at their workplace, and 24% knew the occupational safety representative. For other respondents, the rates were 34% and 37%, respectively. A larger percentage of those who had worked for less than a year knew who the occupational safety officer (36% vs. 12%) and occupational safety representative (40% vs. 19%) were at their workplace compared to those who had worked at least a year as gig workers. Of all respondents, 27% reported that an occupational safety and health action programme had been drawn up.

Two-thirds of all respondents thought their managers knew what OSH responsibilities and duties the managers had (Fig. 1). Half of all respondents thought that employees know their OSH responsibilities and duties, and 28% of the respondents thought that gig workers had this knowledge. A lower proportion (24%) of the respondents working in HCSS compared to others (34%) thought that gig workers know their OSH responsibilities and duties.

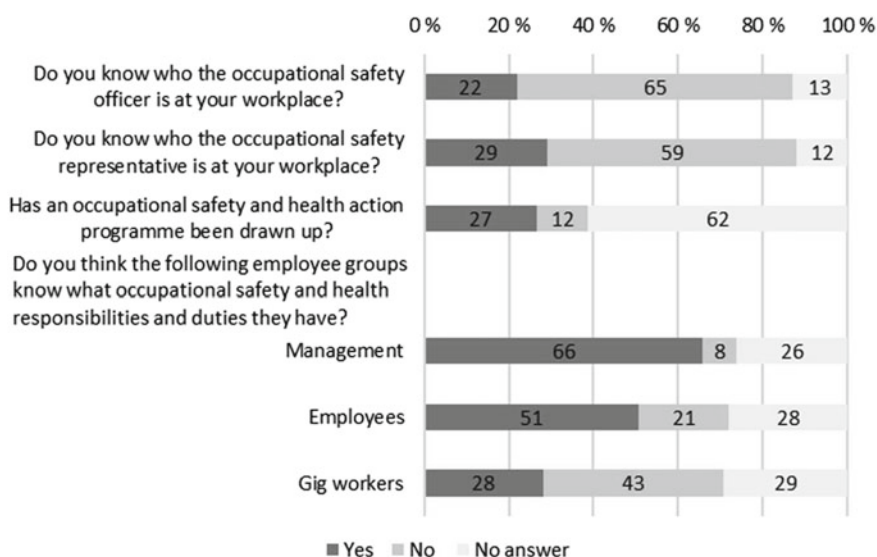


Fig. 1 Respondents' knowledge of occupational safety and health organisation and perceptions of personnel groups' knowledge of responsibilities and duties

3.2 Risk Assessment

3.2.1 All Respondents

Figure 2 shows the risk sections evaluated as “risk exists” by at least one-third of all respondents. The most common risks were awkward work postures, work breaks and pace of work, and inappropriate behaviour.

The work environment, working alone, the equipment used, and lack of ergonomics-related orientation had an impact on awkward work postures. Especially in HCSS, the conditions in customers’ homes and working alone expose workers to poor working postures. As one open answer stated, ‘Especially when working alone on the night shift, you have to give up ergonomics when you change the diaper of, for example, a bedridden, immobile adult alone’.

In the restaurant industry, standing for a long time without even being able to sit causes physical strain. One respondent wrote, ‘Standing for the entire shift is inhumane, in my opinion. In some places, it is even required that you are not allowed to sit during the work shift. According to them, this does not look good to the customers. I think it is unreasonable’.

The respondents identified the pace of work and the lack of being able to take a break from work as a safety risk in all industries. At worst, workers do not have time to take breaks at all and do not even have time to go to the bathroom when needed.

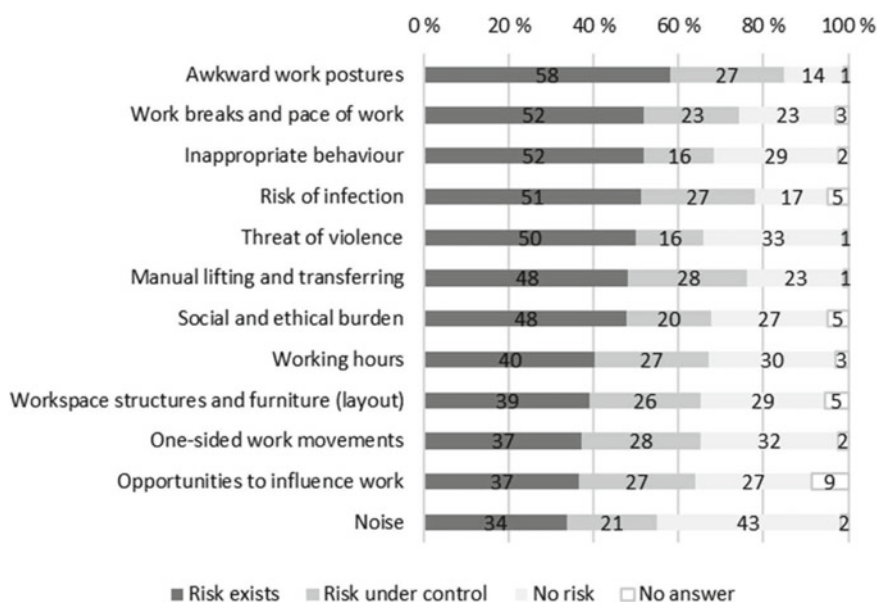


Fig. 2 Risks existing and requiring action evaluated by at least one-third of respondents

For example, one respondent claimed that there is a ‘constant rush, no time to take breaks, sometimes no time to go to the toilet or take a meal break’.

The respondents had experienced inappropriate treatment from customers, the work community, and colleagues, as well as from customers’ relatives. A respondent working in HCSS reported ‘groping, slapping, and dirty talk. But there can also be nasty words, shouting, whispering or not saying hello, etc., from other employees’.

In the sales sector, both customers and colleagues may behave inappropriately towards gig workers, as one respondent wrote: ‘Customers are often rude to the cashier, and permanent workers may be impolite and rude to temporary workers’.

3.2.2 Comparison Between Work Sectors

For the comparison of the risks between work sectors, the respondents were divided into two groups: one consisted of those working in HCSS and the other group consisted of the rest of the respondents. Figure 3 shows the proportion of respondents who had evaluated “risk exists” divided according to the respondents’ work sectors. The figure shows only the risk sections evaluated as “risk exists” by at least one-third of the respondents in one or the other of the groups. A larger proportion of respondents working in HCSS compared to others evaluated risks existing in the threat of violence, social and ethical burden, risk of infection, inappropriate behaviour, lack of opportunities to influence work, and awkward work postures.

Customers, patients and their relatives can cause threat of violence in HCSS. Especially children, older people, disabled people, people with memory loss, mental health patients, drunk patients and substance abusers were mentioned. For example, one respondent wrote: ‘Especially mental health patients and drunk patients might act aggressively’.

Workers in HCSS encounter people with different illnesses and life situations. The work includes hard value judgements concerning patients’ self-determination. Sometimes the values of the workers in HCSS do not meet the values of their customers or work community. Also, lack of time causes a social and ethical burden to workers, as this comment shows ‘Constant social and especially ethical burden, no time or possibility to do the work well enough’.

3.2.3 Comparisons According to Work Experience as a Gig Worker

The responses were divided into two groups according to the respondents’ work experience as a gig worker. One group consisted of those who had worked as gig workers less than a year, the other of those who had worked at least one year as gig workers. Figure 4 shows the risk sections evaluated as “risk exists” by at least one-third of the respondents in one or the other of the groups and how the responses differed according to the duration of the respondents’ experience as gig workers. Usually more of those who had worked longer as gig workers identified risks that

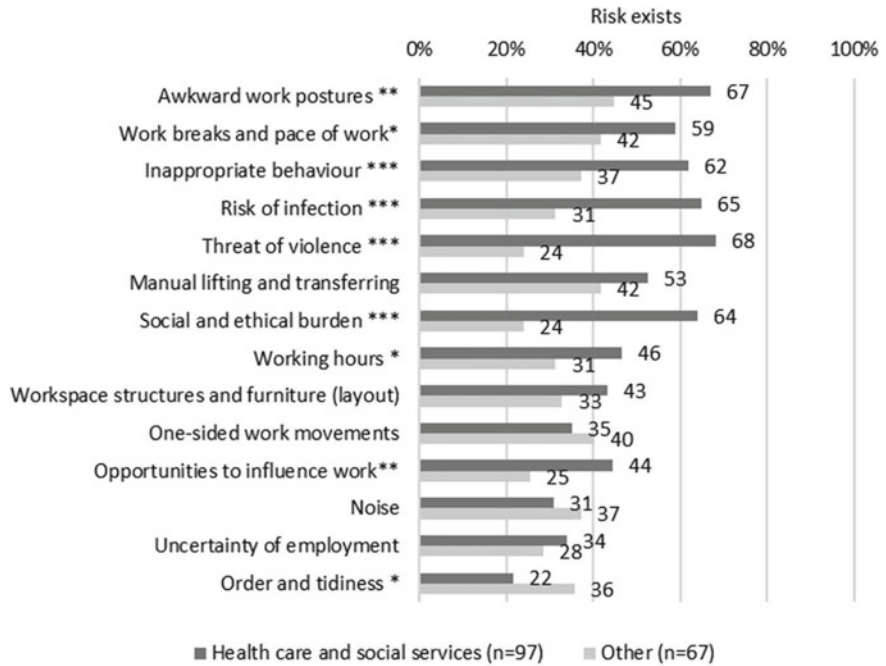


Fig. 3 Comparison between respondents working in HCSS and others regarding risk sections identified by at least one third of the respondents of either group (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)

required actions. The most significant differences were in inappropriate behaviour and social and ethical burdens.

3.2.4 Comparison Between Genders and Age Groups

When comparing responses from different genders and age groups, statistically significant differences were found. A larger portion of females than males identified risks related to infection, threat of violence, workplace structures and furniture (layout), work breaks and pace of work, and social and ethical burdens. The risk of vibration and air impurities (dust, gases, microbes) was a larger concern among men than women. Most of the women (75%) worked in HCSS, whereas most of the men (74%) worked in another sector. A larger portion of young respondents (under 26 years old) compared to the oldest respondents (over 45 years old) identified risks in the work breaks and pace of work, inappropriate behaviour, threat of violence, and working hours.



Fig. 4 Differences in risks according to duration of experience as gig workers regarding risk sections identified by at least one third of the respondents of either group (* $p < 0.05$, ** $p < 0.01$)

4 Discussion

In this study, the OSH risks for gig workers were identified. Based on previous studies, gig work may have adverse effects on workers' OSH (e.g. [2, 3, 9, 15]). Identification of risks is a prerequisite to managing them and proactively improving gig workers' OSH in the workplace.

Only a small percentage of respondents knew their workplace's occupational safety officer and representative. This percentage was lower among the respondents working in HCSS compared to other sectors. One might think that the reason could be a shorter duration of gigs and poorer orientation in HCSS. On the other hand, the results show that more of those who had worked less than a year as gig workers knew their occupational safety officers and representatives than those who had worked longer. The reason could be that the occupational safety officer and the representative are introduced to the gig worker during the orientation but after that gig workers forget them.

A lack of knowledge of gig workers about their OSH responsibilities and duties may indicate that they feel their orientation is insufficient, as [10] found. Poor knowledge of responsibilities and duties may be a risk to OSH.

The length of work experience as a gig worker seems to also affect the evaluation of risks, so that more experienced workers perceive more risks. This may be due to increased awareness or different work tasks.

Many respondents working in HCSS claimed that a lack of opportunities to influence work causes a risk that requires action. High job demands and low job control might increase the risk of occupational injury, especially for temporary agency workers [18].

In the future, questionnaire-based risk assessments should be conducted among all types of staff, including gig workers. This would make people think about risks and could have an impact on their behaviour. Incorporating gig workers into the risk assessments could help identify the specific risks related to gig work. The results of risk assessments should be included in the orientation.

The limitation of this study is the limited number of the respondents and their various backgrounds in different industries, centred on HCSS. The reason for the differences in risks identified by males and females in this study might be the working field. In addition to study general risks of gig work, future research is needed to study OSH risks and related preventive measures at workplaces in different industries to improve the OSH of gig workers. Further research might, for example, explore risk management practices in HCSS.

5 Conclusions

The main OSH risks for gig workers are awkward work postures, work breaks and pace of work, and inappropriate behaviour. Risks related to threats of violence, social and ethical burdens, the risk of infection, inappropriate behaviour, a lack of opportunities to influence work, and awkward work postures are more common in HCSS than in other industries. A minority of the respondents thought that gig workers know their own OSH responsibilities and duties. This lack of knowledge can also constitute an OSH risk. Better orientation based on the results of risk assessments might improve the OSH of gig workers. From a management point of view, knowing the risks is a prerequisite to proactively improving the OSH of gig workers.

Acknowledgements The authors thank The European Social Fund, Tampere University, Metropolia University of Applied Sciences, University of Oulu, and Satakunta University of Applied Sciences for funding.

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Risk Management Process for an Electric Arc Welding Workshop in South Sudan



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Abstract Welding activities are present within several types of industries, present both indoor and outdoor. It is considered as a hazardous activity which may lead to different health and safety risks, and in some extreme cases even lead to the death of the individual. This work's objective was to conduct a risk management process of a welding workshop. For that purpose, it selected a welding workshop located in Juba, South Sudan. For the hazard identification an observation checklist was structured, considering several physical, biological, and chemical agents, ergonomic and accident hazards. The risk rating levels were defined by using the 5×5 Risk Assessment matrix, and finally risk treatment measures were recommended by following the hierarchy of control measures. The results of this study show that noise, electricity, and toxic gases may lead to high-risk consequences, while ultraviolet radiation, manual handling, and repetitive movement to moderate risk consequences.

Keywords Risk assessment · Risk treatment · Risk control · Health risks · Safety risks · Welding

1 Introduction

Welding is regarded as one of the riskiest professions in the world where 1 in 250 welders will die from a welding related injury at some point of their career (Hong 2014). Welding is performed in several industries such as automotive industry, construction industry, manufacturing aerospace industry and the ship building and

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rail industry. The welding process is associated with unique exposure of people to fumes, gases, extreme heat, noise, molten metal splatter and smoke [1]. Welding process is defined by American Welding Society (AWS) as a joining process which produces coalescence of materials by heating them to suitable temperatures with or without the application of pressure or by the application of pressure alone and with or without the use of filler material. The metals used in welding generates a complex mix of noxious gases and fumes (International Agency for Research on Cancer 1990). Welders may be exposed to variety of dust, fumes, and gases inhalation of which can lead to adverse health effects among welders [2, 3]. The task of welding can be conducted either as an indoor or outdoor activity.

Welders are exposed to varied occupational health and safety hazards [4]. Previous studies have shown that there is a high prevalence of occupational eye injuries among electric arc welders [4, 5]. Similar studies found that abrasions, laceration, foreign body in the eye and flash burns are the major occupational injuries associated with welding processes while waist or back pain, metal fume fever, respiratory illness, and hearing impairment accounts for most of the occupational related diseases affecting welders [6]. Majority of the metals used in welding causes an illness known as metal fume fever [2]. Earlier studies also found that respiratory diseases such as cough, dyspnoea, rhinitis, asthma, pneumonitis, pneumoconiosis, chronic bronchitis are very often with welders [1, 7]. The inhalation of welding fumes has been associated with the development of lung cancer among welders in previous studies [8].

Welding occupies 1% of the labour force in some industrialised countries and increasing knowledge of health risks, necessitating improved assessment strategies and controls [9]. This makes welding central to several industries. Therefore, it is imperative to address the health and safety risks associated with this process. The first step in addressing the health and safety exposure begins with conducting a risk management process which itself has several phases/steps. This process starts with hazard identification process which deals with identifying what in a workplace could cause harm to the health and safety of people which is then followed by, analysing, and assessing of their risks this probability of harm from occurring including the severity and consequences and lastly putting in place control measures to address them while following the hierarchy of control for the effective promotion of a safe and healthy working environment.

2 Materials and Methods

The study began with looking at the tasks and activities performed at the welding workshop, quantifying the number of people involved, the types of equipment, tools and materials used in the workshop and finally assessing the working conditions at the time, unless all these are known, it will not be possible to identify all sources of hazards. Hazard is defined by Occupational Health and Safety Assessment Series (OHAS) as a source, situation, or act with potential to cause harm in terms of injury, harm or damage to health or combination of these (ISO31000:2019).

The study was conducted in a welding workshop in Gudele West, Juba, South Sudan. The workshop is located 2 m away from the Juba-Mundri Highway, surrounded by residential homes to the south, west and east direction. On the day of the study, there were 13 people present in the workshop whom of which consisted of 10 workers out of these 3 were painters and 7 were welders) while the other 3 were visitors. The study was done during a hot and sunny day within the month of November. Normal business operating hours for the workshop are from 8:30–5:00 pm, Monday to Sunday. It remains closed only on public holidays.

The tasks performed in the welding workshop consist of planning of the welding tasks, preparing materials to be welded, cleaning of welding materials, connecting mass bag and electrode cable, connecting grounding to material, turning on the welding box panel and adjusting the electric current, welding work materials with electric welding in open places and in height. The tools and equipment used in welding include welding generator as a power source, welding electrode, flat file, Hack saw, try square, ladder, steel rule, wire brush, electrode hammer, chipping hammer and ball pen hammer.

For this study, a risk management process was conducted in accordance with the Irish Health and Safety Authority Guidelines [10], where the data was collected through observations, interviews, review of previous accident records and desktop review of similar studies on risk management in welding workshops. Primary data collected include information on the tools and materials used in the welding process, stages involved in welding and experienced work accidents. Further, the hazards in the workshop were screened using a checklist composed of five groups of hazards [11]: physical (noise, vibration, heat, cold, ionizing radiation, non-ionizing radiation, moisture, abnormal pressures), chemical (dusts, fumes, gases and liquids in use), biological (viruses, bacteria, protozoa, fungi and bacilli, parasites), ergonomic (physical exertion, manual lifting, posture requirements, lighting conditions, excessive rhythms, shift work, night work) and accidents (machine without protection, poor electrical connections, inadequate storage, defective or inappropriate tools, animals, height).

A set of interview questions were administered to workers to better understand the tasks performed at the workshop including the health and safety risk factors the workers are exposed to and lastly phone camera was used for capturing photos of tasks being performed including the condition of the working environment [12].

To identify hazards at the working area, the study adopted the International Labour Organisation (ILO) 5 steps guidelines for risk assessment during the hazard identification process, by walking around the workplace and looking at what could be expected to cause harm to workers, visitors, and the nearby communities, observing how the workers were performing their tasks, reading material safety data sheets of chemicals used on site, Interviewing the workers on site, looking at accident and incident records and reviewing similar literature on hazards at Welding workshops [13].

Hazard analysis was conducted using a qualitative method which involved observation, analysis of images taken from the site, and the analysis of the information gathered from the workers through one-on-one interviews.

Table 1 5 × 5 risk assessment matrix

Likelihood	Severity (Consequences)				
	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Almost Certain (5)	5	10	15	20	25
Likely (4)	4	8	12	16	20
Possible (3)	3	6	9	12	15
Unlikely (2)	2	4	6	8	10
Rare (1)	1	2	3	4	5

*Risk Level *(1–3) = Low *(4–12) = Medium * (13–25) = High

Risk assessment was done using the qualitative risk rating as illustrated in Table 1. The study adopted the ISO 31010 risk matrix. The categorization of each risk scenario such as low, medium, and high is the product of the probability rating and the consequence rating [14]. For instance, the risk rating is calculated by multiplying the likelihood by the risk's consequence.

After the Risk Assessment was completed the risk treatment process the study adopted the Center for Disease Control and prevention (CDC), International Labour Organisation and ISO 45001 hierarchy of hazard control for addressing the hazards found in the workshop (CDC, nd: ILO [13]). The first option was elimination of the hazard and where it was impossible to eliminate, the hazard was substituted together with the use of additional measures such as engineering and administrative controls and lastly the use of personal protective equipment.

3 Results

The hazard identification process began by identifying the main sources of hazards in the welding workshop which included sources like the welding process itself, the materials, tools, and equipment used, and the unsafe work conditions posed by working outdoor on a hot and sunny day. This was done to ensure a systematic process of identifying hazards in all the activities performed at the welding workshop, hence no potential hazard is left out during the risk management process.

During the risk assessment process several health and safety hazards were identified: physical hazards such as noise, Ultraviolet radiation (UVR) and heat; chemical hazards such as dust and fumes; biological risks (viruses); accident hazards such as (risk of electrical shock due to using uninsulated electrical wires, burns and metal pieces getting into workers face or eyes due to the lack of personal protective equipment, trips and falls due to poor housekeeping, risk of moving vehicles hitting workers or something falling or being thrown from passing vehicles, there was also the risk of workers being harmed by wild animals like snakes or insects, and ergonomic hazards such as awkward working posture, inadequate manual handling (Table 2). The working area is shown in Fig. 1.

Table 2 Identified welding hazards, sources, and consequences

Hazard Category	Hazard identified	Source of Hazard	Health and safety risks
Physical agents	Noise	Welding process Hammering, grinding, and drilling activities	Temporal hearing loss; Permanent hearing loss; Stress; Irritability
	Exposure to heat	Working under direct sunlight Welding process	Burns on exposed body parts like the ear and skin. Eye injuries due to hot and flying sparks, slags, or metal chips. Reduced vision due to prolonged exposure to heat
	Exposure to Ultraviolet (UV) radiation	Welding Arc Working under direct sunlight	Skin burns and skin cancer. Reduced vision due to prolonged exposure to UV light. Photo keratoconjunctivitis from prolonged exposure to UV light
Chemical agents	Metal fumes	Welding smoke (The composition is dependent on the base metal, filler rod, coating paint or grease on surface of work piece) Grinding activities	Bronchitis. Metal fume fever; Pulmonary granulomatous disease due to chronic beryllium exposure
	Exposure to Toxic gases like acetylene, propane, carbon monoxide and helium	Welding smoke (The composition is dependent on the base metal, filler rod, coating paint or grease on surface of work piece) Grinding activities. Painting activities	Bronchitis and lung fibrosis due to mineral dusts and gases. Respiratory tract illness
	Exposure to solvents and paints	Painting activities at the workshop	Respiratory tract illness. Skin and Eye irritation
Accident hazards	Welding at height	Welding activity performed on ladder	Injury leading to fracture due to fall from height. Death due to fall from height
	Animal bites	Surrounding bushes	Neurological illness. Death
	Poor Electrical Connections	Welding machine. Welding Generator. Grinder and drilling machine	Burns. Long-term consequences of electrical injuries. Neurological and psychological effects

(continued)

Table 2 (continued)

Hazard Category	Hazard identified	Source of Hazard	Health and safety risks
Ergonomic hazards	Combustible material	Heat, flames, and sparks resulting in combustion of flammable such as paints and fuel and non-flammable materials like paper, wood, and plastic. High pressure gas cylinder	Fire or explosions. Burns and physical injures due to effects of fire and explosions. Psychological trauma due to effects of fire and burns
	Electricity	Welding generator. Welding wires. Electrode holder	Electrocution; Cardiac arrest; Severe burns
	Manual lifting of heavy objects and materials	Lifting of heavy machinery and metal objects	Back pain and injury; Musculo skeletal disorder; Permanent disability
	Repetitive movement and excess rhythms	Repetitive motion while welding and moving materials	Repetitive movement and excess rhythms



Fig. 1 The working area for the study

The identified hazards were further classified according to their distinct categories, sources, and potential health and safety risks to humans in Table 1.

Following the identification of the hazards and their associated sources the study further analysed the risks and consequences of the different hazard categories in Table 3 including the effectiveness of the existing control measures and the exposure time of the workers to those hazards and their risk levels.

Table 3 Tasks performed in the workshop with their respective hazards, consequences, and existing control measures

Task	Hazard	Risk analysis		Risk assessment				Clarification of the RR
		People at risk/ exposure time	Consequence	Existing control measures/ effectiveness	L	S	RR	
Preparing materials for welding Cleaning of welding materials	Ergonomic Hazards such as Manual handling and repetitive movement	Workers involved in the task (Assistant Welder)/2 h a day	Musculo-skeletal disorders and injuries	Lifting of heavier objects is conducted with support from colleagues so that the weight is distributed. Not highly effective	4	3	12 Medium	Workers are involved in the carrying of heavy loads
	Accident hazards like sharp and protruding objects	Workers involved in the task and visitors (Senior welder and Assistant welder)/2 h a day	Cuts and injuries; Tetanus	No control measures in place	4	3	12 Medium	Workers perform tasks without personal protective equipment like hand gloves and safety boots
	Chemical Hazards Such as dust	Workers involved in the task and people in the vicinity of the activity 3 h a day	Respiratory illness; Metal fever	No control measures in place	5	3	15 High	No existing control measures are in place to protect workers from exposure to toxic gases

(continued)

Table 3 (continued)

Task	Hazard	Risk analysis		Risk assessment				Clarification of the RR
		People at risk/ exposure time	Consequence	Existing control measures/ effectiveness	L	S	RR	
Welding process including connecting electrode, actual welding, hammering, and cutting of materials	Accident hazards like sharp and protruding objects	Workers involved in the task (Assistant welder)/2 h a day	Cuts and injuries; Tetanus	No control measures in place	4	3	12 Medium	Workers perform tasks without personal protective equipment like hand gloves and safety boots
	Noise	All workers; Visitors And nearby homes/ 8 h a day	Temporal hearing loss; Headache; Stress; Irritability; Permanent hearing loss	No control measures in place	5	4	20 High	Three generators producing sound of more than 100 dBA Workers performing tasks without hearing protection
	Heat	Workers involved in the task (Welder)/8 h a day	Burns on exposed body parts like the ear and skin; Eye injuries due to hot and flying sparks, slags, or metal chips; Reduced vision due to prolonged exposure to heat	Workers take rest breaks	4	3	12 Medium	Inadequate control measures to prevent or reduce exposure of workers to heat Workers performing tasks under hot sun

(continued)

Table 3 (continued)

Task	Hazard	Risk analysis		Risk assessment				Clarification of the RR
		People at risk/ exposure time	Consequence	Existing control measures/ effectiveness	L	S	RR	
Painting of welded materials	Exposure to Ultraviolet (UV) radiation	Workers involved in the task (Welders, painters, workshop supervisor)/8 h a day	Burns on exposed body parts like the ear and skin; Eye injuries due to hot and flying sparks, slags, or metal chips; Reduced vision due to prolonged exposure to heat	No control measures in place	4	2	8 Medium	Workers performing tasks under hot sun
	Metal fumes	Workers involved in the task (Welders and the colleagues nearby); Visitors/8 h a day	Bronchitis; Metal fume fever; Pulmonary granulomatous disease due to chronic beryllium exposure	No control measures in place	5	3	15 High	No existing control measures are in place to protect workers from exposure to toxic gases
	Exposure to Toxic gases like acetylene, carbon propane, carbon monoxide and helium	Workers involved in the task (Welders and the colleagues nearby); Visitors/8 h a day	Bronchitis and lung fibrosis due to mineral dusts and gases; Respiratory tract illness	No control measures in Place	5	2	10 Medium	No existing control measures are in place to protect Visitors from exposure to toxic gases
	Exposure to solvents and paints	Workers involved in task (Painters) /8 h a day	Respiratory tract illness; Skin and Eye irritation	No control measures in place	3	4	12 Medium	Workers using leadbased paints

(continued)

Table 3 (continued)

Task	Hazard	Risk analysis		Risk assessment				Clarification of the RR
		People at risk/ exposure time	Consequence	Existing control measures/ effectiveness	L	S	RR	
Welding at height on a ladder (2 m high)	Height	Workers involved in task(Welders)/2 h a day	Injury leading to fracture due to fall from height; Death due to fall from height	No control measures in place	3	4	12 Medium	Workers performing welding tasks at a height above 2.5 m
Welding process including connecting electrode and actual welding	Electricity	Workers involved in Electrocution; task (Assistant welder vere burns; long and Senior Welder); team effects Visitors/8 h a day	nervous system Death	Se-Adequate insulation of electrical on wires	4	4	16 High	Bare wires without insulation

* L = likelihood; S = Severity; RR = Risk Rating

4 Discussion

The results of the hazard identification indicate that 12 hazards were identified belonging to the various categories of hazard such as physical, chemical, accident and ergonomic [11]. Some of the hazards such as noise, electricity, metal fumes, ergonomic and accident hazards that were found present in the study workshop were also identified in similar previous studies conducted in a welding workshop [12, 15]. However, exposure to wild animals such as snakes was unique to this study workshop compared to similar studies conducted in Indonesia and Malaysia [12, 15]. The detailed risk assessment of each hazard found in the welding workshop is presented in Table 3. From the analysis of the identified hazards, noise posed a significant risk level followed by electricity, metal fumes and toxic gases; all of them attained a risk rating of high. Prolonged exposure of people to noise above the exposure limits of 85 dB(A) (ILO exposure noise limits), can cause hearing loss, lack of sleep, irritability, heartburn, indigestion, ulcers, high blood pressure, and heart disease [16]. The Major source of noise at this welding workshop was from the three operational generators with each emitting noise levels of 104 dB(A) above the permissible levels. This poses a considerable risk to people working in the workshop and the residential homes neighbouring the welding workshop due to the nonexistence of control measures for reducing the significant noise levels.

The electrical hazard at the workshop exposed the workers to an elevated risk of electric shock, burns, fire outbreak and explosion. This can be attributed to the poor electrical connections and insulations of wires from the generators to the welding electrode [17]. From the information obtained during the interview, one electrical failure incident occurred in the workshop. Therefore, the risk of fire and electrical shock remains high and needs to be addressed by insulation of the bare wires and the maintenance of electrical equipment [2]. In Table 4, the control measures were discussed.

The generation of welding fumes, vapours and dust were also evident, this may expose the welders to a variety of toxic airborne contaminants including manganese (Mn) and hexavalent chromium (CrVI) [18]. However, no control measures were in place to prevent and reduce the exposure of the welders. In other studies, the exposure of welders to metallic fumes have been associated with diseases such as lung cancer and other respiratory illnesses [8, 19]. To reduce exposure to these toxic gasses' measures like local exhaust ventilation has been found to reduce welding fumes exposure to total particulate matter of manganese (Mn) and hexavalent chromium by 40–50% [18].

The study found that the use of masks and personal protective equipment were not in place in the evaluated workshop, this could result into the development of respiratory diseases and other occupational injuries among the welders as evidenced by earlier studies [4, 5, 8, 19]. Earlier studies also shows that 59.7% of the electric/arc welders suffered eye injuries as compared to 40.3% in gas welding [4]. This risk could be higher in the study workshop since it was evident that none of the workers were using eye protection gadgets when welding. The workshop manager reported that he

had previously provided the workers with personal protective equipment (PPE) like welding goggles, heavy duty hand gloves, welding aprons and safety boots however the workers reported that they do not feel comfortable when working with the PPE on as it slows down their work. One of the attributing factors to non-compliance to PPE wearing is attributed to the low levels of education among the workers and the lack of training on the importance of PPE wearing. Training of workers on the use and maintenance of safety gears is vital to ensure compliance.

5 Conclusions

The study identified several welding hazards, including their sources, and the health and safety risks to the people exposed to them, see more in Table 2 found in the result section. It also further examined the risk factors for all the identified measures and proposed their specific control measures.

The results of this study show that noise, electricity, and toxic gases may lead to high-risk consequences, while ultraviolet radiation, manual handling, and repetitive movement to moderate risk consequences.

This was based on the likelihood and severity of the risks using the 5×5 risk assessment matrix found in Table 1. The identified hazards were also proposed control measures to reduce their risk level to an acceptable level using the hazard control hierarchy.

During the study it was very evident that the welding workshop did not have adequate hazard control strategies to minimise or prevent exposure of its workers to dangerous and hazardous conditions and yet according to ILO Convention 155 article 16 and South Sudan Labour Act of 2017, employers are required to ensure that so far, as it is reasonably practicable, the workplaces, machinery, equipment, and processes under their control are safe and without the risk to health.

To fulfil this requirement, the owner of the welding workshop needs to implement the hazard control measures listed in Table 4. Implementation of those measures would help reduce and prevent accidents in the workplace, improve the morale of workers towards work due to reduced incidents and accidents. Also, it helps improve the business reputation of the company and financial losses that may arise due to loss of equipment or cost of treatment of workers.

This study focused on the use of qualitative data for capturing information and analysing data. Therefore, it is recommended that future studies focus on both qualitative and quantitatively methods to accurately quantify the risks posed by the different hazards for example the noise and toxic gasses which are significant to health and safety of welders.

Table 4 Control measures for identified hazards

Hazards identified	Proposed control measures
Ergonomic hazards such as manual handling and repetitive movement	• Use of mechanical lifting aids like trolleys. No worker should be involved in lifting an object that might be too heavy for them - Workers should carry small loads at a time;
	• Use of two-person technique when carrying heavy objects;
	• Training of workers on proper manual handling procedures
	• Initiation of heating up exercises every morning before start of work;
Accident hazards like sharp and protruding objects	• Guarding of unprotected machine edges and sharp objects
	• Proper housekeeping practices should be maintained at the workshop to prevent injuries from sharp and protruding objects;
	• Introduction of standard operating procedure for handling and storage of materials;
	• Use of personal protective like gloves and safety boots with steel cap
Noise	• Connecting the workshop to government metered electricity source to prevent the noise generated from the use of welding generators
	• Replacement of noisy welding generators with those producing lower levels of noise;
	• Redesigning of generators by Installation of noise silencers to reduce the level of noise being generated;
	• Relocating all the welding generators away from the working area to reduce the level of noise being generated at the work area by isolating workers from the source of noise;
	• Installation of soundproof and sound absorbing materials in noisy areas to reduce the level of sound generated to the neighbouring homes and the workshop itself;
	• Introduction of work shifts to reduce the exposure time of workers to noise level;
	• Performing a noise level risk analysis to determine risk posed by the different noise sources;
	• Training of workers at the workshop on the effects of noise on people's health. This training can be offered during the toolbox talks time;

(continued)

Table 4 (continued)

Hazards identified	Proposed control measures
	• Setup of a health surveillance program for the welders; • Developing a work plan for preventative maintenance for all equipment; • Provision of personal protective equipment like earmuffs and ear plugs to workers and visitors to reduce the level of noise being exposed to
Heat	• Installation of working shade to reduce exposure of workers to radiant heat direct from the sun; • Taking of rest breaks to reduce exposure of workers to heat generated by welding operations; • Introduction of work in shifts to reduce exposure of workers to heat generated by welding operations; • Provision of clean and cool water
Exposure to Ultraviolet (UV) radiation	• Installation of working shade to reduce exposure of workers to radiant heat direct from the sun; • Work should be performed under shade to reduce exposure to UV radiation; • Use full cloth protection, gloves, and face shields to prevent burns
Chemical hazards such as exposure to metal fumes and toxic gases like acetylene, propane, carbon monoxide and helium	• Use of local exhaust ventilation to extract toxic metallic fumes in the workshop • Welding should be done in an open environment to reduce inhalation of toxic gases • Replacement of hazardous welding materials with less hazardous ones to reduce exposure to toxic metal fumes; • Rotation of workers according to shifts to limit exposure to metal fumes; • Introduction of Method statements and safe operating procedures for welding; • Training of workers on the health risks generated from welding operations; • Setup of a health surveillance program for the welders; • Provision of personal protective equipment

(continued)

Table 4 (continued)

Hazards identified	Proposed control measures
Exposure to solvents and paints	• Replacement of hazardous paints and solvents with less hazardous ones through the procurement of lead-free paints; • Provide training for workers on painting procedures; • Setting up of a health surveillance program for the painters; • Obtaining chemical data sheets for the paints and solvents used in the workshop; • Provision of personal protective equipment such as gloves, mask, safety goggles and face shield for the painters
Height	• Where practicably possible no welding should be performed at height; • Use of appropriate working platforms when working at height; • Working platforms should be thoroughly inspected and mounted before any work at height can commence; • Use of fall protection equipment when working at height
Electricity	• Fixed wiring should be done in the workshop to prevent hazards posed by loose cables. Insulation of all electrical equipment Protect electrical cables from sharp objects or other materials to ensure that they are not damaged; • Ensure that the welding rod holder is properly insulated before turning on the power source to prevent electrocution of the worker; • Organizing of the working space in the workshop to reduce exposure of workers to electricity; • Insulations and Earth connections must be tested • Avoid welding in wet surfaces or wet conditions to prevent electric shock; • Welding and associated equipment needs to be maintained in a safe condition • Always turn off the welding transformer whenever not in use to prevent electric shock in the workshop; • Work on electrical equipment should be conducted by competent persons

(continued)

Table 4 (continued)

Hazards identified	Proposed control measures
	• Always wear Personal Protective equipment like hand gloves and safety boots when in the workshop
	• Wear dry heavy duty hand gloves when replacing the electrode

Acknowledgements This study was conducted with the support, cooperation, and participation of the workers at RIZIK Metal Workshop.

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A Digital Communication System for Occupational Safety and Health: Requirements Identification and Prototype



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Abstract Shifting the communication process in the Occupational Safety and Health (OSH) field to digital can bring advantages to risk management. A digital communication system can help ensure that all workers find it easier to report hazards, accidents, and near misses. Additionally, it can make possible access to several prevention information. Since companies typically lack this type of solution, this work aimed to

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identify the requirements of an OSH communication system and propose a prototype. To this end, a company in the construction and maintenance sector was used as a case study. Information was collected through visits to a construction site, interviews with the workers and a focus group session. The results showed the company's interest in modernizing communication methods and dematerializing the accidents and near misses reporting. The system can be used to improve information management and maintenance activities. As a result, a prototype for a digital communication system was proposed, contributing to simplifying processes for all end users. However, it must be safeguarded, that the prototype describes preliminary results for the system to be developed. Further studies are ongoing to obtain the final solution.

Keywords Communication · Dangerous situations · Digitization of information · Occupational accidents · Technological advance

1 Introduction

According to data made available by Eurostat, every year, in the European Union, more than 3 thousand workers die as a result of occupational accidents or occupational diseases [6], and more than 3 million workers are involved in non-fatal accidents [7]. Thus, companies must have to continue developing and implementing strategies that reduce workers' exposure to occupational risks, promote a safety culture, including both current risks and emerging risks, and consider the technology as a tool to improve professional risks management [4, 13, 14].

Technological evolution and process digitization have contributed to innovation in the workplace. However, it also entails new challenges for Occupational Safety and Health (OSH) [5]. Companies must continue to develop and implement strategies that reduce workers' exposure to work risks, which promote a safety culture, including both current risks and emerging risks, and that take into account that progress technology can also be a tool to improve the management of professional risks [4, 13, 14].

According to [17], digitization's growing importance is revealing the need to store and process data related to business processes, which is becoming increasingly relevant for companies in their investment choices. Information systems not only help to manage current and to optimize business processes but also create significant changes and new opportunities for companies.

This study aims to facilitate communication between teams and related personnel by creating an efficient and simple communication system to help these stakeholders in better and faster decision-making. This is particularly critical when workers work in dispersed teams and are not always close to the OSH teams, which is particularly relevant in the construction and maintenance sector. Digital communication systems can help them to report accidents, near misses and non-compliance more quickly, contributing to faster responses to critical scenarios and anticipated problems and accidents. Additionally, as the process is easier and more dynamic, it may encourage

workers to report relevant daily activities. However, its implementation has clear barriers, such as workers' literacy and difficulty in using the technology.

Developing a specific platform for managing communication would be of great interest to every company, because it would facilitate the OSH Team tasks, by registering all valuable data for accidents, near misses or even unsafe conditions. Even the Maintenance Department's activities can be improved, by accelerating their process of shipping new material or when old material needs to go to the factory for maintenance, once they would receive the information in real-time through the platform we present. Thus, the implementation of this platform could not only improve the feeling of safety of their workers but could also result in companies' competitive advantages.

2 Materials and Methods

2.1 Case Study Description

For supporting companies' daily activities related to safety and communication, an informatic platform was idealized considering the reality of a company dedicated to the building of electricity transmission and distribution networks, which currently operates in Portugal, France and Germany. Among its main activities are the following: assembly project for low, medium and high voltage overhead and underground lines; construction and maintenance of substations; construction, cleaning and maintenance of medium voltage electrical transformer stations; voltage work at low, medium and high voltage levels; construction, transformation and maintenance of low, medium and high voltage underground and underground electrical distribution networks; construction and maintenance of very high voltage power lines.

The company activity has some particularities considered relevant by the research team for developing the platform: workers are exposed to several risks that can result in serious accidents; there are several work sites with small teams; several workers have low instruction levels; there are foreign workers, from Brazil and Portuguese-speaking African countries (PALOP).

2.2 Study Design

In the first part of the study, the necessary information to define the system requirements was collected, such as functionalities and interface. To this end, forms related to notifications and reports were analyzed, a focus group session with the stakeholders was conducted, a visit to a work site and in-loco interviews were conducted. Based on the information collected and considering the needs and concerns of the stakeholders observed, a system prototype was developed.

2.3 *Focus Group*

In this project, a focus group session was held for gathering information about the organization's communication through the platform, the information that should be shared with stakeholders, the expected difficulties in using an informatic application and how to get around such difficulties. The session had the voluntary participation of three company elements considered specialists: the leader of the OSH Team, an OSH practitioner, and a maintenance technician.

To prepare for this session, it was necessary to define the main issues to be addressed and build a script with key questions to help conduct the discussion. A researcher was responsible for moderating the discussion, and his/her role was to guide the group, preventing them from straying from the themes. Another researcher was responsible for taking notes during the session.

At the beginning of the focus group, the study purpose and session were explained to all participants. Then, according to the guide created, the following questions were asked:

1. Who will have access to the application?
2. What information do you want to be collected in the application?
3. Who should receive the alerts?
4. Should workers receive any feedback after the reports are made?
5. What pertinent information should the maintenance team receive?
6. At this point, what is the procedure for reporting malfunctions?
7. Who receives the notification? All team members or someone with a leadership position?
8. Will there be difficulties, on the part of the workers, to make the occurrence/ notification reports?

The session was conducted and recorded using the Microsoft Teams¹ platform. The recording collected throughout the session was transcribed in full. Then, the answers of all the focus group participants were analysed to retain the necessary information to propose a communication and information-sharing system prototype.

2.4 *Site Observations and Interviews*

Before developing the prototype, a visit was made to a site to observe how the organization's business processes are managed and how the workers deal with the several safety procedures. Some discussions were taken, exchanging ideas with the workers to understand if they were interested, their opinion about the communication software and possible suggestions that they had to make. Some questions were made of the workers:

¹ <https://www.microsoft.com/pt-pt/microsoft-teams>.

1. What would be the ideal design for the application? (in general terms)
2. Which workers should report the occurrence?
3. What difficulties can arise in reporting the occurrence?
4. Are you available to use a digital platform to report accidents, incidents, and non-conformities?
5. What are the main constraints that you identify to the use of this platform?

2.5 Prototype Construction

The research's first phase took into consideration the requirements of the company and the direct observation of the organization's activities. The requirements associated with worker and communication information that should be managed, allowed us to identify the data to be transmitted and the information flows to be adopted in the company under study. Through this data, the communication system architecture was developed.

To start the system architecture design, it was essential to know, conveniently, the organization hierarchy, to which contributed the visits made and the focus group. Furthermore, the concrete definition of access control applied to stakeholders was fundamental to subsequently understanding the information lifecycle for each one of the business processes. In the second phase and to complete the system architecture and build the system prototype, the perceptions, opinions and suggestions collected in the focus group session held with stakeholders were taken into consideration. The prototype development was carried out in the form of an app for mobile phones, through the free online design application. A mockup is a simple sketch of the user interface with the application [15], which facilitates the software understanding and simply demonstrates the features through quick moulding [16].

3 Results and Discussion

The company used as a case study showed the need and willingness to improve communication between the work teams with a focus on safety events. One of these improvements is the information systematization and the development of an informatic application (app) to facilitate communication. In that way, OSH can be improved.

“To improve safety in different working settings (...) by the development of a tool for online reporting of site occurrences, in real-time.” (Leader of the OSH Team)

Also, Zou et al. [20], suggest that informatic systems are important to improve construction safety performance by promoting real-time communication and supporting decision-making and action-taking. These systems can contribute to preventing risks at work [2].

To create a communication system suitable for the company's workers, it is important to understand how the information will best be presented. Thus, it is possible to build a system that is customized and suited to the organization's reality. Therefore, selected stakeholders were asked how they consider that the information should be presented in the app.

3.1 Workers

During the observation visit, some workers were asked about the implementation of a digital communication system.

"(...) it is important that it is a quick way to communicate and that it does not take too long. Also, it must be easy to understand." (Worker 1) *"The simpler and more practical is ideal (...) if it is difficult, I don't make any record."* (Worker 2).

This concern is also mentioned by [1], who state that communication systems, as well as shared information, should take as a reference the ability of comprehension, decision making and cognitive or distractive overload of the workers. Haas and Van Erp [8], add that screens should convey only the necessary information and the speech adopted should not be contradictory or confusing, so through short sentences it will be easier to easy to approach a simple and perceptible speech by any worker. Chu et al. [3], found that all their participants preferred to read something shorter and more concise rather than a paragraph.

"(...) little text and very graphic information (...) should be more attractive." (Worker 2).

Laughery and Wogalter [9] argues that for OSH warnings be effective, they need to grab the attention and influence the knowledge and decisions of those who perceive them, which is in line with the opinion of those present at the focus group session. Vigoroso et al. [18], found that the use of realistic visual images helped participants to identify contexts and tasks, and was considered good means of communicating occupational risks, rules, and safe practices. According to [3], there is a preference for brightly coloured and shiny images, as they attract the users' attention. In general, the participants in the above-mentioned study were interested in bright colours, and colourful and real images rather than drawings, which should only be used in situations with sensitive content, making them more realistic information.

"Everyone should have the resources to communicate but I think it is the foreman who would have a relevant role in communicating the events." (Worker 3).

"(...) sometimes we are in places with no network so it can be difficult to communicate immediately in the app." (Worker 4).

According to the evidence demonstrated above, it is essential user interaction with the target platform should be simplified to allow workers to access it autonomously and without difficulty.

3.2 Occupational Safety and Health Team

From the perspective of the OSH practitioners that participated in the focus group, the communication platform development is a way to reduce the underreporting of occupational accidents and near misses. In fact, it is expected that in the future, mobile devices will dominate fixed electronic devices, and it will be through these means that workers will have greater interaction [19], contributing to improving different kinds of reports in the field of OSH.

In this view, it is relevant to consider a communication system that allows workers to share information with the OSH Team at any time and place, preferably through mobile devices. This information sharing has a great advantage because there is a collaboration between those who know the work and the conditions for its development [2]. This is in line with paragraph d) of point 1 of article 17 of Law No. 3/2014, of January 28, which determines that it is part of the worker's obligation to help the company improve the OSH system. Thus, the platform to be developed should allow access to any worker wishing to report accidents and near misses.

"Workers who suffer an accident at work or are faced with a near miss should be able to report it, immediately." (Leader of the OSH Team).

To optimize the platform and make it even more complete it was found that it would be useful to include the reporting of dangerous conditions and maintenance needs of work equipment. This is related to paragraph e) of point 1 of article 17 of Law No. 3/2014, of January 28, which states that workers must immediately report to their supervisor the malfunctions and deficiencies they observe.

"When I devised this, I thought of three fields, accident, near miss, and non-conformity or malfunction." (OSH practitioner).

"The maintenance team could be included in this process since all equipment is identified with an internal number it will be possible to easily identify faults and maintenance needs." (OSH practitioner).

"The detected dangerous conditions may also be reported through the application." (OSH practitioner).

In addition, the platform should collect information regarding the accident, such as the identification of the person making the report, the place, the time, the day, the description, and some photographic records.

Having identified the main communication needs, the experts were asked about the information receivers. It was suggested that accident and near-miss alerts should be sent to the safety teams, responsible for their investigation and treatment. Alerts related to unsafe conditions should be received by the OSH and Maintenance team. In addition, all equipment maintenance needs should be directed only to the Maintenance team.

"(...) a breakdown would be immediately referred to the Maintenance manager, an incident and accident should be referred to safety and the site manager." (OSH practitioner).

One of the requirements raised by the OSH Team present at the focus group was the simplicity of the communication platform. This idea is the same for the workers.

“Simple, concrete, and schematic communication. When I say schematic, I mean having an image.” (OSH practitioner).

After receiving the alerts each responsible team should put into practice the best diligence giving, in real-time, the biggest and best follow-up to the situation received.

“The safety team after receiving the communication of a work accident should have access to the most relevant information to be able to act quickly, both in the investigation of the accident and in the implementation of measures.” (OSH practitioner).

As Vukicevic et al. 19 suggest, the application should be thought to send an automatic response, to reports made by workers, with instructions, built by safety managers and maintenance engineers, for immediate implementation.

“Yes, one could think of a feedback mechanism for the workers. We could think about a response that tells them that we have received the information and it is being processed. Or indicate the measures that can be applied.” (Leader of OSH Team).

From the perspective of [11], the effectiveness of the communication process is dependent on a clear and objective implementation strategy. Without a well-defined strategy that demonstrates the objectives to improve communication between the company's stakeholders, a modern and optimized system will not be able to achieve the ends by itself. Thus, the experts were asked about the strategy to attract employees to use the application. This question was left open, with the suggestion of implementing a rewarding (with gamification elements) system that would value the workers who make the reports. However, it was mentioned that the most important requirement to captivate workers would be the construction of a simple interface, but one that would collect essential information.

According to the evidence demonstrated above, it is essential to change communication in the organization under study. Therefore, for the prototype development, the Specialist's perspective was considered, who consider the construction of a digital application accessible to all workers a good way to solve the underreporting of accidents, near misses, unsafe conditions, and malfunction in equipment.

3.3 Maintenance Team

From the perspective of the maintenance team present at the focus group, the platform will simplify equipment traceability, i.e., to know which equipment is malfunctioning and where it is being used.

“It is important to specify the internal number of the equipment and the description of the fault in order to try to proceed with the correct treatment.”

“the photographic register is fundamental because the breakdown can be immediately identified.”

The implementation of the digital platform in the company will help to implement a more effective equipment maintenance plan. Also, in the Vukicevic et al. 19 perspective, the communication of this information enables task prioritisation.

“a request is made to treat the broken equipment (...) this treatment can last days/ weeks, it is not immediate.”

Vukicevic et al. 19, suggest the responsible person receives a notification and creates an action (task) concerning the collected information. In this way, the responsible person will initiate a process to deal with the malfunction in equipment more effectively.

“(...) the notification should be addressed to one person, the person in charge of the maintenance team (...) start the equipment maintenance plan.”

They were also asked about the difficulties workers would have in making the notifications.

“There are workers who have difficulty using technology (...) but some training will be required.”

In the view of [12] organizations must ensure their employees have the right skills and competencies as they undergo a digital transformation so workers must be informed about the platform implementation of digital communication systems and how they should be used.

3.4 *Prototype the Communication System*

According to the evidence demonstrated above, it is indeed essential to change and modernize communication in the organization under study. Therefore, for the prototype development built for the communication system, the stakeholders' perspective was considered.

After opening the application on the mobile phone, the main menu will appear where workers must enter their credentials given by the company “Username” and “Password”, as shown in Fig. 1. The application can also be accessed through the “Anonymous” option. This was a situation addressed in the focus group because there are workers who do not want to identify themselves when recording an event. Then a request will appear for information on the number of workers that are reporting the event, but they do not know, they can just enter the town or city. Next, the 4 types of events that can be reported will appear: Accidents, Near Misses, Unsafe Conditions and Malfunction in Equipment, as shown in Fig. 1.

Selecting the option “Accident”, will appear to write the claimant's name and if possible, the number that is associated with the worker. Then, a new screen will appear to characterize the accident type as Serious or Minor. After selecting the accident type, the worker needs to describe what happened using text or voice messages. Finally, the option “Select photo” will appear (optional), allowing users to use the equipment camera to record visual evidence (Fig. 2).

Selecting the option “Near Misses”, will appear to describe what happened, and you have the option of a text or voice message, and if possible, upload a photo, as shown in Fig. 3. Selecting the option “Unsafe Conditions”, as shown in Fig. 4, will ask for the same information as for the “unsafe conditions” option.

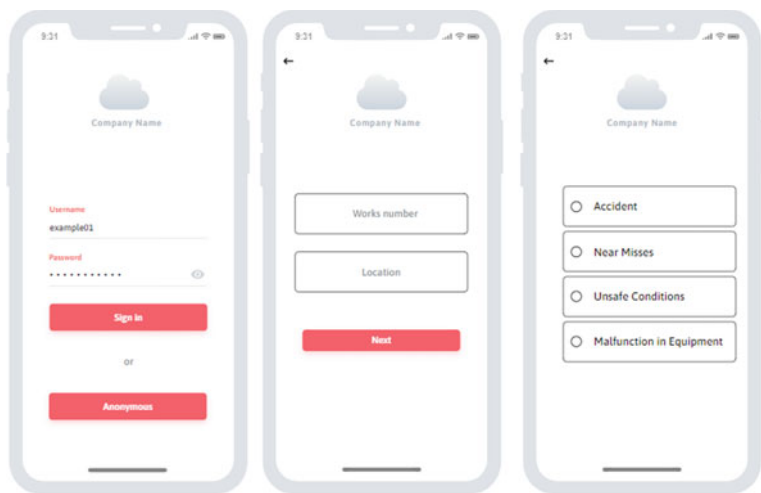


Fig. 1 App login and report options

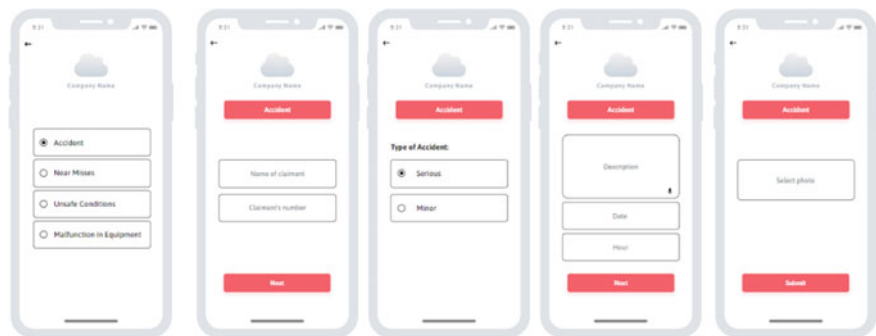


Fig. 2 Information collected for the accident report

Selecting the option “Malfunction in Equipment”, as shown in Fig. 5, the worker needs to indicate the equipment’s internal number, and a description of the malfunction, and it is essential to upload a photographic record.

All occurrences’ records will be notified to the responsible OSH team and only, the notifications of “malfunction of equipment” will be forwarded to the Maintenance team responsible.

The figure shows two smartphone screens side-by-side, representing a digital communication system for occupational safety. Both screens have a status bar at the top showing the time 9:31 and signal/battery icons. Below the status bar is a back arrow and a cloud icon labeled 'Company Name'.

The left screen displays a form with four radio button options:

- ☐ Accident
- ☒ Near Misses
- ☐ Unsafe Conditions
- ☐ Malfunction in Equipment

The right screen displays a form with the following elements:

- A red button labeled 'Near Misses' at the top.
- A text input field labeled 'Description' with a microphone icon at the bottom right.
- A button labeled 'Select photo' below the description field.
- A red button labeled 'Submit' at the bottom.

Fig. 3 Information collected for near misses

4 Expected Impact

The group of investigators identified some positive aspects of the prototype implementation and divided them into 4 different categories: Natural, Social, Economic and Political. Firstly, the use of this environmentally friendly platform provides a solution for collecting data without an ecologic footprint, since the use of paper to store all the data is rejected. Socially, the goal is to ensure workers' safety and contribute to their family's well-being (reducing the risk of injury that could result in financial losses or physical damage). Health system sustainability would also be an impact since fewer injuries from the community would occur. Economically, the use of the platform would provide valuable data to help in accident prevention and risk management, resulting in fewer insurance costs and therefore an increase in the company's productivity. It would also be a critical factor for improving equipment management, as well as accelerating the maintenance process of shipping the equipment for maintenance or accelerating its availability in case of failure. Thus, a company with this platform would have a competitive advantage over others in the market. The development of this platform/application would be of great interest to the government since the statistical data obtained through the platform could assist in the creation of more appropriate legislation. Also, the platform implementation

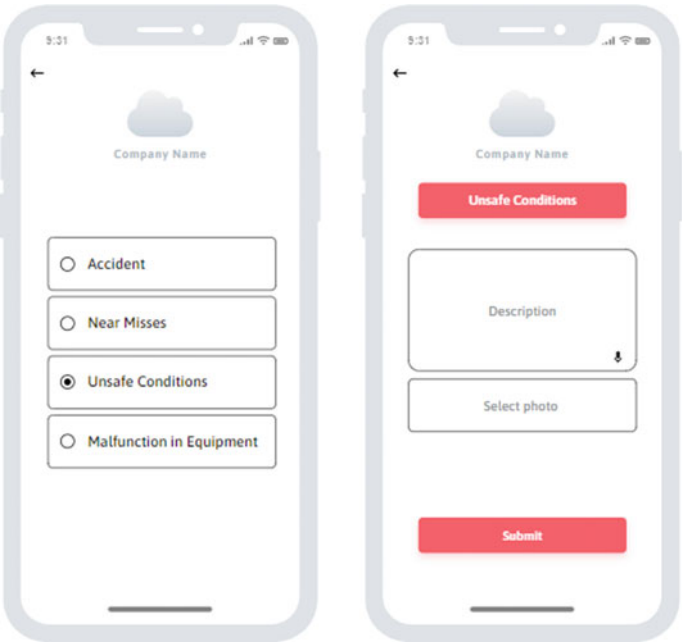


Fig. 4 Information collected for unsafe condition

could in the long run reduce the number of work-related accidents and consequently reduce the costs related to temporary disability pensions.

The figure displays two smartphone screens side-by-side, representing a digital communication system for occupational safety and health. Both screens show a status bar at the top with the time 9:21 and signal indicators. A cloud icon and the text 'Company Name' are centered at the top of each screen.

The left screen shows a selection menu with four radio button options: 'Accident', 'Near Misses', 'Unsafe Conditions', and 'Malfunction in Equipment'. The 'Malfunction in Equipment' option is selected, indicated by a filled radio button.

The right screen shows the form for reporting a malfunction in equipment. It includes a red button labeled 'Malfunction in Equipment' at the top. Below this are three input fields: 'Internal number', 'Description' (with a microphone icon), and 'Select photo'. At the bottom is a red 'Submit' button.

Fig. 5 Information collected for malfunction in equipment

5 Conclusion

The current communication process in the company has faced difficulties in reporting occurrences, accidents, near misses, unsafe conditions, and equipment malfunctions in real time. As a result, various events have been underreported. To overcome these obstacles, a platform for enhancing communication has been proposed. This platform will be an essential asset for the company as it will facilitate the work of the OSH team and can contribute to the implementation of more effective measures that workers can adopt to preserve their safety, ultimately resulting in a decrease in accidents and near-misses. Additionally, it can improve organizational aspects, leading to increased productivity. The maintenance team can quickly identify faults in equipment and maintain documentation, which can prevent future failures.

The platform discussed in this work can increase the company's value in the labour market by showcasing technological innovation. Moreover, it provides the company with a competitive advantage in the market. By embracing this platform, the company can establish itself as a forward-thinking organization that prioritizes its employees' well-being and safety.

Despite the relevance of the proposed platform, it is important to acknowledge that certain challenges may arise. The most critical challenge is worker engagement. Without engagement from workers, leaders, and other stakeholders, the platform will not be of utility to the company. To overcome this challenge, it is necessary to create awareness among workers and other stakeholders about the benefits of the platform. The company can conduct training sessions to educate workers about the platform's features and how it can be used to enhance safety, prevent accidents, and improve productivity. Additionally, it is important to ensure that the platform is user-friendly and accessible to everyone, regardless of their technical abilities and academic level. This was one of the main concerns in our work until the moment. Finally, the company can incentivize workers to use the platform by offering rewards for its use or incorporating its use into performance metrics.

Acknowledgements This work was funded by the project *Link Me Up—1000 ideias*—POCI-03-33B5-FSE-072070.

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Linguistic Adaptation for the Preventive Action Control in Construction Work Environments



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Abstract In the field of construction works, the results of applying the various occupational risk assessment methodologies, both qualitative and quantitative, are communicated to the workers. However, this communication procedure is complex due to its difficult temporal application and complicated interpretation. This study aims to analyse the mathematical results of the Preventive Action Level method to determine the appropriate linguistic communication procedure for the control of preventive action, establishing the bases for safety evaluation. Methodologically, the difference in concept between risk assessment and safety assessment is raised. It is considered that, to determine adequate communication in the construction work environment, more knowledge is required in the discipline of neuroscience that considers social behaviour, the construction environment, and the act of communicating. This communication procedure implies the need to implement body sensors and materials for monitoring to establish a linguistic basis for human-machine environments through artificial intelligence.

Keywords Health and safety · Risk assessment · Communication · Construction · Preventive action · Safety assessment

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1 Introduction

Traditionally, on construction sites, the application of prevention procedures that jointly contemplate Occupational Safety, Industrial Hygiene, Ergonomics and Psycho-sociology techniques has been complex [22]. Risk assessments in construction sites require a detailed study of the different risks [27], applying subjective (qualitative) or objective (quantitative) analysis criteria [28]. Although the evaluation criteria are usually oriented individually in each risk-fighting technique [13], the processes in the construction industry offer a complexity that requires joint risk assessment in different areas such as management, organisation, environmental planning, human resources, and materials [23], auxiliary resources, machinery, preventive safety systems and safety training for workers [13]. Adding personal relationships, roles, safety climate and safe behaviours [10]. Currently, occupational risk assessment procedures are being developed and adapted to the characteristics of the building process [26], from the initial approaches to prevention in business action and project conception [3, 35], going through the study of prevention in the project phase and during the building construction phase [30, 33]. Recent research indicates the need to incorporate the safety climate due to the uncertainty generated by human behaviour in risk prevention [4, 33], which requires analysing psychosocial risks throughout the company's hierarchical structure [17]. It is essential to establish the bases to define a model that brings together all the possibilities of analysis in the field of construction sites [8, 9]. Different occupational risk assessment methods consider, among others, the basic parameters of probability, consequences [19, 29], frequency and degree of risk exposure [11]. Van der Molen et al. [34] proposed developing prevention in design, previous constructive solutions, and planning and control of tasks [34]. Forteza et al. [13] previously reported on the building work environment based on the agents, their functions, type of work and work phases, assessing general safety conditions, the work unit, the safeguards and the means [13]. Pinto bases his QRAM methodology on the Event Tree, analysing the safety climate, severity factors, possibility factors and safety barriers [23]. Reyes et al. unifies criteria for decision-making and evaluates the consequences in the building life cycle [24]. Sousa et al. analyse construction sector accidents and determine suitable measures in the planning and organisation of the work, minimising more than 60% of accidents and managing health and safety during the building life cycle [20]. Finally, Gil Beltrán et al. [16] highlight psychosocial and ergonomic factors, being overconfidence and forced postures the construction accidents leading causes [16]. All these analysed methodologies offer results based on visual inspections on site and by following a checklist. Subsequently, an analytical study (qualitative and quantitative) is provided based on past construction situations, leaving the result as a statistical and information reason for future risk situations.

With the results obtained, it is essential to implement the measures to be taken as soon as possible. This implementation must be provided through communication between the security coordinator and the different hierarchical groups of the company. The communication procedure activates the promotion and working

conditions improvement, generating the need to participate in preventive actions [12] and considering the different participative environments in this communication (documentary, constructive, and social) [6, 7]. This develops a personal attitude towards decision-making, creating a preventive culture among the different hierarchical company groups. Nevertheless, construction workers' attitude is influenced by their risk perceptions, management, safe roles, and communication procedures [15]. A correct or incorrect organisation can influence safety climate perceptions, motivating safe action [31]. It is essential to establish bases for participation in prevention systems between employers and workers [31], setting aside bureaucratic and economic roles and requiring greater involvement of all construction agents [18].

Based on the arguments above, it is essential to discuss what this communication is and how it occurs in the construction sector [1]. The most significant difficulty occupational risk assessment methodologies have is exposing the risk improvement criteria. It is essential to consider the basic knowledge and optimal communication environments as well as the positive and negative influences [2, 32].

The objective of this study is to analyse the control criteria of preventive action based on the risk assessment method defined as Level of Preventive Action (Lpac) and to determine the linguistic adaptation to transmit the results of risk assessment in the construction work environments and immediately after data collection.

2 Methodology

2.1 *Lpac Methodology*

The Lpac is an occupational risk assessment methodology adapted and adjusted to construction works' "special" complexity [6]. The parameters of the Lpac observe the building work reality in each preventive environment: initial, documentary, constructive and social [7], comprising four techniques to combat risk: Safety at Work, Industrial Hygiene, Ergonomics and Psychosociology. Lpac parameters are: in the Initial Environment, Probability (P) and Consequences (C); in the documentary environment, Relative Risk (Rr) and Border Risk (Br); in the construction environment, degree of exposure to risk (E) and Economic Capacity (Ec); and in the social environment, Participatory Interest (Pi) and Level of Satisfaction (Ls); and its mathematical expression (1) is:

$$Lpac = (R_{ab}) \left(\frac{R_r \cdot B_r \cdot E}{E_e \cdot P_i \cdot L_s} \right) \quad (1)$$

2.2 *Preventive Action Control*

The evaluation procedure begins with the risk analysis of the Health and Safety Plan, technical observation, and a psychosocial survey. The characteristic values for each parameter are obtained, and their incidence on each risk to be evaluated is interpreted [5].

The result indicates the preventive action amount that is required. Therefore, the concept of preventive action is focused on an optimal control situation or “Safety Assessment”. Next, individual recommendation criteria are determined (in parameters and risks); and global in nature (in disciplines and construction processes).

Depending on the result, the method determines preventive action controls, identified by colour, which are called [5]:

- Optimal Control (light blue). Values less than 4%;
- Adequate Control (dark green). Values between 4 and 12%;
- More Control (light green). Values between 12 and 20%;
- Greater Control (yellow). Values between 20 and 36%;
- Intensive Control (orange). Values between 36 and 60%;
- Exhaustive Control (red). Values greater than 60%.

Finally, recommendations for system improvement and preventive actions are established, and their progress is verified. In order to achieve optimal control responses, it is necessary to coordinate preventive action with the Health and Safety Plan risk assessment, with the designers through adequate constructive solutions; with the building agents during the work development; and with all people through psychosocial recommendations, in an environment based on the Neuroscience of communication.

2.3 *Communication*

Communication and occupational risk prevention are firmly related to preventive management. Communication is essential to spread the company’s preventive policy, knowledge of existing occupational risks, analyse the situation, find preventive solutions, check the effectiveness of preventive procedures and develop skills for correct action. All this through dialogue, obtaining the people’s collaboration and participation in the constructive-preventive process [14].

In communication, the participants interrelate, establishing an exchange of information through elements such as the information sender, the information channel, the transmission code, body expressions or sounds, the receiver and the response. Communication can be oral or written, incorporating technological systems (such internet, cybermedia, and artificial intelligence) [12].

In communication, research focuses on the brain’s functioning to understand the regulatory mechanisms of controlling human reactions and behaviour. Neurosafety

is based on Neuroscience that seeks how the brain works, its potential and limitations towards risk situations, conditioning the worker's brain and creating safe work habits, safety climate and cultural change [21].

Based on these arguments, considering communication and how it occurs is essential. One of the biggest difficulties that occupational risk assessment methodologies have is exposing the criteria for improving risk conditions.

2.4 Practical Cases

Several implementations of the Lpac method have been made in actual works:

- Building in Madrid (Spain). Building with six semi-detached houses, with a total constructed area of 1,528.26 m². The data collection was in 2016 and 2017.
- Building in São Paulo (Brazil). Twenty-story residential and commercial tower, with a total constructed building area of 4,500.00 m². Data collection was in 2021.
- Building in Toledo (Spain). The expansion project in a Special Education School. The enlarged area was 215.32 m². Data collection was in 2018.
- Stopping Point in Aguda (Portugal). Stop railway adaptation on the northern line of the country. Data collection was in 2021.

3 Results

3.1 Lpac Results

The Lpac method establishes numerical results that show the work's chronological evolution and the preventive action required levels. The results can be extracted with different approaches: the Lpac global result in the preventive environments, prevention disciplines and the chronological result of the Lpac; partial result according to the construction systems, evaluated risks and perception of the environment by the workers; and punctual result, in each one of the parameters and on the workers' behaviour. The graphs of Figure 1 show the chronological results of the Lpac concerning each of the inspections carried out.

These graphs show, on the one hand, the degree of risk that diverges from the initial approach, and on the other, they identify the amount of preventive action required to make the situation optimal.

In each work, the construction process was inspected from beginning to end in Madrid and Toledo. In Brazil, the construction process of excavation, foundation and first levels of the building structure, and the reinforced concrete systems (walls and platforms) in Aguda.

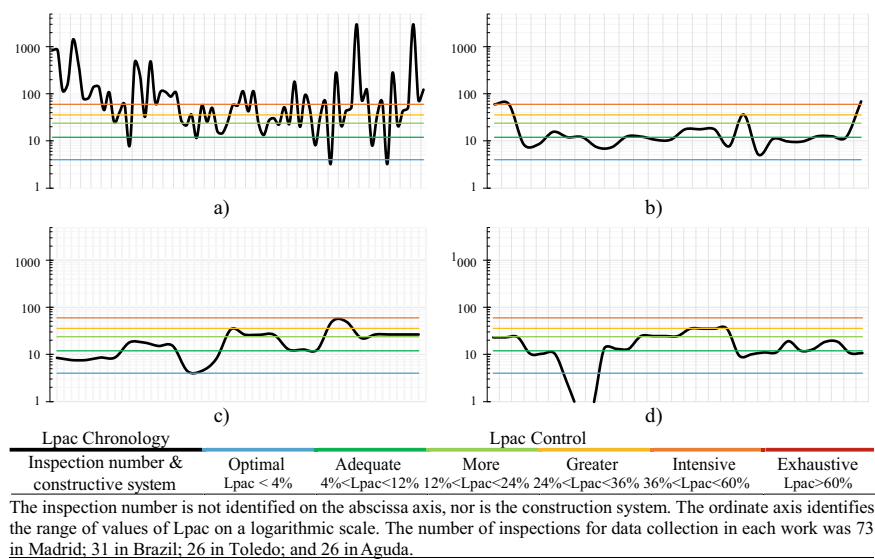


Fig. 1 Lpac chronology. **a** Madrid; **b** São Paulo; **c** Toledo; **d** Aguda

3.2 Communication of Preventive Action Control

The control bases for preventive action are defined in Sect. 2.2. The Lpac results show the preventive action amount that must be implemented to improve the situation to an optimal control level. The term “amount” is interpreted as the tools to be used in the communication procedure, such as text resources, speech, signals, sounds, face-to-face interviews and technological systems. The worse the result of the Lpac, the greater the number of tools to improve the situation.

The preventive action control bases and the number of tools must be adapted with linguistic algorithms to establish a preventive communication environment with the worker.

Depending on the spectrum of results of the control bases, to a greater or lesser degree, the bases of tools for improvement must be considered at a first level of communication. The communication procedure between two or more people may be direct (face-to-face) or indirect (with technological systems), and the tools for improving the situation are:

- **Communication for the improvement of the documentary environment.** The worker is interacted with, informing him of the work unit complexity (Relative Risk) and to remind him of the work unit location (Border Risk) based on the distance to the danger zones.
- **Communication to improve the construction environment.** Interacts with the worker informing him of the intensity of exposure (Degree of Exposure) to the

risk and informing him of the work constructive-preventive procedure (Economic Capacity).

- **Communication for the improvement of the social environment.** The worker is interacted with to inform him of his interest degree in prevention (Participatory Interest) and his behaviour and state of mind (Satisfaction Level) according to the congruence of response concerning the evaluator.
- **Communication with acoustic signals.** The worker has an acoustic device to communicate the degree of nearby risk with different tones and frequencies.
- **Communication with visual signals.** The worker is previously informed where the visual signals are and what kind of risks they show.

In a second level of communication, the control base of preventive action is communicated to the worker, incorporating a linguistic condition of the quantity of preventive perception of the environment and required preventive action. The linguistic conditions are:

- Much more perception and preventive action of the environment is required.
- More perception and preventive action of the environment are required.
- Perception and preventive action of the environment are required.

In the third level of communication, the worker must provide a response containing the expected linguistic elements, which improves the preventive perception of the environment. Preventive action is also required, improving the conditions of the modifiable parameters of the Lpac (Exposure Degree, Economic Capacity, Participatory Interest and Satisfaction Level).

A practical example is presented (Table 1) on a risk assessment of a construction system in the work of Madrid. The results of the Lpac are shown concerning each one of the risks evaluated, each one of the disciplines evaluated and the total Lpac for the construction of a brick factory on the façade located on the first floor. The resulting values of the Lpac correspond to the control base of the preventive action required to ensure an optimal situation.

The communication of the results must follow the following guidelines:

- The global control base requires an exhaustive level of preventive action (total value of $177.29 > 60\%$) to construct the brick factory. The tool base proposes much more preventive perception of the environment with much more preventive action. Through direct or indirect communication, the worker is informed of the values obtained in the evaluation and the parameters that intervene in that value. The fixed parameters are not modified. However, the modifiable parameters can be acted upon. Action will be taken on one of the modifiable parameters: decreasing the degree of exposure, increasing the individual and collective protection systems, increasing their participatory interest in safety, or increasing their level of satisfaction by controlling their state of mind and stress level. The answers that the worker communicates are added to the evaluation, and the improvement of the results is checked.
- The discipline control base requires an exhaustive level of preventive action for Safety at Work, Industrial Hygiene and Ergonomics; and requires a higher level of

preventive action for Psychosociology. The tool base proposes much more preventive perception of the environment with much more preventive action for Safety at Work, Industrial Hygiene and Ergonomics. The tool base proposes more preventive perception of the environment with more preventive action for Psychosociology. Next, proceed in the same way as in the previous section, informing the worker and writing down the answer.

- The risk control base requires an exhaustive level of preventive action for the risks of Different Level, Same Level, Handling of Loads, Thermal, Lighting and Displacement; requires an intensive level of preventive action for the risks of Entrapment and Loads; and requires a higher level of preventive action for the risks of Relationships and organisation. The worker is informed of the risks to which he is subjected. The tool base proposes much more preventive perception of the environment with much more preventive action for the risks that involve an exhaustive and intensive level.

In all cases that the worker is required to respond, he has to communicate his situation to be aware of the perception of the environment and the preventive action to follow to improve the work environment.

Finally, the risk assessment procedure goes to its last phase, verifying the improvement of the Lpac.

The entire communication procedure must follow very specific guidelines with the application of neuroscience concepts, seeking the awareness of workers based on their responses.

4 Discussion

The participation of all building agents and all workers is essential for improvements to be made in the construction works prevention systems. Consequently, in terms of communication, improving a safe climate can be contemplated immediately, so it is necessary to examine the need to implement both material and body sensors in the construction process. The Lpac methodology allows parameterisation and monitoring of data collection. This circumstance allows for increasing the criteria and recommendations for preventive action.

In addition, implementing BIM (Building Information Modelling) technology during building construction is already a reality. It allows automation of the work budget, improves management due to work modifications, view construction planning and programming, analyses energy efficiency, considers materials life cycle, and even manages occupational health and safety with collective protection models [25]. In this aspect, seeking the workers' motivation and participation is fundamental, getting the work teams to collaborate effectively through the people's emotional involvement.

Lpac can be implemented with BIM technology, and the workers' responses regarding the environment's preventive perception and their preventive actions can

be monitored. For this, implementing workers' body sensors and constructive-preventive processes material sensors is essential to communicate preventive actions immediately.

Technological communication systems bring together all the monitored information of the construction process and human behaviour. An artificial intelligence system is required for the communication of preventive action to take effect. Communicating the requirements of the control bases and the control tools to the workers, raising it through two approaches: directly, interacting between two or more people, and indirectly, through artificial intelligence systems that bring together all the monitored information, assessment results and responses.

Based on the previous approaches, the Lpac method can be applied in known environments with data collection and sensorisation. However, it can also be applied to unknown environments by implementing distance, volume, material, and biometric recognition sensors.

5 Conclusions

The scope that the Lpac method allows is clear, with its adaptation to changing and particular construction conditions, so the modifiable parameters of Lpac must be known during the construction process. A linguistic adaptation procedure is essential for the results and responses. Data collection can be monitored by implementing body sensors that measure the individual's biometric variables and their positioning during work development. On the other hand, installing position sensors of different protection systems (such as railings, nets, and helmets). In addition, during the documentary phase, the construction model is incorporated into BIM technology, which implies knowledge of the fixed parameters of the method.

It is necessary to lead the way to ensure the effective communication of the risk assessment. The entire communication procedure must focus on neuroscience criteria to modify the workers' criteria and improve the safety climate during construction. This improves their preventive perception of the environment and work safety conditions. Artificial intelligence systems are fundamental support that facilitates communication between machines and man. In addition, the possibility of recognising the unknown environment is added using sensors to identify distance, volume, material, and biometric characteristics. All the knowledge transferred through these communication systems based on risk assessment from material and human sensors opens the doors of Safety Assessment.

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Occupational Psychosociology and Human Factors

Individual Factors as Predictors of Risk Perception: Mediation of the Physical Safety Climate, in a Sample of Portuguese Workers



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Abstract Risk perception is a phenomenon that has been studied by researchers from different areas of scientific knowledge, as it assumes a crucial role in risk management and intervention and accident prevention. The aim of this investigation was to observe the effect of individual factors (self-efficacy, internal locus of control and mental toughness) on risk perception (RP) and to analyze the mediating effect of the physical safety climate in this relationship, in a sample of 216 Portuguese workers of both genders (Mage = 34.30; SDage = 9.45). The multiple regression analysis showed that the predictive variables considered explained 26.6% of the risk perception, with the variables self-efficacy and internal locus of control being the only ones that presented a statistically significant contribution. Mediation analysis showed a partial mediation of the physical safety climate in the relationship between self-efficacy and risk perception.

Keywords Self-efficacy · Mental toughness · Internal locus of control · Work accidents · Safety behavior

1 Introduction

The way in which occupational risk is perceived is one of the factors that implies the adoption of preventive behaviors by individuals [30]. Therefore, studying the perception of risk is relevant for controlling exposure. It is a complex issue which, due to the already very diverse working conditions and risks (e.g., work environments, technologies, different types, and levels of demands), adds to the process of social

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and cultural construction, reflecting values, symbols, history and ideology (e.g., [10, 28]).

According to Rundmo and Iverson [29], risk perception (RP) represents the way people think, analyze, and classify the threats to which they are subject. There is a positive relationship between RP and safety behaviors, that is, the greater the perceived risk, the more individuals develop safety behaviors (e.g., [36]). Therefore, RP is a predictor of safety behaviors at work (e.g., [10]). Thus, understanding RP predictors is essential to make work environments more adapted to workers in terms of safety.

In addition to the inherent characteristics of jobs, several personality attributes are pointed out in the literature as associated with RP such as sensation seeking, optimism, risk taking, proactive personality, etc. (e.g., [19]). In a study focused mainly on RP, Sjöberg and Wåhlberg [31] included personality traits as predictors of RP. In turn, the cognitive perspective assumes that attitudes and expectations of future outcomes contribute to safety and health protective behaviors (e.g., [23]). In this regard, the Health Belief Model (HBM, [13]) considers that the motivation for protection results from the RP and the desire to avoid potential negative outcomes, aside from the perceived costs and benefits of taking precautionary action [27, 13].

In turn, the theory of planned behavior and perceived control are determining factors of protective behaviors (e.g., [11, 20]). Thus, among the personality variables, we are concerned with attributes associated with the perception of safety control, namely, self-efficacy, internal locus of control (intLOC) and mental toughness (MT) (e.g., [1, 6, 7, 24, 30, 33]).

MT concerns the personal ability to constantly produce high levels of subjective and objective performance, despite daily challenges and stressful events [14]. This is a construct that has been mostly addressed in the sports field and, although there are no studies in the literature on this construct in the occupational context, some studies carried out previously in the field of sports have already pointed out that it plays a very active role in the perception of risk (e.g., [12]). These studies argue that individuals with a high level of MT have a sophisticated risk assessment [8, 21].

And, regarding self-efficacy and intLOC, both are related to an individual's perception of their ability to manage work situations to avoid injuries and accidents.

While safety self-efficacy focuses on the perception of the ability to carry out safety-related activities effectively, the safety locus of control focuses on the perception of control to avoid accidents [25, 34]. According to [2] self-efficacy, as a belief in one's own ability to deal with crisis situations and demands of the social/work context, as well as exercising control over them, allows the individual not to be disturbed so sharply by the stressor event. Thus, the greater the level of self-efficacy and control over situations of work crisis, the greater the individual's effort to adopt and maintain behaviors that promote occupational safety.

In turn [9], developed a model that proposed the evaluation of RP in the work context, relating it to the participation of workers in hygiene and safety programs developed in the organizations to which they belonged. These authors considered that the RP on the part of the workers depended on the history of accidents in their

organization and on the attitudes that the workers perceived towards their surroundings (e.g., managers, co-workers) influencing their participation in issues of hygiene and safety at work. And, according to this study, they concluded that the perceptions of the attitudes of co-workers, understood as a climate of safety (i.e., shared perceptions) can influence the RP [3].

Considering that safety climate affects the RP and considering that personality traits constitute a predictive and descriptive tool of RP, it is our expectation that the physical safety climate (PSC) mediates the relationship between personality traits MT, intLOC and self-efficacy and the RP.

2 Methodology

2.1 Sample

The sample of 216 workers was selected for convenience and/or accessibility [35], through the snowball process and it was not restricted to a single organization. Inclusion criteria for participation were as follows: (i) age over 18 and Portuguese worker and (ii) voluntary willingness to participate. The sample is composed of 55.1% female participants and 44.9% male participants, aged between 21 and 63 years ($M = 34.30$; $SD = 9.45$). Regarding professional situation, most participants are employees (89.8%) and have been in their current job for between 0 and 40 years ($M = 7.50$ and $SD = 8.25$). It was also found that most respondents did not perform management functions (70.8%).

2.2 Instruments

The following instruments were applied:

Mental Toughness Index Scale [14]: The Portuguese version validated by [26] was used. It is a one-dimensional measure, consisting of 8 items operationalized according to an increasing Likert-type scale from 1 (False, 100% of the times) to 7 (True, 100% of the times). It is a measure that aims to assess individuals' perception of their abilities and emotions to meet challenges (e.g., item 1 "I believe in my ability to achieve my goals").

Aviation Safety Locus of Control Scale [17]: the Portuguese version adapted by Pinto [26] was used. It is a one-dimensional scale, consisting of 10 items rated according to an increasing Likert-type scale from 1 (completely disagree) to 5 (completely agree). It is a measure that aims to assess the capacity for personal control (e.g., item 1 "If workers follow all the rules and regulations, they manage to avoid many accidents at work").

Self-Efficacy Scale: A scale was developed for the perception of self-efficacy regarding compliance with safety rules. To test the scale and correct possible semantic problems, 15 participants were invited to answer this created version (pre-test). These participants were not included in the study sample. It is a unifactorial scale, composed of 6 items operationalized according to an increasing Likert-type scale that goes from 1 (totally disagree) to 5 (totally agree). It is a measure that aims to assess self-efficacy in complying with safety rules (e.g., item1 “I am able to focus on safety rules whenever I perform my tasks”).

Physical Safety Climate Scale: Adapted version for the Portuguese population [32] of the original scale created by Hall et al. [15] and Idris et al. [18]. The original version [15] with 12 items structured in 4 dimensions: (1) PSC priority (items 1–3, e.g., item 1 “The physical well-being of employees is a priority for this institution”); (2) commitment to the physical safety climate (items 4–6, e.g., item 4 “At my workplace, my supervisor acts quickly when it comes to correcting problems/situations that affect the physical health of employees”); (3) communication about the physical safety climate (items 7–9, e.g., item 7 “There is good communication about the physical safety issues that affect me”); and (4) participation in promoting a physical safety climate (items 10–12, e.g., item 10 “Employees, works councils and physical health and safety coordinators participate and are consulted regarding physical health and safety issues”). [6] added three more items based on the study by Brondino et al. [5] and forming a new dimension, (5) Group norms and behavior related to physical health and safety (items 13–15, e.g., item 13 “At our workplace, we discuss/talk about risks to physical safety and incident prevention.” It is a 5-value Likert-type scale, in which answers are given between 1 (totally disagree) and 5 (I totally agree).

Risk Perception Scale [22]: Concern and fear scale, which assesses concern and fear of accidents and serious unforeseen events. It is a unidimensional scale composed of 5 items (e.g., item 3: “I get worried when there are many accidents at work”), operationalized in a Likert format, ranging from 1 (not at all) to 7 (a lot). A minimum score corresponds to less fear, worry or likelihood of having accidents.

2.3 Procedures

Upon approval by the Scientific Committee (entity responsible for monitoring the research’s ethical procedures and guarantees) and guaranteeing ethical criteria (for example, information on the voluntary and anonymous nature of the study). After guaranteeing the ethical criteria, the participants were asked to answer a self-response questionnaire, through an online platform (SURVEY). The questionnaire link was sent by email, and through social networks, on average, participants took about 10 minutes to respond. Data were collected only once in time, that is, it is a cross-sectional design.

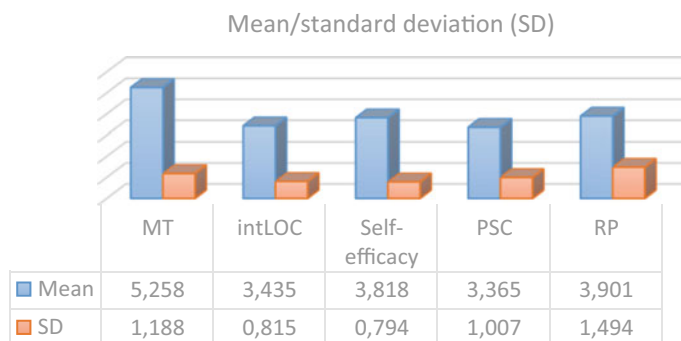


Fig. 1 Descriptive values—mean and standard deviation (N = 216)

2.4 Data Analysis

After collection, the data obtained were introduced and analyzed using the SPSS statistical package version 28. The verification of the predictive power of the independent variables over the dependent variable was performed using multiple linear regression analyses. The mediation analysis was performed using the SPSS macro PROCESS [16]. A significance level of 0.05 was assumed.

3 Results

3.1 Descriptive Statistics

Firstly, an analysis of the descriptive statistics of the variables under study was carried out. Figure 1 shows the values related to the mean scores and standard deviations of each of the variables.

Regarding individual variables, MT showed a higher mean followed by self-efficacy and intLOC respectively.

3.2 Hierarchical Multiple Regression Analysis

To observe the predictive effect of individual factors (MT, intLOC and self-efficacy) on RP, the following hierarchical regression analysis was performed (Table 1).

Self-efficacy explains about 23.4% of RP. And by adding intLOC, the explanatory power of the model increases ($R^2 = 0.030$). The insertion of the MT variable does not add significant changes to the model. This model thus contributes to an explanation of the RP, around 26.6%, with the self-efficacy variables ($\beta = 0.340$, $p <$

Table 1 Hierarchical regression for predicting risk perception

Risk perception					
	r^2	ΔR^2	β	t	p
Self-efficacy	0.234	0.234	0.340	4.400	0.000
Self-efficacy + intLOC	0.264	0.030	0.211	2.928	0.004
Self-efficacy + intLOC + MT	0.266	0.002	0.050	0.768	0.443

Table 2 Model of coefficients for RP (PSC as a mediating variable)

			M (PSC)			Y (RP)		
Antecedent		Coef	SE	p		Coef	SE	p
X (Self-efficacy)	a	0.389	0.235	<0.001	c	0.076	0.255	<0.001
X ¹ (MT)	$a1$	0.175	0.056	0.002	$c'1$	0.238	0.080	0.003
X ² (intLOC)	$a2$	0.296	0.082	0.004	$c'2$	0.643	0.111	< 0.001
M (PSC)		–	–	–	b	0.036	0.097	<0.001

0.001) and intLOC ($\beta = 0.211$, $p = 0.004$) those that present statistically significant contributions.

3.3 Mediation Analysis

To assess whether the PSC mediates the relationship between the individual factors under study and RP, a mediation analysis was carried out, using the mediation model 4 proposed by [16]. The proportion of mediation is evaluated using the formula: direct effect/total effect = e ; $PM = (1 - e)$.

According to the mediation analysis, the mediation effect (indirect effect) of PSC between self-efficacy was statistically significant ($\beta = 0.143$, 95% BCa CI = 0.047–0.269), because zero is not contained in the range bootstrap bias-corrected confidence at 95% [16]. The PSC mediated approximately 17% of the relationship between self-efficacy and RP. The same was observed in MT ($\beta = 0.086$, 95% BCa CI = 0.035 – 0.026), with PSC mediating 29% of the relationship between MT and RP. Also, regarding intLOC, the effect of PSC mediation was statistically significant ($\beta = 0.127$, 95% BCa CI = 0.042 – 0.244), mediating 16.5% of the relationship between intLOC and RP.

4 Discussion and Conclusion

A quantitative study was developed with the aim of observing self-efficacy, the intLOC and MT as predictors of RP and analyzing the mediating effect of the PSC in this relationship.

The results obtained confirmed that some of the individual factors studied and the PSC play an important role in explaining RP. The results showed that the variables self-efficacy and intLOC are predictors of RP, as described in the literature. The lack of relationship between MT and RP can be explained by the fact that the one-dimensional model of the scale used is generic (for adaptation in any context) and thus has generated failures in the interpretation of each of the items that measure the MT variable, that is, the respondents may not have interpreted the items in the sense of the occupational context.

Regarding the mediation analysis, our results showed that PSC is a statistically significant mediator of the relationship between the three individual variables and RP. This result corroborates the findings of [9] who concluded that the perceptions of the attitudes of co-workers, understood as a climate of safety (i.e., shared perceptions) and the experience of accidents experienced can influence RP [3].

In terms of limitations, we can point out that the activity sector is an aspect that was not considered in this study. Considering its importance in the context of safety, namely in the variables that affect RP and the safety climate, it is understood that it should be incorporated in future studies. For example, the studies have shown that control beliefs can favor a low RP and a tendency to engage in dangerous behavior (e.g., [4]). Another added value for future investigations would be the replication of the present study with a larger sample, thus making it possible to generalize the results obtained, as well as to analyze influences of variables not covered in this study, such as professional experience, since the worker's experience is of paramount importance in terms of knowledge of the risks and dangers. Future investigations could also replicate the present study, analyzing influences of other individual variables not contemplated in this study, such as, for example, neuroticism, sensation seeking, among others.

The index of accidents at work, both at national and European level, indicates that this type of investigation must continue. Understanding the effects of personality variables on the RP and the mediation of the PSC in this relationship can contribute, on the one hand, to implementing measures that improve the adaptation of jobs to workers, and, on the other hand, to the design of education and training strategies in the field of occupational health and safety. It is essential to consider both the characteristics of the jobs and the workers in improving the safety performance of organizations.

Acknowledgements This work was funded by national funds through FCT—Fundação para a Ciência e a Tecnologia—as part the project CIP/UAL—Ref^a UID/PSI/04345/2020.

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Pre-pandemic Versus Pandemic Times: The Impact of Psychosocial Risk Factors on Work-Related Musculoskeletal Disorders in Healthcare Workers



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Abstract Healthcare workers, particularly nurses, perform an emotionally exhausting daily work activity, making them susceptible to, namely psychosocial risks. This study aims to assess and compare the impact of psychosocial risk factors on nurses' work-related musculoskeletal disorders. It was developed in two distinct moments, at pre-pandemic vs. pandemic times, in a total sample of 456 nurses from public and private hospitals in Portugal. The INSAT—Health and Work Survey—was used to evaluate the impact of psychosocial risk factors on musculoskeletal disorders. Results showed a strong exposure to psychosocial risks. Work pace and intensity, work relationships and emotional demands stood out with higher global average percentages in a different expression before and during covid times. It is important to develop working conditions' interventions and organizational practices to reduce these health problems that affect a high number of nurses. Therefore, research in this area is essential to understand the psychosocial risks that affect nursing professionals and assess the less visible work-health relationships.

Keywords COVID-19 · Psychosocial risks · Occupational health · Musculoskeletal disorders · Nursing workers

1 Introduction

The pandemic caused by COVID-19 is unprecedented in many respects, healthcare is one of the sectors most affected [20]. The health system is facing a major challenge, which has intensified the physical and emotional strain on healthcare workers [18, 24, 26]. Healthcare workers and, more specifically, nurses, due to the specific

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nature of their work activity and the characteristics of work organization and occupational health environment, aggravated with the pandemic conditions, present a higher probability of physical and mental health risk [22, 26, 27]. In fact, nurses are one of the most vulnerable professional groups manifesting physical and psychological disorders, increased by work pace and intensity, emotional demands and exhaustive shifts [4, 10, 11]. Factors such as patient care, hyper-demand and constant availability of time, working time and shift work, lack of means of support have put these professionals in critical situations that negatively affected their health.

Several studies measured the impact of psychosocial risks on healthcare professionals' health and well-being due to the increased exposure to different categories of psychosocial risks, including increased workloads, time pressure, difficulties in communication and work organization, high emotional demands, lack of support from staff and management [3], European [12, 13, 19, 23]. Studies have been developed showing that nursing is one of the professions most affected by work-related musculoskeletal disorders (WMSDs) [7, 14, 15]. The intense pace of work, the contact with suffering and death, the emotional overload of work, associated with time pressure and shift work are risk factors to which nurses are exposed during their work activity related with the risk of developing musculoskeletal disorders [1, 2, 17]. The Health and Work Survey—INSAT has been used in several health-related studies, namely in work-related musculoskeletal disorders [4, 5, 9].

Therefore, the purpose of the study is to compare the impact of psychosocial risk factors on work-related musculoskeletal disorders in pre-pandemic vs. pandemic times.

2 Materials and Methods

2.1 *Study Design and Ethics*

A cross sectional study was conducted in Portuguese healthcare workers from public and private hospitals, namely nurses, in two distinct moments, before covid and during covid times. Participants received all materials consisting of the INSAT-Health and Work Survey, a covering letter explaining the purpose of the survey, and the guidelines to complete the questionnaire. Participation was voluntary, all of the participants gave their informed consent to participate, and their confidentiality and anonymity were ensured. Data were collected using a self-administered paper and pencil questionnaire, followed by the researchers' guidance in a total sample of 456 nurses in Portugal. 172 nurses in pre-pandemic times (September–November 2019) and 284 in pandemic times (May–July 2021). Each healthcare worker received an envelope from Human Resources with information regarding the goals of the study and the tools used in the study protocol, which were later returned in a closed envelope after its completion. The study protocol was approved by the Ethics Committee of Fernando Pessoa University (Ref. PI-112/20), respecting all the Declaration of Helsinki procedures.

2.2 *Materials*

This study was supported by the INSAT, a self-reported questionnaire, that measure working conditions, risk factors, and health problems. Concerning the main goal of the present study, only the psychosocial risk factors and musculoskeletal disorders were used. The psychosocial risk factors were: high demands and work intensity; lack of autonomy; work relations with coworkers and managers; employment relations with the organization; emotional demands and ethical and value conflicts. These categories are organized in different items. All items were measured on a 6-point Likert scale ranging from 0 (not being exposed) to 5 (being exposed with high discomfort). The musculoskeletal disorders variable is a nominal variable (no:0; yes:1). In terms of psychometric properties, INSAT has a good internal consistency, in a Rasch PCM analysis, with a reliability coefficient >0.8 [6].

2.3 *Statistical Analysis*

Data analysis was performed with the support of the IBM SPSS statistical program for Windows, version 28.0 (SPSS Inc.: Chicago, IL, USA). The significance level adopted was $p \leq 0.05$. Frequency and percentage analysis were performed on psychosocial risk factors. To analyze the effect of exposure to psychosocial risk factors (ordinal variable with a Likert scale from 0: not exposed to 5: being exposed with high discomfort), on musculoskeletal disorders (nominal variable, no:0; yes:1) a logistic regression was performed, after the variable transformation of psychosocial risk factors to a nominal scale (no:0; yes:1), because the aim of the study was to identify the effect of exposure and not the effect of the degree of discomfort generated by that exposure [8]. The compliance with the assumptions of the method was verified, and the results obtained were considered reliable.

3 *Results*

A total sample of 456 nurses working in public and private hospitals in Portugal's north and center regions participated in this study, 172 nurses in pre-pandemic times (September–November 2019) and 284 in pandemic times (May–July 2021). The sample is mainly composed of female nurses (pre-pandemic 84,8% and pandemic 82,0%) aged between 21 and 64 years (pre-pandemic $M = 37.52$; $SD = 8.69$; pandemic $M = 38.85$; $SD = 10.03$). Professional experience ranges considerably from those who had worked for less than one year to those who had worked for 42 years (pre-pandemic $M = 11.22$, $SD = 8.59$; pandemic $M = 13.49$; $SD = 9.63$). Regarding the contract type, almost 91% of the participants work under permanent or open-ended contracts, more than 93% have full-time working hours, more than 65% work rotating shifts.

The INSAT survey's descriptive analysis (Table 1) shows the frequency distribution of “yes” answers to psychosocial risk factors at work that have a significant impact on the nurses' professional practice. Results show a high exposure to psychosocial risks. Work pace and intensity and emotional demands stand out as risk factors with higher overall mean percentages.

Table 1 Descriptive analysis of psychosocial work factors in pre-pandemic and pandemic times

Psychosocial work factors	Pre-pandemic	Pandemic
Work pace and intensity	% Yes	% Yes
Working at an intense pace	98.1	94.4
Relying on direct orders from customers	90.5	76.1
Managing contradictory instructions	78.1	82.9
Frequent interruptions	86.7	82.4
Hyper-solicitation	88.6	81.0
Working hours	% Yes	% Yes
Exceeding normal working hours	89.5	86.3
“Skipping” or shortening a meal or not taking the break at all because of work	94.3	82.7
Maintaining permanent availability	71.4	51.1
Work relationships	% Yes	% Yes
Needing help from colleagues and not having it	48.3	46.1
My opinion being disregarded for the service's functioning	54.4	44.4
Little recognition by management	49.2	47.5
Not having anyone I can trust	33.1	30.0
Being exposed to bullying	37.2	39.4
Employment relationships	% Yes	% Yes
Lack of means to perform the work	69.5	50.7
I feel exploited most of the time	66.7	50.0
Being afraid of suffering a work-related injury	82.9	71.1
The company disregards my well-being	74.3	63.0
Emotional demands	% Yes	% Yes
Confronted with public relations tense situations	94.3	94.7
Fear of verbal aggression	93.3	86.3
Being exposed to the difficulties and/or suffering of other people	98.1	94.7
Simulate good mood and/or empathy	83.8	75.4
Hiding emotions	88.6	75.0
Ethical and value conflicts	% Yes	% Yes
Doing things, I disapprove of	71.4	64.8
My professional conscience is undermined	32.4	52.8
Lack of necessary means to perform a good job	65.7	57.7

The descriptive analysis of musculoskeletal disorders is presented in Table 2. As shown the percentage of participants with this type of disorder is higher than 50% in both moments, and more than 60% of the participants confirmed that these disorders were caused/aggravated by work activity (62,3% in pre-pandemic and 80% in pandemic times).

The results in Table 2 showed that “Musculoskeletal disorders aggravated by my work activity” increased while “Musculoskeletal disorders not related with my work activity” decreased in pandemic times.

To analyze the association between psychosocial risk factors and musculoskeletal disorders a logistic regression analysis was performed. In the study carried out, compliance with the assumptions of the method was verified, and the results obtained were considered reliable. The results are presented in Tables 3 and 4.

As shown in Table 3 three key psychosocial risk factors have significantly increased the perception of musculoskeletal disorders in pre-pandemic times. The

Table 2 Descriptive analysis of musculoskeletal disorders in pre-pandemic and pandemic times

	N	Pre-pandemic % Yes	N	Pandemic % Yes
Musculoskeletal disorders	172	56.2	284	63.2
Caused by my work activity	97	28.9	180	23.1
Aggravated by my work activity	97	33.4	180	56.9
Not related with my work activity	97	37.7	180	20.0

Table 3 Logistic regression analysis to identify associations between musculoskeletal disorders and psychosocial risk factors: pre-pandemic times

Psychosocial risk factors	<i>p</i>	OR (C.I.95%)
Managing contradictory instructions	0.001	20.743 (3.447–124.818)
Exceeding normal working hours	0.049	4.822 (0.979–23.743)
Simulate good mood and/or empathy	0.003	7.359 (1.862–29.080)

p—*p* value; OR—odds ratio; C.I.—confidence interval

Table 4 Logistic regression analysis to identify associations between musculoskeletal disorders and psychosocial risk factors: pandemic times

Psychosocial risk factors	<i>p</i>	OR (C.I.95%)
Being afraid of suffering a work-related injury	0.013	2.744 (1.234–6.104)
The company disregards my well-being	0.002	4.116 (1.709–9.915)
Lack of necessary means to perform a good job	0.006	3.195 (1.402–7.279)
Needing help from colleagues and not having it	<0.001	4.090 (1.945–8.603)

p—*p* value; OR—odds ratio; C.I.—confidence interval

factor “Managing contradictory instructions” increased the perception of musculoskeletal disorders more than twenty times (20.743; C.I. 95%: 3.447–124.818), the factor “Simulate good mood and/or empathy” increased more than seven times (7.359; C.I. 95%: 1.862–29.080), and the factor “Exceeding normal working hours” increased almost five times (4.822; 95% CI 0.979–23.743).

Table 4 shows four key psychosocial risk factors that significantly increased the perception of musculoskeletal disorders in pandemic times. The risk factor “The company disregards my well-being” increased the perception of musculoskeletal disorders more than four times (4.116; C.I.95%: 1.709–9.915), almost the same for the risk factor “Needing help from colleagues and not having it” (4.090; C.I.95%: 1.945–8.603). The risk factor “Lack of necessary means to perform a good job” increased the perception three times (3.195; C.I.95%: 1.402–7.279), and finally the risk factor “Being afraid of suffering a work-related injury” increased almost three times (2.744; C.I.95%: 1.234–6.104).

4 Discussion

Nursing is a physically and emotionally exhausting work activity that became more demanding with the pandemic, increasing the vulnerability to physical and mental health problems [25, 26]. In fact, among all other professions, nursing has the highest potential for developing work-related musculoskeletal disorders (WMSDs) [21]. Studies have revealed that nurses’ experiences with musculoskeletal pain are not only related to the physical factors associated with the exercise of their activity, but are mainly related to psychosocial factors [9, 22, 28]. Therefore, results revealed that psychosocial risk factors are significantly present. Work intensity, emotional demands related to stress with patients, having to deal with serious situations and the lack of organizational support, leveraged by the COVID-19 pandemic, have potentiated the worsening of WMSDs [16, 26, 27].

Results actually show a consistency between psychosocial risks and work-related musculoskeletal disorders. A set of psychosocial risks, mainly work pace and intensity, social relationships, and emotional demands, may predict the manifestation of musculoskeletal disorders. In fact, increased work pace and intensity, lack of work and working hours organization, accompanied by the lack of support and resources [22, 23] increased nurses’ health problems associated with musculoskeletal pain [9, 14, 28].

However, differences were found in the set of psychosocial risks that most affected the development of WMSDs in the pre-pandemic vs. pandemic times. Intense rhythm of work, working hours and emotional demands were more significant in pre-pandemic times. Working relations, employment relations and ethical and value conflicts were the most significant in pandemic times. Beyond the psychosocial risks, normally associated with nurses’ work activity, such as emotional demands and the pace and intensity of work, other types of risks emerged during the pandemic times. Lack of support and resources, fear of being contaminated, associated with

the lack of means to perform quality work, aggravated during the pandemic times, increased nurses' psychological stress and enlarged the development of WMSDs.

In fact, when we compare the results in the pre-pandemic and pandemic times, we see that the psychosocial risks have changed. In the pre-pandemic times, the psychosocial risks most frequently reported were the intense pace of work, working hours and emotional demands. On the other hand, during the pandemic times the most reported psychosocial risks were: work relationships, employment relationships and ethical and value conflicts. It seems that nurses had naturalized the first set of risks, as intrinsic to their work activity, but allowing the emergence of other type of psychosocial risks. . In fact, a better understanding of the risk factors allows better intervention practices, both at the individual and organizational levels, in order to prevent and promote health and well-being at work.

5 Conclusions

Psychosocial risk factors have a significant impact on work-related musculoskeletal disorders. Research in this area is essential to understand the psychosocial risks that affect nursing professionals and assess the less visible and less obvious relationships between work and health. Although this research has made significant contributions for better knowledge about the impact of psychosocial risk factors in work-related musculoskeletal disorders during Covid-19 it has some limitations. A larger sample and extended to other healthcare workers like physicians and other health supporters, could give more confident results. Moreover, establishing causality in any relationship between work and health is complex, as physical and psychological health may be both a cause and a consequence of a change in work environment and performance, particularly during pandemic times. Therefore, more studies should be conducted to better understand this relation and endorse better working practices during alarming and other emergency situations.

Acknowledgements To be included in the resubmission phase.

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The Impact of the COVID-19 Pandemic in Social Workers' Quality of Life—A Study Case



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Abstract Quality of life is associated with physical health, psychological state, level of independence, social relationships, personal beliefs and their relationship to salient features of their environment, reporting to a subjective evaluation, embedded in a cultural, social, environmental and professional context. On the other hand, some authors argue that people's quality of life depends on their access to certain social and economic goods and services that naturally vary depending on the culture the subjects are inserted in. The pandemic brought about nefarious consequences to people's routines and their quality of life. Some companies stopped or reduced production, and adopted telework, facing the governmental measures that emerged to tackle the pandemic. However, most IPSSs (Private Social Solidarity Institutions) kept with their work, which lead to physical and emotional burnout. This study aims to assess the impact of the COVID-19 pandemic in the quality of life of IPSS workers, using the WHOQOL-BREF scale. We have found that workers hold a “reasonable” perception both of their quality of life and the state of their health. The physical, social and environmental domains, which were defined as facets of quality of life, were rated between “reasonable” and “good”. The psychological domain was rated the lowest, with a “reasonable” rate. We were able to establish a negative correlation between two

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domains (physical and environmental) and age. Conversely, level of education was positively correlated with the physical, psychological and environmental domains.

Keywords Pandemic · Quality of life · IPSS · COVID-19 · WHOQOL-BREF

1 Introduction

The concept of quality of life comprises many different meanings, which is why it is characterized as a broad, diversified and complex notion [28]. According to World Health Organization (WHO), quality of life is defined as “an individual’s perception of their position in life in the context of the culture and value systems in which they live, and in relation to their goals, expectations, standards and concerns. It is a broad ranging concept, affected in a complex way by the person’s physical health, psychological state, level of independence, social relationships, personal beliefs and their relationship to salient features of their environment.” This definition reflects the idea that quality of life refers to a subjective evaluation, embedded in a cultural, social and environmental context [35]. As a whole, we can associate quality of life with such concepts as health status, longevity, job satisfaction, income, leisure, family relationships, disposition, pleasure and spirituality [16, 20, 28]. Each person’s life can be characterized by the combination of these factors. However, it is acknowledged that only the individual can assess its own quality of life [17].

The COVID-19 pandemic brusquely affected the day-to-day of everyday people and companies, as well as worldwide human mobility and commerce. Consequentially, it had an effect in the world economy [14] and increased the prevalence of depression, anxiety, stress and sleep disorders among the population, when compared with pre-COVID 19 times [22]. Quality of life was, thus, negatively impacted [1, 3, 27].

In March of 2020, at the beginning of the pandemic, the International Labour Organization [15] predicted that COVID-19 would affect the world of work in three fronts: “(1) the quantity of jobs (both unemployment and underemployment); (2) the quality of work (e.g. wages and access to social protection); and (3) effects on specific groups who are more vulnerable to adverse labour market outcomes (for example, people with mental health issues, older people and self-employed workers)” [15].

Many professions were affected by this pandemic, leading to the emergence of new ways of working. Some professionals kept working from the office, even with some adaptations, while others started giving their first steps in teleworking, doing their jobs from home. Others still alternated between the two. In the first scenario, the fear of contagion tends to be high, naturally impairing interpersonal relationships in the workplace. In the second case, workers face the expected difficulties in adapting to this new way of working, where their home, normally associated with a place of rest and leisure, is now, also, a space of work. Additionally, there is frequently a work-family conflict, due to the difficulty in balancing work with house chores, especially when there are dependent children, who are not in school, or dependent elders,

needing care [19], which are described as variables that affected the population's quality of life during the COVID-19 pandemic [1, 3, 27].

Unlike many other companies who stopped or reduced production and adopted telework, facing the governmental measures that emerged to tackle the pandemic, most IPSSs (Private Social Solidarity Institutions), as well as healthcare workers, kept with their work, as much as possible. With the declaration of the state of emergency, some social responses were suspended, namely day care, kindergartens and study centres, as well as day centres [5]. This became a threat to the financial stability of these organizations. However, home care, residential structures and others, meant to support the elderly, people with disabilities and homeless people, kept working.

Several contingency plans were design and put into practice by these social organizations, according to the multiple COVID-19 orientations that were being released by DGS (Directorate General of Health of Portugal), the Labour, Solidarity and Social Security Ministry, their partners in the social and solidarity sectors, the Social Security Institute and Lisbon's Santa Casa da Misericórdia. Mainly in the beginning, orientations and communiqués were frequently being changed, expiring or evolving into new guidelines or rules, some days after their release. Nevertheless, institutions adapted quickly [6].

During the pandemic, the priority was to ensure the quality of service, as much as possible, while still respecting the many guidelines that were being announced. We would like, here, to emphasize the capacity to quickly adapt that was required of workers, both in their work routine, in the tasks they were asked to perform and in the daily interactions with clients and co-workers. On the other hand, there was a constant need to come up with measures to balance the pandemic and the world of work. All this brought great challenges to workers, including burn-out, lack of motivation, anxiety, mental health disorders and even lack of compensation for the extra hours that pandemic work conditions implicated [29]. Effectively, all this is likely to have an impact in the quality of life of professionals, who strive to do good work, while trying to keep themselves and their families safe and healthy [6].

This study was conducted by Santa Casa da Misericórdia of Oliveira do Bairro, in the district of Aveiro (Portugal), aiming to assess the impact of the COVID-19 pandemic and of the measures adopted to mitigate it in the workers' quality of life. This institution provides the following services: Children and Youth Centre, Elderly Care Centre, Social Work Department and Long-Term Care Unit.

Quality of life was assessed using WHOQOL-BREF. "In spite of it not being originally designed for the COVID-19 pandemic times, this instrument seems to have been widely used to study this period around the world [1, 2, 9, 12, 22, 34].

2 Materials and Methods

2.1 *Quality of Life Assessment*

To assess the workers quality of life, the WHOQOL-BREF scale, developed by the World Health Organization's Quality of Life Group, was used. The scale was translated and validated for use in Portugal by Vaz Serra et al. [30] and Canavarro et al. [7, 8]. The questionnaire is made up of 26 items/questions, graded using a Likert scale (from 1 to 5, 5 corresponding to the best quality of life). The first two questions regard the subjects' general perception of their quality of life and their general perception of their quality of health. The other 24 questions are divided in four domains: Physical, Psychological, Social and Environmental.

For sociodemographic effects, the questionnaire also includes some questions regarding personal information, such as age, sex, level of education, occupation, civil parish, municipality and district. The questionnaire asked respondents to report on pandemic times.

2.2 *Sample*

Data was collected from the 29th of September to the 22nd of October of 2021, in an IPSS, in the district of Aveiro, Portugal. An IPSS is a private non-profit organization, aiming to express the moral duty of solidarity and justice among individuals. This institution includes a Children and Youth Centre, an Elderly Care Centre, a Social Work Department and a Long-Term Care Unit, amounting to 165 staffers. Of these, 54 workers (i.e., 32,7% of total workers), aged between 21 and 66 years, with an average age of 42,5 years ($SD = 11,8$), participated in the study. The sample, as well as the working population, is mainly made up of women (94,4%). Concerning professional occupation, 34% were janitors; 23,4% were care centre helpers, 14,9% were general staffers, 12,8% were technicians (psychologists, physiotherapists, social assistants), 12,8% were kindergarten teachers and 2,1% held executive positions.

Regarding their education level, 3 of the staffers (5,6%) finished 4th grade, 4 of them (7,4%) finished 6th grade, 7 (13%) finished 9th grade, 21 staffers (38,9%) finished 12th grade, 14 (25,9%) went on to finish a university level course and 5 (9,3%) did not reply. Concerning marital status 13 of the staffers (21,1%) are single, 25 (46,3%) are married or live in a domestic partnership, 8 of them (14,8%) are divorced, 3 (5,6%) are widowers and 5 (9,3%) did not answer.

2.3 Data Analysis Methodology

The data was processed with IBM-SPSS Statistics 28. The WHOQOL-BREF guidelines were followed to calculate each domain's score, noting that the Likert scales of three out of the 26 questions were inverted. In order to standardize each domain's score and allow for comparisons among the sections, the total sum of each domain was divided by their respective number of items. Thus, the D1 domain's total score, which includes 7 items (3, 4, 10, 15, 16, 17 and 18) was divided by 7; D2 (items 5, 6, 7, 11, 19 and 26) was divided by 6; D3 (20, 21 and 22) was divided by 3 and D4 (8, 9, 12, 13, 14, 23, 24 and 25) was divided by 8. Quality of life was established by adding the four domains' total scores and dividing it by 4.

Internal consistency, measured using Cronbach's alfa (α), shows acceptable values, both for the 26 items of the questionnaire ($\alpha = 0,854$) and the four domains: Physical, $\alpha = 0,863$; Psychological, $\alpha = 0,812$; Social, $\alpha = 0,667$; and Environmental, $\alpha = 0,751$. The scores for the two first questions, as well as each domain, and total quality of life (mean and standard deviation) are shown in Table 1.

Regarding quality of life in the various domains, Psychological shows the lowest rate, while Physical shows the highest, followed by Social.

In order to ascertain whether age and level of education are correlated to quality of life, we calculated Pearson's correlation coefficients. Correlation between the D1 and D4 domains and age, as well as D1, D2 and D4 with level of education were shown to be statistically relevant. Likewise, correlation coefficients were calculated between the domains and, as expected, there is a statistically significant relationship between them. We were also able to determine a statistically significant negative correlation between age and level of education (Table 2).

In order to judge whether the workers' quality of life was related to their marital status, the one-way ANOVA parametric test was applied, using Bonferroni's correction. Table 3 shows those results.

Afterwards, we looked into the age distribution among the three marital statuses. Graphic 1 shows the age boxplot depending on the marital status.

Table 1 Scores for the two first questions, as well as each domain, and total quality of life (mean and standard deviation)

Question/domain	Mean (standard deviation)
How do you rate your quality of life?	3,32 (0,94)
How satisfied are you with your health?	3,61 (0,66)
D1 (Physical)	4,14 (1,00)
D2 (Psychological)	2,99 (0,48)
D3 (Social)	3,70 (0,73)
D4 (Environmental)	3,45 (0,61)
Quality of life	3,65 (0,55)

Table 2 Correlation coefficients between the domains, age and level of education

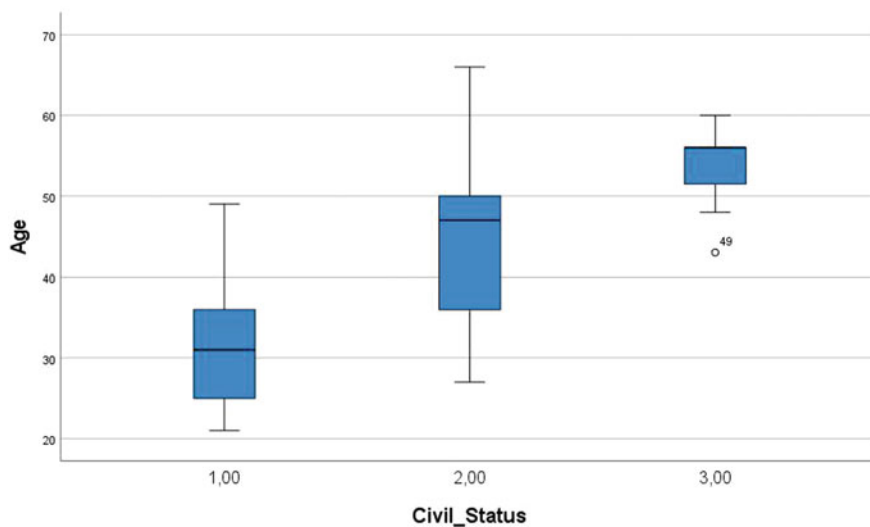
Domains	D1	D2	D3	D4	Age	Level of education
D1		0,447**	0,549**	0,706**	-0,362*	0,574**
D2			0,470**	0,507**		0,440**
D3				0,657**		
D4					-,343*	0,431**
Dtotal						0,410**

* p value < 0,05; ** p value < 0,01

Table 3 Average score for each domain, according to marital status (single, married or in a domestic partnership and divorced), F-statistic and p value

Domains	Mean		Divorced	F	p-value
	Single	Married or in a domestic partnership			
D1	4,65	4,09	3,47	3,545	0,038*
D2	2,99	3,04	3,17	0,306	0,738
D3	3,51	3,76	3,53	0,480	0,623
D4	3,72	3,44	3,25	1,618	0,211
Dtotal	3,72	3,61	3,53	0,260	0,773

* p value < 0,05

**Graph 1** Boxplot of age according to the marital status (1—single; 2—married or in a domestic partnership; 3—divorced)

3 Discussion

The results for the Cronbach indexes are similar to those observed by other authors [11, 30]. It is important to notice that the Cronbach coefficient for Domain 3 (Social) is lower than for any other domain. This was expected since instruments made up of a smaller number of questions tend to have lower Cronbach coefficients.

Looking at the first two questions, workers have a reasonable opinion of their quality of life during the pandemic. Likewise, they reported being reasonably satisfied with the state of their health. The mean of all domains obtained was 3.65, to the ones obtained by Von [33]. The staffers' quality of life during the pandemic, regarding "Medication and Treatment Dependency", "Mobility" (Physical Domain), "Social Relationships" and "Friend Support" (Social Domain) was classified as good, showing the highest values from all the Domains. In other words, generally speaking, workers were not dependant on medication/treatments, nor on external help to commute, during the pandemic. IPSS workers, despite restrictions, kept their social relationships at work, which didn't happen to workers working from home, who reported feelings of solitude, depression and anxiety, related to reduced social interactions [13, 32].

Prior studies show that the pandemic caused stress, anxiety, depression, insecurity and fear, among others, in many people, impacting them psychologically [4, 18, 23–25]. However, just like doctors and nurses, social workers were praised and seen as heroes by their peers. This could be why these workers, a posteriori, have a reasonable perception (2,99) on Domain 4 (Psychological).

We also concluded that older workers reported worse quality of life, as it regards the Physical and Environmental Domains, during the pandemic. There is a statistically significant weak negative correlation between the respondents' age and their quality of life, concerning these domains. The environmental domain includes such topics as physical safety and protection, physical environment (pollution/noise/traffic/weather), financial resources, opportunities to acquire new information and skills, participation in/opportunity for leisure, home environment, health and social care (availability and quality) and transportation. Some authors consider that age has a negative impact in quality of life [9, 10, 27]. A statistically significant negative correlation was also observed in the physical health domain by Shanshal et al. [27].

Conversely, workers' quality of life increases with their level of education. There is a statistically significant strong positive correlation between quality of life in the physical, social and environmental domains, as well as overall quality of life, and level of education, during the pandemic. This same result was reached for women in a study by Ramos and Martínez [26]. Velarde-Jurado and Ávila-Figueroa [31] reported that quality of life includes such factors as education, employment and financial situation satisfaction. Thus, workers with higher levels of education tend to be more satisfied with their financial situation, since they occupy better paying positions. The relationship between quality of life, age and level of education is confirmed by the moderate negative correlation between the last two variables. Pereira [21] confirmed that, in Portugal, older people generally have lower levels of education.

Looking into the relationship between worker quality of life and marital status, we realized that the only statistically significant difference is between single and divorced workers, as it regards to the Physical domain. This, however, could be explained by the fact that the single group is also the youngest group, as can be confirmed in Graphic 1.

4 Conclusion

This study aimed to assess the quality of life of IPSS workers during the COVID-19 pandemic.

The WHOQOL-BREF questionnaire allowed us to establish that the workers' perception on their quality of life during the pandemic period was "reasonable". The "Mobility", "Social relationships" and "Support from friends" parameters were graded as "good", showing high ratings.

We have concluded that as age increases quality of life decreases, in the physical and environmental domains. Conversely, quality of life increases proportionately to the level of education.

This study reports on a study case with a small sample, hence any generalizations should be carefully contextualized. We would suggest a broadening of the sample for future studies, possibly including several institutions with similar purposes.

Acknowledgements NECE-UBI, Research Centre for Business Sciences, Research Centre and this work are funded by FCT – Fundação para a Ciência e a Tecnologia, IP, project UIDB/04630/2020.

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Decision-Making Styles as Human Factors in Occupational Context



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Abstract During the past years business environment changed and many businesses adapted through creating new and different markets. In parallel, a need arose for critical information explaining important human factors during the decision-making process. Therefore, this paper aims to discover the prevalence of decision-making style (intuitive or analytical) in different studies and how that knowledge can be incorporated in occupational context. The methodology for the conceptual paper is based on rapid review. A total of 13 studies were found that fitted several criteria (comparison of different decision-making types in occupational setting), while the final number of examined studies was 10. The main findings are that intuition is often utilized in the first steps of decision-making process while exploring potential topics and afterwards analytical style is used for operationalization of topics for testing. Interesting finding is that intuitive style is being utilized again when managers are faced with final decisions. The aim of the paper is to provide recommendations for human factors that managers can use for decision making in occupational context. As such, it outlines key steps that managers need to do during decision making in order to transfer these findings to occupational safety and improve well-being of employees.

Keywords Decision-making styles · Intuition · Analysis · Human factors · Occupational context

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1 Introduction

Ghobakhlo [8] argues that we are living the fourth industrial revolution and there is underlying digital transformation, known as Industry 4.0. This industry progresses exponentially and reshapes the way individuals live and work fundamentally. The author concludes that Industry 4.0 includes advanced technology trends such as the Industrial Internet of Things (IIoT) or Cyber-Physical Production Systems (CPPS). The industry relies on the integration of AI, machine-to-machine communication, industrial controllers, smart sensors, cloud data, big data analytics, and semantic technologies. The end results are creation of different dynamic cyberphysical control systems that ensure efficiency and reliability of industrial operations. Rosin et al. [26] examined the implementation of Industry 4.0 technologies and concluded that there is a substantial improvement in decision-making process. The authors proposed a model of seven types of autonomy associated with the decision-making process in operational context. The seven types of autonomy that are based on Industry 4.0 technologies in a manufacturing context are as follows: (1) Cyber Monitoring, (2) Cyber Search, (3) Standard Decision Support, (4) Cyber Control, (5) Cyber Design, (6) Customized Decision Support and (7) Cyber Autonomy. It is a showcase of how new technologies are mobilized to facilitate and strengthen horizontal, vertical, or end to end information exchanges. Their model clearly demonstrates how 4.0 technologies can enhance decision-making processes and how they affect the autonomy of the resources involved at an operational level.

Hamilton et al. [11] write that individuals differ in the way that they make decisions. Some people prefer lengthy deliberation, while others prefer quick “gut” feel. Also, some people use affective and affective and unsystematic approach and other are making decisions cognitively and systematically. These authors developed and validated Decision Styles Scale based on rational and intuitive approaches. They decided to use rational and intuitive style classification based on theoretical and empirical reasons. One argument is that the dual-process framework of individual differences of cognitive style has been conceptualized for these two systems: rational/reasoning and intuitive/experiential component. Different authors [13, 16] have labeled the cognitive model as intentional, analytic, relatively slow, rule-governed, and logical, while the intuitive model as automatic, preconscious, relatively fast, affect-laden, heuristic, and experience-based. Their findings suggest that there is a relationship between intuitive (not rational) decision styles and intuitive related constructs (experiential ability, experiential engagement, and nonlinear decision making). Another important finding is that rational related constructs (rational ability, rational engagement, linear decision making) are related to both rational and intuitive decision styles. Their explanation is that expertise-based intuition relies on application of individuals’ knowledge and experience in a particular domain.

Decisions are being made every day in different settings. Ranging from decisions which clothes to put every morning or which route to take to work to decisions that involve investment at work and may be decide on the future of the company people work. On top of that, there are decisions that need to be made in digital environment

with many unclear outcomes. There is a need for critical information explaining how to be efficient during the decision-making process, especially at the global level within digital sources [15]. At the moment digital environment still remains unexplored area; and therefore, utilization of different decision-making styles is needed in order to propose optimal models for managers.

Okoli and Watt [24] express the notion that the modern society has been taught to mistrust intuition and prefers explicitly articulated expressions, theoretical or codified knowledge. These authors even mention the early work of Albert Einstein who raised a criticism of society's quest for deliberation at the expense of intuition. In his words: The intuitive mind is a sacred gift, and the rational mind is a faithful servant. We have created a society that honors the servant and has forgotten the gift (Albert Einstein, 1879–1955; as cited in Klein [19, p. 3]). Therefore, this paper aims to discover the prevalence of decision-making style (intuitive or analytical) in different studies and how that knowledge can be incorporated in new digital context. In addressing the topic, the current paper structure is as follow. First, the paper focuses on setting up the context and explaining digital revolution. What follows is discussion of intuitive and analytical decision-making processes with relevant empirical findings. At the end, conclusion relates to application of results for managers in digital age when it comes to different decision-making styles.

2 Materials and Methods

2.1 Methodology

The methodology for the conceptual paper is based on rapid review. According to Khangura ([17], cited in [4]) “rapid reviews are a form of knowledge synthesis that follow the systematic review process, but components of the process are simplified or omitted to produce information in a timely manner.” Having in mind the objectives and timeframe the authors decided to use this methodology. The search for relevant papers was done using the criteria that included a comparison of intuitive decision making and analytical decision making in occupational setting with managers. The relevance of the studies was assessed through its results e.g. whether there were findings in favor of one or another decision-making type. Apart from these criteria, all chosen studies were evaluated regarding methodology whether they were empirical studies that involved human participants (primarily managers), were relevant for organizational decision making and had potential implications for occupational context. A total of 43 studies were found, but after the screen out only 13 studies were included. Three duplicates (similar studies) were deleted and the final number of examined studies was 10.

The final rapid review examined 10 studies that were selected after the initial screen out of shortlisted studies from Google Scholar databases considering above-mentioned inclusion and exclusion criteria. The research question was to detect prevalence of decision-making style (intuitive or analytical) and draw practical recommendation that can be incorporated into organizational context. The rapid review was done in May 2022.

3 Results Regarding Prevalence of One Style Over Another

Orlandi and Pierce [25] consider the debate between analytical and intuitive decision making as longstanding debate that ranges from 1938 and it is still active today. Orlandi and Pierce [25] claim that the discussion for primacy of each factor has been polarized by management scholars in two main sides. The intuition is given favorable position, while there many authors prefer to write about the primacy of analytical information processing and decision-making. The results are summarized in Table 1. The studies that were included in the rapid review are presented together with the main findings of the study. The paper explores current research studies in order to detect best practices for decision-making styles in occupation context through taking holistic perspective. The studies are presented in chronological order. Each of the studies related to the question of interest is explained and afterwards a table that provides summary about arguments in favor of one approach or another. Apart from that, the table includes potential interactions related to combination of both approaches.

The research of Öhlmér [23] shows that decision support systems and other information services that farmers use, are based on analytical methods, but most of them intuitively make decisions. Based on literature review and case studies, Öhlmér [23] develops conceptual model of decision making. The summary of results shows that most farmers use intuitive decision making. Öhlmér [23] provides explanation that this concept provides a reasonable explanation of the decision-making process used by farmers. On the other hand, the author states that the perceived uncertainty about the best alternative is higher at intuitive decision making than at analytic decision-making. The decision maker can reduce the risk by implementing of a new alternative or testing alternatives in small scale. However, the author notes that if alternative involves a big irreversible action (building investment) then the decision maker will rarely use intuitive decision making. In addition, it should be accented that decision makers believe that the more analytic a decision process is, then it has higher chances to get correct choice. It means that they expect more benefits from an analytic decision process, since it is a cheap and quick to use broad information and intuition. Also, analytic processing is costly and time consuming and the perceived benefits and costs depend on the person and situation.

Baldacchino et al. [2] mention the work of Mitchell et al. [22] which suggest a more combined approach. According to this stance, entrepreneurial intuition involves

Table 1 Summary of results about prevalence of intuition versus analytical approach

Study	Arguments in favor of analytical approach	Arguments in favor of intuitive approach	Combination of both approaches
Öhlmér [23]	Decision support systems are based on analytical methods	Majority of farmers use intuitive decision making	
Mitchell et al. [22]			Interaction between conscious (i.e., more analytical) and non-conscious (i.e., more intuitive) forms of information processing
Kickul et al. [18]	Analytical entrepreneurs have higher self-efficacy in the later stages—evaluation	Intuitive entrepreneurs have high self-efficacy in the early stages—identification	
Vaghely and Julien's [28]			Intuition and analytical processes are interchangeable
Baldacchino [1]		Intuition is positively related to the number and innovativeness of opportunities	Requires a versatile cognitive strategy of combined intuition and analytics
Baldacchino et al. [2]		Intuition is associated with four important characteristics: sense of knowing, pattern recognition, related to emotions/affect and connected to expertise/ experience	
Orlandi and Pierce [25]	Intuition still has a central role in managers' decision-making processes	In situations when the environment of the industry is highly dynamic, then analytical information is used	Both styles (intuitive and analytical style) are relevant
Gopaul and Rampersad [9]		Preferential mode of decision-making was inclined towards intuitive tendencies. The findings support the thesis that decision strategies were of iterative and informal style and were opposed to a procedural rational style	

(continued)

Table 1 (continued)

Study	Arguments in favor of analytical approach	Arguments in favor of intuitive approach	Combination of both approaches
Lebefromm [20]	Business Intelligence systems are based on data	Systems are based on experience of decision makers	
Merino-Núñez et al. [21]	Chain of events and knowledge of alternative steps. Decision makers must be sure what is to be done and to be convinced that it is the right alternative		

an interaction between conscious (i.e., more analytical) and non-conscious (i.e., more intuitive) forms of information processing.

The study of Kickul et al. [18] demonstrated that intuitive entrepreneurs have high self-efficacy in the early stages of a new venture creation process (opportunity identification), as compared to those who were pre-dominantly analytical which were more likely to have higher self-efficacy in the later stages of a new venture creation process (opportunity evaluation and exploitation).

Another model proposed by Vaghely and Julien’s [28] suggests that entrepreneurs’ process information by means of algorithmic (pattern-recognition) or heuristic (trial and error) processes. Their conclusion is that both processes involve intuition and analytical processes (formulae and interpretation).

Baldacchino [1] found that intuition is positively related to the number and innovativeness of opportunities identified. However, the author also found that identification of highly innovative opportunities requires a versatile cognitive strategy that includes both analytical processing and intuition.

The review of Baldacchino et al. [2] revealed that research on intuition cannot be located in one single field of research, but it is dispersed in different fields like across entrepreneurship, general management, organization studies and psychology journals. Also, these authors mention that intuition is association with four important characteristics. The first is related to definitions which claim that intuition led to a sense of “‘knowing’ without knowing why” [14, p. 279]; and it is considered to originate beyond the conscious thought and without conscious deliberation. The second characteristic is that intuitive processes are associative and holistic that is linked to perception and pattern recognition. The third important characteristic of institutive approach is that emotions and affect play a key role in intuitive processes [7, 27]. This is seen in using the term “gut feeling” for intuition [12]. The fourth characteristic is that experience and expertise are considered to play a vital role in intuitive processing, and it is thought that intuition is lined to domain-specific experience and expertise [7].

Orlandi and [25] conducted a study on 251 managers that had responsibility for organizational decision-making processes. Their findings suggest that both styles (intuitive and analytical style) are relevant in the actual context characterized by mobile technologies. Their conclusion is that intuition still has a central role in managers' decision-making processes. On the other hand, these authors mention that in situations when the environment of the industry is highly dynamic, then analytical information processing play crucial role in organizational responsiveness and performance.

Gopaul and Rampersad [9] conducted a study in order to assess the strategic decision-making process in small and micro service enterprises in South Africa. It was a qualitative approach that captured the dimensions of the decision-making process. The data collection techniques consisted of semistructured interviews with ten respondents, four focus groups with five respondents per group and five businesses that were chosen for observation. Main findings of the study showed that the preferential mode of decision-making was inclined towards intuitive tendencies on the intuition-rational decision-making continuum rather than analytical proficiencies. The decision-making process was pivoted on the intuitive decision-making tendencies of the business owners. The findings support the thesis that decision strategies were of iterative and informal style and were opposed to a procedural rational style. This study found that the phases of the strategic decision-making process were uncomplicated among the business owners. The process constituted of the following phases: (1) information gathering, (2) interpretation, and (3) options for implementation. However, the phases in the process were non-sequential and allowed overlaps and interconnectivity in the phases of decision formation rather than a step-by-step approach to making decisions.

Lebefromm [20] conducted a study to explain and proof higher predictive efficiency when using predictive analytics based on machine learning as well as more accurate future-oriented business. He showed the development of analytics through description of evolution of different tools. Traditionally, it was about standard reports using graphics to visualize. Further development was about creation of reporting system that allowed users to select ad hoc figures and calculate key figures. Afterwards, additional information systems were created for better visualization and faster recording of key figures that were relevant to decision-making (i.e., Balanced Scorecard). The advancement of technology and establishment of business warehouse system enabled creation of a data pool for interdisciplinary reporting. Eventually, all these systems were merged into a single reporting system, called Business Intelligence (BI). The availability of big data enables discovery of relationships between the data. Finally, predictive analytics lead the way to more intelligent market processes that were useful for business decisions. These arguments are in favor of predictive analytics. The conclusion is that if a company that does not use the new technology of data science and the associated possibilities for making future oriented decisions, it will be eventually overtaken by competition. However, he notes that usually the prediction is based on the experience of decision makers which is more into intuitive model.

Merino-Núñez et al. [21] claims that before making any decision, it is necessary to understand implications and consequences. Apart from that, the authors stress that any decisions cause a chain of events in motion. Accordingly, decision makers must be sure what is to be done and to be convinced that it is the right alternative. This argument is in favor of analytical approach. These authors conducted descriptive and quantitative research with an aim to analyze the importance of good decision-making in the business sector. Therefore, they surveyed companies in Peru and Chile. The sample size of the strata by country was 260 for Peru and 124 for Chile. However, the result of the study shows that there is a low level of knowledge and application of qualitative and quantitative models in the decision-making process of the business sector during the COVID-19 pandemic in Peru and Chile during 2021.

The table shows that only one study out of ten clearly favors analytical approach, while two studies clearly favor intuitive approach. The other seven studies take combined approach and show different patterns when it comes to prevalence of intuitive and analytical style.

4 Discussion

The results show that situation is not black and white regarding prevalence of one style. It seems that there is a combination that in early-stage intuition is crucial while analysis dominates in the latter stages. The above-mentioned finding matches the results from the study of [24] who discuss whether intuition and analytics are two sides of the same coin. They quote de Groot [3] who analyzed how grand chess masters used their intuition to recognize the next moves which required close examination and this process allowed the masters to change to analytical mode according to circumstances. In the book named “Thought and Choice in Chess,” de Groot [3] describes this transition which provides additional time for reflection on next move. Grand masters made visualization of moves (mental stimulation) and were able to predict the less rewarding moves and were left with a single move that was considered playable. Okoli and Watt [24] explain the rationale behind this process which considers intuition as default thinking mode that provides additional mental energy that is afterwards used to perform the more difficult (non-routine) tasks. The analytical mode is tuned on when intuition cannot solve the current problem or when there is a need for justification of the acted.

Another contribution to the debate in order to make things clear, is the study of Dörfler and Ackermann [5] who use the analogy of the human eyes to provide example how intuitive and analytical systems generally operate. The intuitive mode is compared to the peripheral vision which ensures that operators have good awareness of their surrounding environment, and this implies that environmental cues are tracked alongside one main task that is performed in the moment. On the other hand, the analytical mode is compared to the foveal functioning of the eyes. Analytical mode focuses on one element at a time (i.e., the conscious element of the decision maker). The conclusion from this finding is that the lack of flexibility of the analytical

mode provides explanation why during crisis in the environment, analytical mode is not used as a viable option. Another important finding worth mentioning is the research of Efremov [6] who found that emotions play a role in safety climate e.g., emotions that employees have about the organization are in line with employees attitudes towards safety climate.

In line with the results of the study is the study of Gustafsson's [10] who has shown that intuitive processing is used by entrepreneurs in the context of higher rather than lower uncertainty. When there was a context with lower uncertainty then analytical processing was more likely to be used. However, this was a case only among expert entrepreneurs and not among novices. However, there are some contrary results on behalf of Baldacchino [1] that deserve future attention. The author found that experienced entrepreneurs were more intuitive and cognitively versatile (i.e., scoring high on both intuition and analysis) than less experienced entrepreneurs, regardless of the level of task uncertainty.

There are limitations of the current study which are common and general for research in the field. First, the study focused on managerial decision-making process in the perspective of analytical and intuitive style. The study did not conduct meta-analysis approach as a methodology. Future studies on the topic can be conducted using systematical review focused on combination of analytical and intuitive decision-making styles. Second, the study aimed to provide recommendations for digital reality; however, studies including digital reality was limited. As a suggestion for future research, studies measuring managerial decisions using digital platforms, such as Metaverse™ and SecondLife™ could be conducted. Last, because of the dearth of the evidence-based research, it was hard to support perspectives based on the practices.

The further research in the area could be conducted in different settings with different populations and related directly to occupational safety and employee well-being. As the world experienced measurements and closures because of COVID-19 pandemic, the research focusing on managerial styles based on distance work could be conducted. Especially, both national and international companies having employees working from their houses can be included in studies and use the findings of this study.

5 Conclusions

The conclusions from current study are intended to be practical implications for managers in occupational context space when reaching decisions about occupational safety. The study summarizes current empirical findings in a new way through comparison of existing knowledge. The aim is to propose framework for managers that they can use for decision making in occupational context based on current studies. A such, it outlines key steps that managers need to do during decision making in order to transfer these findings to occupational safety. Decisions about occupational safety are made every day in different situations and therefore using the proposed

framework will ease the decision-making process. It should be accented that intuition is being utilized in the first steps of decision-making process when decisions about potential topics are explored (opportunity identification or bottle neck detection). Afterwards analytical style is used to define which topics and potential outcomes to test. Looking at the big picture, intuitive style is being utilized when final decisions are being made. Using these approaches at the same time in the process of decision-making can help experts and employers communicate more efficient about safety with employees and customers. Apart from those applications, safety managers can apply these principles in everyday work when advising management for actions that improve occupation safety of employees. These conclusions should serve as a guideline to managers in occupational context when to use intuition over analytics and will improve the decision-making process and contribute to informed decision making in order to decrease injuries and fatalities at work. Last, evidence-based studies including public and private organization could help policy makers and administrators/managers create new policies to increase productivity, well-being, whole life balance, and life satisfaction.

Acknowledgements To be included in the resubmission phase.

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Shift Work, Satisfaction with Work Schedule, and Well-Being: An Analysis in the Health Sector



Daniela Costa and Isabel S. Silva

Abstract Shift work, especially if it involves night work, has been associated with several consequences for workers, not only in terms of health, but also in other spheres of life such as family life. In general, the greater difficulty of this schedule is owing to the requirement to invert the sleep-wake cycle and the need to work in periods that are highly valued from the social perspective. In the analysis carried out, two work schedules (shift work versus normal hours) were compared in terms of satisfaction with work schedule and well-being. Data were collected online that involve 386 healthcare professionals (273 shift workers and 113 day workers). The results indicate that there are differences in satisfaction with work schedule and well-being depending on the work schedule. Specifically, shift workers have lower satisfaction and lower well-being as compared to day workers. In both groups, satisfaction with work schedule was positively correlated with well-being. In shift workers, differences were found depending on the gender and age of the children. In this group, a correlation was also observed between well-being and the age of workers. Finally, the importance of implementing strategies that can minimize the impact of shift work has been discussed.

Keywords Work schedules · Psychosocial risks · Health professionals

1 Introduction

The implementation of nonstandard work schedules such as shift work or night work has been increasing in the recent decades [5, 17].

Portuguese legislation defines shift work as “any organization of teamwork in which workers successively occupy the same jobs, at a given pace, including rotating,

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continuous or discontinuous schedule, and may perform work at different times in a given period of days or weeks.” (Article 220°, Law No. 7/2009, of February 12). According to the *Sixth European Working Conditions Survey*, shift work is most common in health (41%), transport (33%), industry (28%), and trade and hospitality (28%) [8].

Shift work, especially involving work at night, is associated with several problems in terms of workers’ health. In fact, the literature has found adverse impacts of shift work on sleep (e.g., [1, 3]), cardiovascular system (e.g., [22]), and well-being (e.g., [1, 5]) among others.

In terms of well-being, the qualitative study by McHugh et al. [12], with eight focus groups and 43 interviews, found that shift workers described their work schedule as detrimental to their well-being. Likewise, in the study by Suleiman et al. [21], workers reported that nonstandard work schedules, especially those involving irregularity, unpredictability, and longer duration, represented the greatest obstacles to their well-being. Other authors (e.g., [1, 15]) have also found a negative association between shift work and the well-being of workers subjected to it.

Shift work can also trigger problems in terms of organizational variables such as job satisfaction. For example, in the study by Ferri et al. [9], carried out in an Italian context, nurses who worked in shifts showed lower levels of job satisfaction than nurses working regular hours. In the same sense, Jaradat et al. [10] found that shift workers reported lower job satisfaction than day workers. Other authors (e.g., [2, 4, 6]) have also found these negative effects of shift work on job satisfaction. These consequences gain greater prominence in the light of findings of authors such as Nakata [14], wherein they observed that the relationship between 12 h shifts and depressive symptoms is mediated by job satisfaction. Satisfaction with working hours has also been related to variables such as physical and psychological health, reconciliation with life outside the company, or organizational support (e.g., [4, 18, 19]). For example, in the study by Peters et al. [18], shift workers who had more social support and job autonomy and lower job demands were the most satisfied with their work schedule. On the other hand, Moradi et al. [13] found that shift workers who voluntarily chose shift work were more satisfied with their schedule than those who were forced to work shifts. In this sense, worker involvement in managing their own work schedule may be an important factor in adapting to shift work.

This paper presents partial results of a broader research project on the impacts of shift work on family and social life. Specifically, this work analyzes the impact of shift work on satisfaction with work schedules and well-being comparing two groups: shift workers and day workers. Regarding the shift workers, the aim is also to understand the role of organizational support in the management of work schedules. Finally, differences will be analyzed in terms of sociodemographic variables such as age, gender, and age of children in the evaluated dimensions, namely satisfaction with work schedules and well-being. It should be noted that data from the health sector will be used, which, as previously mentioned [8], is one of the sectors with the highest prevalence of shift work.

2 Materials and Methods

2.1 Sample

The sample consists of 386 workers in the health sector, of which 273 are shift workers and 113 are day workers (Table 1). Shift workers were allocated rotating shift systems that included rotation between different shifts (morning, afternoon, and night) and weekend work. In contrast, day workers worked from Monday to Friday during the day at fixed times. The data have a national geographic distribution, with Faro (26.9%), Viseu (21.0%), and Porto (10.1%) as the most represented districts.

As shown in Table 1, most participants are female (76.7%), with higher education (91.2%) and a mean age of 40.50 years ($SD = 8.64$). In turn, Table 2 presents the family characterization of the participants. All participants, regardless of their marital status, cohabited with a partner, on average, for 11.67 years ($SD = 8.99$), and more than 70% had a child up to 12 years old.

In professional terms, participants had been at the current work schedule for an average of 13.51 years ($SD = 8.90$). It should also be noted that in terms of health professions, most workers were nurses (56.5%). Besides nurses, the main groups were physicians (19.7%), operational assistants (5.9%), senior diagnostic and treatment technician (5.9%), and technical assistant (5.7%).

Table 1 Sociodemographic characterization of the participants

Variable	Shift work (n = 273)		Normal (n = 113)		Total (N = 386)	
	n	%	n	%	n	%
Gender						
Female	206	75.5	90	79.6	296	76.7
Male	67	24.5	23	20.4	90	23.3
Age						
M (SD)*	38.94 (8.16)		44.27 (8.64)		40.50 (8.64)	
Marital status						
Married	156	57.1	77	68.1	233	60.4
Union	114	41.8	36	31.9	150	38.9
Divorced	3	1.1	–	–	3	0.7
Education level						
9th grade	–	–	1	0.9	1	0.3
12th grade	20	7.3	13	11.5	33	8.5
Higher education	253	92.7	99	87.6	352	91.2

* M (Mean), SD (Standard Deviation)

Table 2 Family characterization of the participants

Variable	Shift work (n = 273)		Normal (n = 113)		Total (N* = 386)	
	n	%	n	%	n	%
Number of years of marriage						
M (SD)**	10.42 (8.07)		14.69 (10.32)		11.67 (8.99)	
Number of people household						
2 people	93	34.1	31	27.4	124	32.1
3 people	87	31.8	19	16.8	106	27.5
4 people	75	27.5	47	41.6	122	31.6
5 people	15	5.5	13	11.5	28	7.2
6 people	3	1.1	3	2.7	6	1.6
Children's age						
Under 6 years	98	55.1	37	46.3	135	52.3
7–12 years	37	20.7	19	23.7	56	21.7
13–18 years	29	16.3	13	16.3	42	16.3
Over 18 years	14	7.9	11	13.7	25	9.7

* The N obtained may be different from the sample size (N = 386) due to missing values in some variables; ** M (Mean), SD (Standard Deviation)

3 Instruments

3.1 Sociodemographic Questionnaire

The questionnaire consists of sociodemographic questions (e.g., gender, age), professional (e.g., profession, seniority in work schedule), and family questions (e.g., number of years of marriage/union, age of children).

3.1.1 Scale of Organizational Support in Work Schedule Management [OS]

Scale developed by [20]. It aims to assess the worker's perception of the organization's support in managing their work schedules. It consists of 4 items (e.g., “*In general, when workers need to change shifts, your organization responds favorably*”), assessed on a 5-point Likert-type scale (1 “Strongly disagree” to 5 “Strongly agree”). The higher the score, the greater the perceived support in managing work schedules. The value of Cronbach's alpha is 0.84.

3.1.2 Scale of Satisfaction with Work Schedules [SWS]

Scale developed by Silva [20]. It aims to assess workers' satisfaction with their work schedule. It consists of 4 items (e.g., "*Compared to others, your work schedule is definitely your favorite*"), assessed on a 5-point Likert scale (1 "Strongly disagree" to 5 "Strongly agree"). The higher the score, the greater the perception of satisfaction with work schedules. The value of Cronbach's alpha is 0.89.

3.1.3 Personal Well-Being Index [PWB]

Scale originally developed within the International Wellbeing Group through the *Comprehensive Quality of Life Scale* [7]. It was adapted to the Portuguese context by Pais-Ribeiro and Cummins in 2008. It consists of 7 items (e.g., "*How satisfied are you with the security of your future?*"), assessed on a 11-point Likert scale (0 "Totally dissatisfied" to 10 "Completely satisfied"). As with the previous scales, the higher the score, the greater the perception of well-being. The value of Cronbach's alpha is 0.81.

3.2 Procedures

Data collection took place at a national level, in online format, through a project dissemination website created for this purpose (<https://projeto-horarios-de-trabalho6.webnode.pt>). Several health professional unions (e.g., nurses, physicians) as well as public and private hospitals were contacted. Once participation in the study was accepted, the organizations disseminated the study to their members or workers. All participants had access to an informed consent provided in each online questionnaire. Data collection was carried out between July 2021 and August 2022. The project obtained a favorable opinion from the Ethics Committee of the University of Minho (CEICSH 098/2020) and is part of a PhD project funded by the Fundação para a Ciência e a Tecnologia (FCT) (SFRH/BD/147176/2019).

3.3 Data Analysis

Data were analyzed using the *Statistical Package for the Social Sciences* (IBM® SPSS®, version 28.0). Descriptive and correlational analyzes and group comparisons were performed. The assumptions for the use of parametric tests were also analyzed, and in case of non-compliance, non-parametric tests were used. In both cases, a significance level of $p < 0.05$ was defined.

4 Results

The non-parametric Mann-Whitney *U*-test indicated statistically significant differences between the group of shift workers and the group of day workers in satisfaction with work schedules ($U = 3726.50, p < 0.001$) and personal well-being ($U = 3726.50, p < 0.001$). Specifically, shift workers reported lower satisfaction with work schedules and lower personal well-being than day workers. Figure 1 graphically represents the differences between the two groups in the two analyzed variables—satisfaction with working hours (SWS) and well-being (PWB)—based on the respective mean rank.

Regarding to satisfaction with work schedules and in order to obtain a finer analysis according to the type of work schedules, the items were also analyzed individually (Table 3), with the mean, standard deviation, and median calculated for this purpose. It can be seen that the item least scored by shift workers was recommending their work schedule to other people.

Regarding to well-being, shift workers reported a lower degree of satisfaction at all levels as compared to day workers (Table 4). Considering only the results of the group of shift workers, it can be seen that “safety with the future”, “personal fulfillment”, and “health” are the least well evaluated aspects, while “safety on the streets” and “personal relationships” are the best evaluated aspects.

In terms of associations between variables, “Satisfaction with Work Schedules” was positively correlated with “Personal Well-Being” for shift workers as well as day workers (Table 5). Thus, the greater the perception of satisfaction with work schedules, the greater the perception of well-being. Considering only the group of

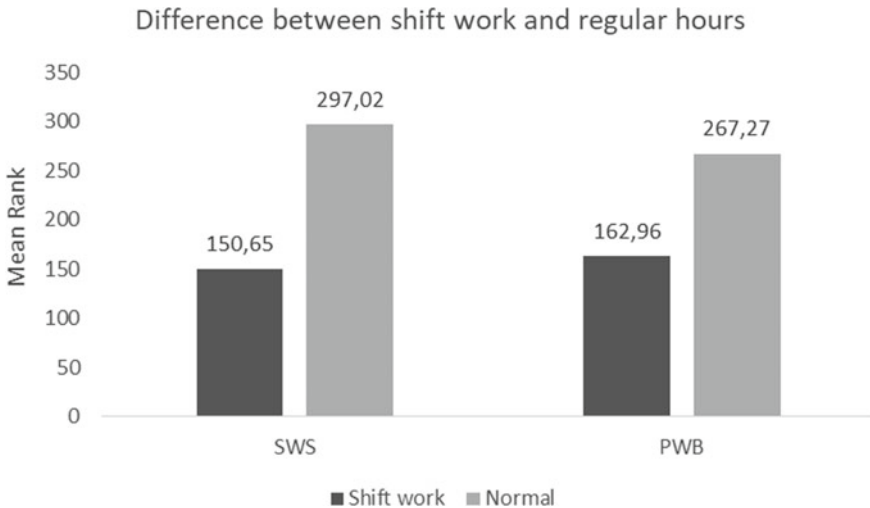


Fig. 1 Difference between shift work and regular hours in terms of satisfaction with work schedules (SWS) and personal well-being (PWB)

Table 3 Comparison between shift work and regular hours at the level of satisfaction with work schedules (items)

Aspects evaluated on the scale by [20] (items)*	Shift work		Normal	
	M (SD)**	Median	M (SD)**	Median
You are completely satisfied with your work schedule	2.10 (0.99)	2	3.61 (1.14)	4
Compared to others, your work schedule is definitely your favorite	2.15 (1.02)	2	3.80 (1.14)	4
Your work schedule has more positives than negatives aspects	2.39 (1.06)	2	4.01 (1.07)	4
You would recommend your work schedule to a family member or close friend	1.88 (0.99)	2	3.92 (1.19)	4

* All items were rated on a 5-point Likert scale (1 “Strongly disagree” to 5 “Strongly agree”)

** M (Mean), SD (Standard Deviation)

Table 4 Comparison between shift work and regular hours at the level of well-being (items)

Aspects evaluated on the scale by Pais-Ribeiro and Cummins (2008) (items)*	Shift work		Normal	
	M (SD)**	Median	M (SD)**	Median
Standard of living	5.44 (2.36)	6	7.16 (2.38)	8
Health	5.37 (2.69)	6	7.49 (2.27)	8
Personal fulfillment	4.88 (2.78)	5	6.83 (2.67)	7
Personal relationships	5.60 (2.43)	6	7.79 (2.21)	8
Safety on the streets	6.39 (2.56)	7	7.90 (1.98)	8
Connection to the community	5.44 (2.60)	6	7.64 (2.03)	8
Safety with the future	4.45 (2.75)	4	6.92 (2.55)	8

* All items were rated on a 11-point Likert scale (0 “Totally dissatisfied” to 10 “Totally satisfied”)

** M (Mean), SD (Standard Deviation)

shift workers, it was observed that “Organization Support” was positively correlated with “Satisfaction with Work Schedules” and “Personal Well-Being”. The greater the perception of support from the organization regarding the management of work schedules, the greater the satisfaction with work schedules and the well-being.

Table 5 Correlations between satisfaction with work schedules (SWS), personal well-being (PWB), and organizational support (OS), and respective Cronbach alphas (displayed diagonally)

	Shift work			Normal	
Variables	SWS	PWB	OS ⁺	SWS	PWB
SWS	(0.88)			(0.94)	
PWB	0.378**	(0.89)		0.673**	(0.91)
OS	0.513**	0.344**	(0.78)	–	–

⁺ This scale was applied only to shift workers

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Regarding the sociodemographic variables, statistically significant differences were found in terms of satisfaction with work schedules and/or personal well-being among shift workers, namely:

- as a function of **gender**: satisfaction with work schedules ($U = 5375.00, p < 0.01$) and personal well-being ($U = 5608.00, p < 0.05$). Men are less satisfied with their work schedules, and have a lower perception of personal well-being than women;
- as a function of **marital status**: satisfaction with work schedules ($U = 7588.00, p < 0.05$). Married workers are more satisfied with their work schedules than workers who live in a de facto union;
- as a function of **children's age**: personal well-being, $\chi^2(3) = 10.52, p < 0.05$. Mann-Whitney tests with Bonferroni correction revealed differences between the group of participants with children up to 6 years of age and the group with children having age between 7 and 12 years, $U = 1216.50, z = -2.944, p < 0.008$. Shift workers with children having age between 7 and 12 years report lower personal well-being than shift workers with children up to 6 years of age;
- as a function of **workers' age**: for shift workers, a negative association was found between personal well-being and workers' age ($rs = -0.145; p < 0.05$). That is, the older the shift workers, the lower the perception of personal well-being.

In the case of day workers, no statistically significant differences were found in terms of satisfaction with work schedules and personal well-being as a function of the sociodemographic variables mentioned above.

Regarding “seniority in the work schedule” and “number of years of marriage”, no statistically significant associations were observed with satisfaction with work schedules and well-being in both groups of workers.

5 Discussion

The results point to the impact of the type of work schedules on satisfaction with work schedules and personal well-being, with shift workers being less satisfied and having a lower perception of well-being as compared to day workers. Overall, these

results corroborate previous studies (e.g., [1, 2, 6, 12]) that found the same type of consequences for workers.

Considering the evidence available on this issue, it is important to try to minimize the impacts of shift work on the workers. As noted by Costa et al. [6], flexible working time can have a beneficial effect on the health and well-being of workers. Furthermore, according to the same authors, flexibility has been the most important factor influencing job satisfaction. In fact, the joint management (i.e. organization and worker) of work schedules can help minimize the impacts of shift work. In this sense, Moradi et al. [13] found that workers who voluntarily chose their work schedule were more satisfied with their work schedule.

The results also pointed to a positive relationship between satisfaction with work schedules and personal well-being, i.e., the greater the job satisfaction, the greater the workers' perception of well-being. These results have also been found in the literature in studies such as Carneiro and Silva [4] or Nakata [14]. For example, in the study by Carneiro and Silva [4], satisfaction with work schedules was positively correlated with the workers' perception of physical and psychological health.

The interdependence between the various spheres of an individual's life makes good management of work schedules fundamental. In addition to the strategies listed above, the organization's support in this management can also play an important role in the process of adaptation to work schedules. The results obtained in our study indicating a positive association between such support and satisfaction with work schedules and the perception of well-being. The study by Carneiro and Silva [4], also carried out with health professionals, observed an association between job satisfaction and the perception of support from the organizational context. While interpreting the results, one should take into account their limitations, namely the fact that they only concern the health sector, which is why it is recommended that they should be extended to other sectors of activity. In addition, the perspective of third parties (e.g., spouses) can be used to understand the various effects associated with this work arrangement.

6 Conclusions

Shift work, especially involving night work, has an impact on the health and well-being of workers as well as on their satisfaction with work schedules. In this context, strategies such as greater flexibility and workers' involvement in managing their own work schedules, provided by the organizational context, are fundamental in reducing the observed effects.

Acknowledgements The authors express their gratitude to all the participants of the research as well as to the public and private entities that collaborated in the dissemination of the research among their workers, such as the Centro Hospitalar Universitário do Algarve.

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Stress Adaptation Profiles in Higher Education Students: Relationship with Coping and Burnout



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Abstract This study sought to understand whether different stress and cognitive appraisal profiles corresponded to differences in students' coping and burnout. The sample included 547 students from four university courses aged 17–52 years ($M = 20.6$; $SD = 4.4$). The assessment protocol included: the Stress Questionnaire for Students, the Primary and Secondary Cognitive Appraisal Scale, the Reduced Coping Inventory, and the Shirom-Melamed Burnout Measure. The results showed that work overload and academic evaluation were the main sources of stress, and there was a higher use of adaptive coping strategies to cope with stress. Students with a higher stress profile and moderately positive cognitive appraisal profile used less adaptive coping strategies and showed higher levels of burnout. In summary, these findings may be used to develop intervention strategies focusing on students' ability to manage stress and how they appraise their academic activity.

Keywords Cognitive appraisal · Burnout · Coping · University students · Stress

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1 Introduction

Stress is intrinsic to several life contexts and affects people of different age groups [1], being understood as a condition that combines physiological and psychological elements and results from a deficit in the individual's perception of their resources to cope with the situation to which they are exposed [23]. In other words, when people feel that they do not have sufficient skills and resources to cope with the demands of the situation, dysfunctions in human functioning may arise [20]. The same happens with higher education students, considering that their entry into this education cycle represents an essential step in their life cycle and may be associated with situations capable of generating stress [30]. Specifically, starting a Higher Education course requires an adaptation to a new life stage, which may affect students' personal, affective, cognitive, social, and professional development [23]. Therefore, it can generate stress and anxiety, and depending on how the student copes with the situation, it may interfere with academic performance [3, 27].

To better understand the reactions to stressful events, it is essential to know the role of cognitive appraisal [12]. Cognitive appraisal represents how individuals evaluate or judge the personal meaning of a stressful event and its importance for their well-being [22], and it encompasses two different processes: the primary and the secondary cognitive appraisal. The primary cognitive appraisal refers to how the individual evaluates the situation and the importance they attach to it, in other words, primary cognitive appraisal indicates the extent to which the stressful situation is evaluated as challenging or threatening [4, 15]. On the other hand, secondary cognitive appraisal focuses on the individual's coping resources to deal with the stressful event [4, 11].

In this study, we draw on this transactional perspective of adaptation to stress to understand how university students are exposed to occupational stress, how they evaluate academic stressors (primary and secondary cognitive appraisals), the specific strategies they use to cope with these stressors (coping strategies), and the type of burnout reactions they may experience in their activity. In general, the literature on stress in university students has shown that students are exposed to heightened levels of pressure and stress and, therefore, may evidence various adverse reactions at the physical and psychological levels [8, 29].

Studying these relationships is important because it may provide relevant information about how students assess, cope with, and react to stress in the academic environment. However, there is still not much evidence about the possible combination of stress and cognitive appraisal, namely that they may correspond to differences in how students cope with stress (coping strategies) and the type of reactions they manifest to stress, such as their experience of burnout. In this sense, this study started by defining profiles of lower and higher stress perception and profiles of worse or better cognitive appraisal of the student activity to explore possible differences in coping strategies and burnout experience. More simply, do different ways of assessing stress and student activity correspond to differences in how students deal with stress and how they feel daily?

Given these aspects, this study examined whether different stress and cognitive appraisal profiles correspond to differences in students' coping strategies and burnout experience. Based on this objective, the following hypotheses were defined:

Hypothesis 1: Higher stress profiles in student activity correspond to the use of less functional coping strategies and higher burnout levels when compared to lower stress profiles;

Hypothesis 2: Less positive cognitive appraisal profiles of student activity correspond to using less functional coping strategies and higher burnout levels when compared to more positive cognitive appraisal profiles.

2 Materials and Methods

2.1 Participants

A total of 556 students participated in this study; however, the total sample consisted of 547 students. Regarding students' courses, 267 were in Psychology (48.8%), 62 in Law (11.3%), 82 in Economics and Management (15%), 86 in Nursing (15.7%), and 50 in Physiotherapy (9.1%). The students identified the gender with which they identified, being included 451 female students (82.4%), 92 males (16.8%), and four students who did not disclose their gender (0.7%). The students' age ranged from 17 to 52 years old, with only one student having more than 50 years old ($M = 20.6$; $SD = 4.4$). Regarding the type of institution, 234 students attended private education (42.8%) and 313 public education (57.2%). Considering the year of the course curriculum, 216 were 1st-year undergraduates (39.5%), 88 2nd-year undergraduates (16.1%), 162 3rd-year undergraduates (29.6%), 23 4th-year undergraduates (4.2%), two 5th-year undergraduates (0.4%), 37 1st-year masters (6.8%), and 19 2nd-year masters (3.5%).

2.2 Measures

The evaluation protocol included the instruments described below. We tested each instrument's psychometric properties regarding construct reliability and construct validity. We used Cronbach's alpha measure of internal consistency (α) for reliability, for which values below 0.6 are unacceptable [24]. Construct validity was conducted through confirmatory factor analysis (CFA) to test the instrument's latent structure. To estimate the model fit, we used the following indicators: the chisquare goodness-of-fit statistics (χ^2) and the absolute index (χ^2/df), the Steiger-Lind Root Mean Square Error of Approximation (RMSEA), its 90% confidence interval and p -value for H_0 : $RMSEA \leq 0.05$, the standardized root-mean-square residual (SRMR); the Comparative Fit Index (CFI) and its p -value; and the Tucker-Lewis Index (TLI)

[24]. The cut-off measures followed the most acceptable criteria described in the literature [19]. The chi-square goodness-of-fit statistics, testing for the significance of the discrepancy function, indicated the best fit of the global model to data for a lower statistical test value and probability higher than 0.05 [19]. Values of RMSEA in the range [0.05, 0.08] constituted an acceptable fit, and inferior to 0.05 indicated an excellent fit. SRMR of 0.05 and 0.10 is considered good and adequate fits, and inferior to 0.05 indicated an excellent fit. Values of CFI and TLI in the range [0.90, 0.95] indicated a good adjustment, and values higher than 0.95 an excellent adjustment [24].

2.2.1 Stress Questionnaire for Students (SQS; [16])

This instrument includes 28 items related to possible sources of stress associated with the student activity, organized into seven subscales: (1) academic performance: stress arising from the possibility of the student's underachievement (four items; α for this study = 0.88); (2) academic evaluation: stress resulting from the evaluation moments foreseen in the teaching-learning process (four items; α for this study = 0.75); (3) motivation: stress arising from low motivation to engage in study activities (four items; α for this study = 0.82); (4) learning: stress arising from the difficulty in following the teaching-learning process (four items; α for this study = 0.90); (5) work overload: stress arising from too many activities and school tasks (four items; α for this study = 0.91); (6) future expectations: stress arising from the student's disbelief about the usefulness and interest of studies for their future (four items; α for this study = 0.81); and (7) financial problems: stress arising from the infeasibility of continuing one's studies due to monetary difficulties (four items; α for this study = 0.89). Items are answered in a 5-point Likert-type scale (0 = No stress at all; 4 = Very high stress) with higher values indicating higher levels of stress in each dimension. Confirmatory factorial analysis (CFA) revealed good psychometric properties for this instrument, χ^2 (324) = 898.360, χ^2/df = 2.773, p < 0.001; RMSEA = 0.057, 90% CI [0.052, 0.061], p = 0.008; SRMR = 0.0534; CFI = 0.943; PCFI = 0.808; TLI = 0.933.

2.2.2 Primary and Secondary Cognitive Appraisal Scale (PSCAS; [17])

Evaluates primary and secondary cognitive appraisal with a total of five scales: (1) importance perception: where the participant evaluates the personal significance of the student activity (three items; α for this study = 0.87); (2) threat perception: where the participant evaluates the disruptive and harmful potential of the student activity (three items; α for this study = 0.83); (3) challenge perception: where the participant evaluates the stimulating and exciting potential of the student activity (three items; α for this study = 0.69); (4) coping perception: where the participant assesses the personal resources they believe they have to cope with the demands of their schooling (three items; α for this study = 0.84); and (5) control perception: where the participant evaluates the decision power they believe they have over their

school path (three items α for this study = 0.69). Items are answered in a 7-point Likert scale with higher values indicating higher levels of cognitive appraisal in each dimension. Instructions to fulfill the instrument were adapted to academic activity, meaning that participants answered the questions thinking about their student activity. CFA revealed good psychometric properties for this instrument χ^2 (80) = 254.38, χ^2/df = 3.18, $p < 0.001$; RMSEA = 0.062, 90% C.I. [0.054; 0.071], $p = 0.009$; SRMR = 0.0578; CFI = 0.957; PCFI = 0.729; TLI = 0.943.

2.2.3 Reduced Coping Inventory (Coping-R; Developed by Gomes [13], from the Work of Carver et al. [6], Carver and Scheier [5])

This questionnaire assesses students' coping strategies to deal with stress in their academic activities. It is composed of 16 items answered on a 5-point Likert-type scale, 1 (Never used it) to 5 (Used it often), assessing four domains of coping: (a) active coping: direct actions taken by the person to solve the problem at hand (four items; α in this study = 0.78); (b) humor: use of jokes or anecdotes designed to remove the negative charge of the problem (four items; α in this study = 0.94); (c) denial: use of thoughts designed to deny the occurrence of the problem or its potential negative consequences (four items; α in this study = 0.82); and (d) emotional support: talking and sharing the problem with others to get emotional help (four items; α in this study = 0.93). The proposed instrument showed good psychometric properties in this study, χ^2 (96) = 252.998, χ^2/df = 2.635, $p < 0.001$; RMSEA = 0.054, 90% CI [0.046; 0.062], $p = 0.186$; SRMR = 0.0425; CFI = 0.974; PCFI = 0.779; TLI = 0.967.

2.2.4 Shirom-Melamed Burnout Scale (SMBS; Shirom and Melamed 2006; Adaptation [33])

Evaluates three dimensions of burnout: (1) physical fatigue: feelings of physical tiredness in the face of work, translating into a decrease in physical energy (six items; α for this study = 0.94); (2) cognitive weariness: feelings of cognitive weariness in the face of work, translating into decreased thinking and concentration capacity (five items; α for this study = 0.93); and (3) emotional exhaustion: feelings of emotional fatigue when dealing with others, which is translated by decreased cordiality and sensitivity to other people's needs (three items; α for this study = 0.85). Items are answered in a 7-point Likert scale (1 = Never or almost never; 7 = Always or almost always). CFA revealed good psychometric properties for this instrument χ^2 (70) = 162.39, χ^2/df = 2.320, $p < 0.001$; RMSEA = 0.049, 90% C.I. [0.039; 0.059], $p = 0.567$; SRMR = 0.0385; CFI = 0.986; PCFI = 0.758; TLI = 0.982.

2.3 Procedure

This research began with the request for approval from the Ethics Committee for Research in Social Sciences and Humanities of the first authors' University. After a favorable response from the committee (CEICSH 034/2019), we started the execution of the work plan. The first step consisted of entering the instruments into an electronic platform (Qualtrics) that generated an online link for participants to complete the evaluation protocol. We collected the data in the middle of the first semester of the academic year—2021/2022. By accessing the electronic platform, students had information about the objectives, the voluntary and anonymous nature of their participation in this study, and the informed consent for those who decided to participate.

3 Results

3.1 Data Analyses Strategy and Preliminary Analyses

Using the G*Power, we calculate the sample size for the study. This analysis revealed that a minimum of 190 participants was needed, given a mean effect size of 0.30, alpha of 0.05, and statistical power of 0.80. We should recall that 556 students participated in this study, of which we removed nine because they presented values lower than or equal to two points on the “importance” subscale of the PSCAS, following the “cut-off point” indications suggested in the literature (see [14]).

After these procedures, we performed a set of analyses using IBM® SPSS® (version 28.0) and AMOS (version 28.0). The first one consisted of a cluster analysis, using the K-means approach, to create two distinct groups of profiles regarding the student's experience of academic stress (i.e., considering all the stress factors assessed by the SQS) and two distinct groups of profiles regarding the student's cognitive appraisal (i.e., considering the four factors assessed by the PSCAS: threat, challenge, coping, and control perceptions). Thus, for stress, we formed two groups, designated the group of students that experience a “lower level of stress” ($n = 237$) and the group of students that experience a “higher level of stress” ($n = 310$). Regarding the cognitive appraisal profiles, we also formed two groups of students—with a “moderately positive profile” of appraising the academic activity ($n = 253$) and with a “very positive profile” of appraising the academic activity ($n = 294$). Next, we analyzed whether the stress and cognitive appraisal profiles differentiated the groups in their respective dimensions (SQS and PSCAS subscales) using the t-test for independent samples. Afterward, we performed a chi-square test to understand if some variables, such as the type of course, year in the curriculum, type of institution, and gender, had a similar distribution across the distinct groups of students created according to the stress and cognitive appraisal profiles mentioned. The results of this test revealed detectable differences only regarding gender, with the proportion

of males and females being different in each group of stress profile; specifically, we found a higher proportion of female students in the group with a higher stress level profile and a higher proportion of male students in the group with a lower stress level profile [$\chi^2(2) = 23.74, p < 0.001$]. Subsequently, we controlled for this variable in the factorial MANCOVA analyses.

Finally, a factorial MANCOVA was performed to analyze the differences between the groups – two stress and two cognitive appraisal profiles. The stress and cognitive appraisal profiles were the independent variables, and the Coping-R and Burnout dimensions were the dependent variables. These analyses aimed to understand whether students who perceived their academic activity as more or less stressful and with a more or less positive cognitive appraisal profile had different coping strategies and levels of burnout.

3.2 Differences in Coping and Burnout as a Function of Stress and Cognitive Appraisal

This analysis sought to verify whether students with different stress and cognitive appraisal profiles had different perceptions of coping strategies and burnout in student activity. We began by using a t-test for independent samples to verify whether the profiles created differentiated the groups in the respective stress and cognitive appraisal dimensions. For the dimensions of stress, the results indicated statistically significant differences in academic performance, academic evaluation, motivation, learning, work overload, future expectations, and financial problems. Considering the mean values of these variables, we found that students with a higher stress level profile showed higher mean values in all dimensions of this questionnaire (see Table 1). Concerning cognitive appraisal, the results showed statistically significant differences between students with a moderately positive profile and a very positive profile in the perception of threat, challenge, coping, and control. For threat perception, students with a moderately positive profile of appraising their academic activity showed higher mean scores than students with a very positive profile, who perceived their academic activity as less threatening. For challenge perception, coping, and control perceptions, students with a moderately positive profile of appraising their academic activity had lower mean scores than students with a very positive profile, who perceived their academic activity as more challenging, revealing higher coping and control perceptions (see Table 1). These results indicated that the selected profiles differentiated the groups from one another, so we proceeded with the following analyses.

We performed a factorial MANCOVA (see Table 2) to investigate whether there were statistically significant differences in burnout levels and coping strategies among students with different profiles of stress (i.e., lower and higher levels of stress), and different cognitive appraisal profiles (i.e., moderately positive and very positive), controlling for gender. The results showed that the effect of the interaction

Table 1 Differences in stress and cognitive appraisal dimensions as a function of stress profiles and cognitive appraisal profiles

Stress profiles			
Stress dimensions (SQS)	Lower level of stress ($n = 237$) $M (SD)$	Higher level of stress ($n = 310$) $M (SD)$	t -test
Academic performance	2.4 (0.8)	3.3 (0.6)	$t (411) = -14.33, p < 0.001$
Academic evaluation	2.4 (0.8)	3.4 (0.5)	$t (373) = -17.15, p < 0.001$
Motivation	1.9 (0.8)	2.9 (0.7)	$t (458) = -15.88, p < 0.001$
Learning	2.2 (0.8)	3.3 (0.6)	$t (392) = -17.57, p < 0.001$
Work overload	2.7 (0.8)	3.6 (0.6)	$t (406) = -15.03, p < 0.001$
Future expectations	1.8 (0.9)	3.0 (0.8)	$t (545) = -16.64, p < 0.001$
Financial problems	1.3 (1.0)	2.5 (1.0)	$t (545) = -13.36, p < 0.001$
Cognitive appraisal profiles			
Cognitive appraisal dimensions (PSCAS)	Moderately positive ($n = 253$) $M (SD)$	Very positive ($n = 294$) $M (SD)$	t -test
Threat	3.5 (0.9)	1.2 (0.9)	$t (545) = -31.49, p < 0.001$
Challenge	4.0 (1.0)	4.8 (0.8)	$t (545) = 10.19, p < 0.001$
Coping	3.5 (0.9)	4.4 (0.8)	$t (545) = 12.04, p < 0.001$
Control	4.0 (1.0)	4.7 (0.8)	$t (484) = 9.49, p < 0.001$

between stress and cognitive appraisal was not statistically significant for burnout [Wilks' $\lambda = 0.99$, $F (3, 540) = 2.05$, $p = 0.106$, $\eta p^2 = 0.01$] nor for coping strategies [Wilks' $\lambda = 0.96$, $F (4, 539) = 0.65$, $p = 0.627$, $\eta p^2 = 0.01$]. Based on these results, we further investigated the simple main effects.

Regarding the differences according to stress profiles, the main effect result was significant for coping strategies [Wilks' $\lambda = 0.98$, $F (4, 539) = 2.20$, $p = 0.067$, $\eta p^2 = 0.02$]. There was a significant effect on the denial strategy, showing that students with a lower stress level profile had a lower mean value of denial compared to students with a higher stress level profile. In the case of burnout, the main effect result was also significant [Wilks' $\lambda = 0.87$, $F (3, 540) = 26.93$, $p \leq 0.001$, $\eta p^2 = 0.13$], with a significant effect on physical fatigue, cognitive weariness, and emotional exhaustion.

Table 2 Differences in coping and burnout as a function of stress and cognitive appraisal profiles

Dimensions		Stress profiles				Cognitive appraisal profiles				Interaction (stress × PSCAS)					
		Lower level of stress <i>M (SD)</i>	Higher level of stress <i>M (SD)</i>	<i>F</i> (1,542)	<i>p</i>	<i>ηp2</i>	Moderately positive <i>M (SD)</i>	Very positive <i>M (SD)</i>	<i>F</i> (1,542)	<i>p</i>	<i>ηp2</i>	<i>F</i> (1,542)	<i>p</i>	<i>ηp2</i>	
<i>Coping-R</i>															
	Active coping	3.3 (0.1)	3.2 (0.0)	0.39	0.531	0.00	3.1 (0.1)	3.4 (0.0)	24.31	<0.001	0.04	0.18	0.669	0.00	
	Denial	2.3 (0.1)	2.5 (0.1)	8.67	0.003	0.02	2.5 (0.1)	2.3 (0.1)	1.65	0.200	0.00	0.18	0.671	0.00	
	Humor	3.2 (0.1)	3.3 (0.1)	1.67	0.197	0.00	3.4 (0.1)	3.1 (0.1)	3.87	0.050	0.01	0.02	0.900	0.00	
	Emotional support	3.5 (0.1)	3.4 (0.1)	1.02	0.314	0.00	3.3 (0.1)	3.5 (0.1)	3.78	0.052	0.01	2.48	0.116	0.01	
<i>SMBS</i>															
	Physical fatigue	4.7 (0.1)	5.4 (0.1)	48.54	<0.001	0.08	5.4 (0.1)	4.6 (0.1)	62.77	<0.001	0.10	0.34	0.563	0.00	
	Cognitive weariness	4.1 (0.1)	5.0 (0.1)	74.31	<0.001	0.12	4.9 (0.1)	4.2 (0.1)	47.46	<0.001	0.08	3.10	0.079	0.01	
	Emotional exhaustion	1.9 (0.1)	2.3 (0.1)	11.78	<0.001	0.02	2.4 (0.1)	1.9 (0.1)	24.63	<0.001	0.04	1.04	0.309	0.00	

Considering the mean values of these variables, we found that students with the lower stress profile perceived lower levels of physical fatigue, cognitive weariness, and emotional exhaustion compared to students with the higher stress level profile. For the cognitive appraisal profiles, the main effect result was significant for coping strategies [Wilks' $\lambda = 0.95$, $F(4, 539) = 7.04$, $p \leq 0.001$, $\eta^2 = 0.05$], showing a significant effect on the active coping strategy, where students with a moderately positive profile show a lower average value of active coping compared to students with a very positive profile, who show higher resources of active coping. In the case of burnout, the main effect result was also significant [Wilks' $\lambda = 0.87$, $F(3, 540) = 25.91$, $p < 0.001$, $\eta^2 = 0.13$], showing a significant effect on physical fatigue, cognitive weariness, and emotional exhaustion. The results showed that students with a moderately positive profile had higher levels of physical fatigue, cognitive weariness, and emotional exhaustion than those with a very positive profile.

4 Discussion

The results obtained in this study highlighted some interesting aspects. First, the stress and cognitive appraisal profiles found in this sample differentiated groups of students from each other regarding their experience of academic stress and cognitive appraisal of their academic activity. Concerning stress profiles, university students in the higher stress level group perceived more significant stress associated with academic performance, academic evaluation, motivation, learning, future expectations, financial problems, and work overload. In cognitive appraisal profiles, the perceived threat is highest in students with a moderately positive profile of appraising academic activity. Conversely, students with a very positive profile of appraising academic activity had a higher perception of challenge, coping, and control perceptions.

Another highlighted aspect is the differences in coping strategies according to stress profiles. In this case, the results indicated that students with a higher stress level profile used more denial strategies to cope with academic stressors than those with a lower stress level profile. Research has shown that problem-solving and emotion-centered coping strategies make people better cope with occupational stress [2]. In a study conducted in a university setting, the authors found that participants experienced specific organizational and professional stressors that gave rise to distressing emotions. Still, participants also used adaptive coping strategies (e.g., emotional support, humor) and proved effective in coping with stressors [28]. Also, regarding the stress profiles in this study, the differences in the students' experience of burnout were analyzed. In this case, we found that students with a higher stress profile had a higher perception of physical fatigue, cognitive weariness, and emotional exhaustion.

Given that burnout syndrome results from an affective reaction to chronic stress, where there is a gradual decrease in intrinsic personal resources [25, 31, 32], we expected that students with higher levels of stress would experience more significant physical fatigue, cognitive weariness, and emotional exhaustion. In a study of medical students, the authors found that higher levels of burnout were significantly associated

with fear of failure, lack of belief in what they were doing, lack of help or supportive resources, and uncertain future, that is, students experienced stressors related to academic achievement, motivation, learning, and future experiences [26]. In sum, these results allow us to confirm the first hypothesis of this study, which highlighted that profiles of higher stress concerning students' academic activity would correspond to the use of less functional coping strategies and higher burnout levels compared to those with profiles of lower stress levels.

This study showed that students with a very positive cognitive appraisal profile, compared to their peers with a moderately positive cognitive appraisal profile, used more active coping as a strategy to face the academic activity. Thus, the students in this sample who evaluated academic activity with a more positive cognitive profile tended to use a coping strategy based on active coping, assuming a greater ability to deal directly with academic stress. This pattern of results is in line with scientific research, which highlights the role of cognitive appraisal in coping strategies used to deal with stress [7]. The relationship between cognitive appraisal profiles and burnout is also noteworthy, with students who presented a moderately positive cognitive profile showing higher levels of physical fatigue, cognitive weariness, and emotional exhaustion. These results are in line with the theory in this area [12, 21] because if people interpret stressful situations more negatively, they tend to be less effective in managing the stress situation and, eventually, may end up experiencing more significant symptoms of burnout [9, 10, 18]. In sum, these results allow us to confirm the second hypothesis of this study, in which less positive cognitive appraisal profiles of student activity corresponded to the use of less functional coping strategies and higher levels of burnout compared to more positive cognitive appraisal profiles. All in all, the results of our study reinforced the need to develop intervention practices based on scientific evidence, allowing students to both learn stress control strategies and construct positive cognitive appraisals of academic activity in order to increase their ability to cope with the demands of university education and, consequently, increase their levels of mental health.

This study has some limitations to address in future studies. The results do not include students from all areas of university education, with a higher representation of students from the Psychology course and lower percentages of students from the remaining courses, and this also resulted in more female than male participants in our study because this course includes a majority of female students. Besides this aspect, there may be other variables capable of influencing the perception of stress and burnout, namely the characteristics of the course, the semester when data were collected, and the socioeconomic level. In future studies, a more consistent sample regarding gender and year in the curriculum would be desirable. In conclusion, this study shows the importance of analyzing how students experience their academic activity, reinforcing the importance of stress and cognitive appraisal profiles in coping strategies and the experience of burnout associated with student activity.

Acknowledgements This study was conducted at the Psychology Research Centre (CIPsi/UM) School of Psychology, University of Minho, supported by the Foundation for Science and Technology (FCT) through the Portuguese State Budget (UIDB/01662/2020).

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Teleworking Experiences During the Pandemic Among Managers of Clothing Trade Stores



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Abstract The resources presented derive from a broader research carried out in 2021 in several Portuguese clothing retailers. This chapter examines the results of the working conditions reported by a group of managers during the pandemic context, namely what was the experience of working in a teleworking scheme during the periods of mandatory confinement and returning to work in the store with all the contingency measures required by law to prevent contamination by Covid-19. The approach took into account different data collection procedures, namely the analysis of the contingency measures adopted in 2020 and 2021, the questionnaire on working conditions, and the testimonies collected through interviews with managers on their personal experience of teleworking during this period. The results show that the majority of respondents consider the working conditions to be favourable, indicating the company's constant concern about hazards and compliance with established safety rules and procedures, especially during the most critical period of the pandemic. The teleworking experience was more positive in the second period of mandatory confinement, due to the learning process when the pandemic broke out.

Keywords Working conditions · Remote working · Psychosocial risks · Covid-19

1 Introduction

The COVID-19 pandemic has significantly transformed the dynamics of the world of work. Firstly, more abruptly due to the great lack of knowledge about this new strain of the virus, and then due to the need to adapt in order to respond to the problems and to keep societies functioning. The perception of the high contamination potential and the lack of certainty about the consequences for the well-being of populations led

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P. M. Arezes et al. (eds.), *Occupational and Environmental Safety and Health V*, Studies in Systems, Decision and Control 492, https://doi.org/10.1007/978-3-031-38277-2_50

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several countries to introduce mandatory confinement periods at different times in 2020 and 2021 [8, 14]. This was the case of Portugal, where the government imposed periods of mandatory confinement for most socio-professional activities, as well as periods of conditioned professional practice, in which, only certain services/types of organisations were open due to certain safety rules and/or in which only some of the workers could be in the establishments [7].

These measures forced a profound reorganisation in work dynamic, with many workers going into lay-off and others shifting to teleworking. Everything happened very quickly, especially in the first half of 2020, with the changes having to be implemented without much planning. For example, many workers had to switch to the telework regime without ever having a history of providing activities in this format, which made the transition more difficult. A number of risks can be associated with teleworking, such as physical risks related to the conditions of the space, risks of Work-Related Musculoskeletal Disorders (WMSDs) due to long periods of sitting and working with Display Screen Equipment (DSE), psychosocial risks at work resulting from greater isolation and difficulties in reconciling, in the same space, the professional and personal spheres, but which ended up being exponentiated for those who had not planned to develop their professional life in this way and in their domestic space [5, 9, 12].

It was also the first time that many companies adopted this arrangement, which posed great difficulties and the possible adaptation. As noted by the European Agency for Safety and Health at Work (EU-OSHA) [5], it was a huge challenge for organisations to ensure, in a relatively short time and on an unprecedented scale, that workers had a safe option to work remotely and had access to a whole technological infrastructure that would allow them to work remotely in a consistent and continuous way. For this very reason, it is important to understand how these processes of change took place, in order to learn lessons for the future [9], even if the context of the pandemic experienced may not be repeatable.

In a certain way, it is the principle inherent in the research that underpins this text, which is based on a broader research carried out in 2021 in the various clothing stores of a multinational company operating in Portugal. The aim was to assess the psychosocial working conditions and to understand the pandemic impact on workers and on the work reorganisation that the company had to undertake in order to continue operating during that period, looking into the use of teleworking, lay-offs, dismissals of fixed-term workers and the conditioned opening of stores due to obligatory safety measures.

In the specific case of this text, the results on the working conditions during the pandemic context reported by a group of managers will be explored, namely what was the experience of working in a teleworking regime during periods of mandatory confinement and upon returning to in-store work with all the contingency measures required by law to prevent contamination by Covid-19.

It is important to bear in mind that the concept of teleworking and its application assumptions have already been present in the Portuguese Labour Code for many years (Law No. 7/2009 and subsequent amendments), but, its widespread application during the aforementioned 2020 and 2021 periods did not fully comply with the legal

requirements explained in the legislation, since its use, in many companies, resulted from the imposition of the government decree.

Telework is defined as “the performance of work carried out under legal subordination to an employer, at a place not determined by the employer, and through the use of information and communication technologies” [1, 2, p. 3]. This means that the worker chooses the place where the service is provided, and it is not mandatory to provide it at home, although this is the most common practice (working from home). However, the place or places must be specified, also as a guarantee for both parties, in order to insure insurance cover for accidents at work and occupational diseases and other Occupational Safety and Health (OSH) consequences.

Sometimes, the terms teleworking and remote working or working at a distance are confused, with indistinct uses, but it is important to emphasise that they are different concepts. The worker can be working remotely without being a teleworker. The teleworking regime is a way of working remotely or at a distance, assuming a more restrictive dimension. However, within the practice of teleworking itself there may be a variety of forms, namely: regular teleworkers who work at home or in another place of their choice, occasional teleworkers who work outside the employer’s premises (at home or in another place of their choice), and highly mobile teleworkers who work from multiple locations, including from home [5, 6].

The adoption of the teleworking scheme in Portugal needs to be formalised and included in the employment contract or in an addendum thereto [1, 2]. It is subject to mutual written agreement, and may involve permanent teleworking or alternating periods of distance work and face-to-face work. If the proposal for a teleworking agreement comes from the employer, the employee’s objection does not have to be justified, but if the proposal comes from the employee, the employer can only reject it in writing, stating the reasons [2]. However, OHS issues can be the basis for this refusal. The law defines that the practice of teleworking is prohibited for activities that involve the use of or contact with dangerous substances and/or materials, where it is not possible to ensure the necessary safety conditions to guarantee the health and physical integrity of workers [2].

A teleworker has the same rights and obligations as other workers, including OSH, and compensation for work accidents and occupational diseases. Therefore, it is up to the employer to ensure the necessary means to fulfil its responsibilities in terms of OSH, namely by complying with the measures required for the Decree-Law No. 349/93, on the minimum safety and health requirements for working with DSE [2, 11]. It should also promote occupational health examinations prior to introduction of teleworking and then carry out annual check-ups to assess the physical and mental fitness of the worker to continue working under this arrangement. In turn, the worker must allow access to the place where the service is to be provided, so that a proper assessment and control of safety and health conditions can be carried out [2].

Nevertheless, as mentioned above, many of these assumptions were not advocated in 2020 and 2021, because many workers switched to teleworking by legislative decree of the Portuguese government. The mutual agreement was therefore not respected. It was a transition by imposition, which also creates a specific scenario with its own peculiarities. These circumstances have to be considered when analysing

the phenomenon during the pandemic period of 2020 and 2021, which is why this study was developed.

2 Materials and Methods

This text stems from a broader study carried out in a multinational company with several clothing retail establishments in Portugal, with the aim of assessing the psychosocial working conditions in the organisation, also paying attention to a series of initiatives adopted during the periods of the Covid-19 pandemic (years 2020 and 2021), as was the case with the transition of professionals with the function of managers to teleworking during moments of mandatory confinement or conditioned professional practice that covered the company.

This chapter will focus on analysing the working conditions reported by the managers, namely what the experience of teleworking and returning to work in the store was like, and whether a number of mandatory safety measures were needed. The field work was carried out during 2021, and the data and results have been systematised since then.

The company's group of managers comprises 103 workers, 56.8% of whom are women. All have a permanent contract and work 40 h a week. The vast majority have been in their positions for several years, with 97.1% working for the company for three years or more. In the pre-pandemic period, the function was carried out in person in the store. Teleworking was used for the first time when the first general period of mandatory confinement was decreed in 2020.

The manager's main responsibility is to manage the store, in general terms or in its different aspects, including tasks such as managing and assigning work teams, stock management, accounting and financial reporting of the store, preparing information and training, and monitoring the functionality of the infrastructures. There may be different managers in a store, from the store manager to the functional managers, with responsibility for specific areas, such as human resources, specific clothing segments, etc.

The collection of data for the results that will be presented and discussed was supported by four main actions: analysis of documentation, visit and observation of the context of the stores, use of questionnaire and individual interviews. In terms of documentation, it is important to highlight the analysis of documents such as the contingency plan with the measures to be adopted in 2020 and 2021, and the educational materials that supported the information and training activities carried out at different stages to prepare and train the workers to implement safety measures in the stores during the pandemic. It should be noted that the questionnaire was applied digitally through the Google Forms platform. The link to the survey, which could be completed anonymously and confidentially, was accessible to each manager. The questionnaire had several blocks and parameters for characterising the psychosocial working environment in the company (eg, block A—with questions about the participants socio-professional characterization and their health conditions, the company's

OSH activities, etc.; block B—likert-type questions about psychosocial risk factors related to work, organisation, interpersonal relationships, connection with personal life, etc.; block C—questions about satisfaction and opportunities to improve working conditions), but here will be focused only indicators related to satisfaction with working conditions and with the safety measures adopted by the company in stores.

With regard to store visits, these were carried out to confirm in loco the implementation of the measures set out in the contingency plan. All the 10 stores were visited and associated with that observation, 20 interviews were conducted with store managers and/or human resources managers from different stores. The data from the interviews were not treated by store, but in aggregated way. The interview guide included general questions to explore the company's approach to OSH, the contingency measures and safety conditions in the stores and the personal experience of teleworking (e.g., general working conditions at the store; OSH aspects source of concern in the store; Personal balance of teleworking experience; Evaluation of contingency measures and safety conditions in the store during pandemic context).

3 Results

All data compiled and cross-referenced made it possible to assess a very positive global scenario, with professionals recognising the investment that the company has been making to ensure adequate OSH conditions for its employees. The different managers emphasised this reality, which was confirmed by the positive levels of satisfaction with the working conditions registered in the survey. Of the 103 managers, 74.8% were satisfied with their working conditions and 9.7% were very satisfied. No respondents were very unhappy, only 15.5% were dissatisfied.

It was also possible to verify, either through the documentation analysed and the testimonies collected, or from the visits to the stores, a proactive and structured organisational approach to OSH, even before the pandemic period. A very robust and consistent safety system was identified, showing a very positive performance and response capacity. This was clearly reflected in the response prepared to deal with the pandemic, facilitating the adaptation to the reality and the activity continuance. During periods when the stores were closed due to legal requirements, managers switched to teleworking in order to continue the management tasks that were pending and to prepare for the reopening of the stores when legal permission was granted to do so. The other professional groups (supervisors, staff, etc.) went into lay-off. When the stores gradually reopened, workers progressively returned to work, working in shifts and rotating to comply with the maximum number of people allowed in the premises. At that time, the managers switched to a hybrid system, with some days spent working from home and others in the store, depending on the planned schedule.

It was possible to verify the depth and robustness of the OSH preparations made to minimise the risk of contagion at different times. Care was taken to: (i) assess the risk of exposure to the biological agent Covid-19 in store operations; (ii) define measures to reduce the risk of exposure and contamination; (iii) provide the necessary

individual and collective protective equipment; (iv) inform and train the workers on the measures to be taken and the expected behaviour; and (v) carry out regular follow-up activities and communication between the stores and the internal OSH services in order to obtain information on the evolution of the situation.

The contingency plan developed covered several aspects and the specificities of store operation. Complementing it with meetings and training to help frame the overall context of its application was also considered relevant in the evaluation carried out. Of particular note were the training actions developed which allowed basic safety information to be covered during the re-opening of stores and included visits to the stores to explain the procedures and demonstrate the new safety measures and equipment to be used in the different locations. The training itself also covered safety guidelines related to the prevention of contamination by Covid-19 at different times in the workers' daily lives: before going to work; while commuting to work, depending on the mode of transport; when arriving at the store; during the working day, and when using the work areas; and when returning home.

All of this work clearly demonstrates the perceived sense of safety reported by the managers surveyed, as shown in Table 1. It can be seen that, despite the context, most managers felt safe working in the stores and felt that the company was concerned about the safety of the workers and had a response tailored to their needs.

The testimonies of the interviewees support this vision, with some even emphasising the external recognition the company has received or the good fortune they have to work in such an organisation:

Table 1 Perceived sense of safety and evaluation of company performance (%)

	1. Strongly disagree	2. Disagree	3. Agree	4. Strongly agree
Do you feel safe in doing your job during the pandemic period	0.0	6.8	31.1	62.1
Do you feel that your employer is concerned about the safety and health of workers during this pandemic phase	1.0	1.0	15.8	83.2
Has the company provided you with information/ training on the prevention of contamination by COVID-19 in your workplace	0.0	0.0	11.7	88.3
Has the company provided you with appropriate personal protective equipment to prevent the spread of COVID-19 in your workplace	0.0	0.0	10.7	89.3

Fortunately, (...) in terms of working conditions it is one of the best in the industry (...) as far as I know, there is no better, from canteens, independent changing rooms (...) in terms of facilities I think that (...) there is no better;

It is something that is often referred to (...) we even comment and joke among ourselves that we are lucky (...) to have such conditions;

During the ACT and ASAE visits we were congratulated for being the best place they had visited in terms of preparation for COVID measures.

Regarding the telework experience, opinions were mixed, as there were managers who assessed the situation positively and envisaged its use in the future, and others found it very difficult and did not intend to return to this situation. The interviews sought to explore precisely these three dimensions, i.e., what were the positive and negative aspects of the experience, and whether teleworking could be a future option for the company in the organization of work and its teams.

The testimonies recorded indicate an improvement in the experience from the first confinement to the second one, mainly because they there were better organised. In the first confinement, everything happened very quickly and nobody was prepared. In the second moment, the transition was already better structured, with timely provision of technological means, better organisation of working hours, activities and forms of control. Positive aspects of the experience were highlighted, such as, the ability to catch up on delayed tasks and having fewer interruptions. On the negative side, some managers hated the experience, as it was difficult to reconcile work with their children being at home and the need to work in the same space, or even because of increased stress and work overload.

The teleworking context of these workers was very specific, in that, due to the mandatory confinement, their children were also at home at the same time and had to follow the teleschool, which created immense difficulties in managing time and space. Teleworking outside of this pandemic context may not be as difficult for this segment of the population, as the remaining managers who did not have descendants made a more positive assessment of the experience. The employees did not rule out the possibility of teleworking in the future. They felt that, despite the fact that their role was essentially a store activity, it would be feasible and even beneficial to consider the possibility of having the option of working from home a whole day or part of a day during the week. This suggestion was widely shared in the interviews, in order to be studied and operationalised in the future. Table 2 lists some testimonies that illustrate these conclusions.

4 Conclusion

The results show that most managers consider the working conditions favourable, signalling the company's constant concern about hazards and compliance with established safety rules and procedures, especially during the most critical period of the pandemic. These data confirm what several studies have shown about the importance/influence of OSH and good working conditions on worker satisfaction and

Table 2 Testimonials collected from interviews—teleworking experiences

Negative aspects	“in the first confinement it was terrible, it was very stressful, I found myself working 16 h (...) my personal part of the house was in conflict (...) with my professional one” “the company asked us a lot (...) and the company didn’t give us those conditions, so we didn’t have the laptops, (...) there was a lot here (...) stress in the first confinement, in this second confinement (...) the company already gave us some conditions” “there were things in telework that I couldn’t follow up on, that I had to be in the store, that I had to see what was going on” “has never been in telework [before], in an initial phase there was some pressure, that is, we had three or four meetings a day (...) we learned a lot (...) now we realize that this is not the way” “my vision of teleworking is terrible, (...) it was very, very difficult to manage (...) the fact of having tasks (...) to fulfil and accompany my son in school activities (...) it was quite complicated and I often had to do tasks before they woke up”
Positive aspects	“There are a lot of projects that are left behind (...) and that we looked for in these two confinements (...) and that you can never do in a store (...) if you look at these two confinements and look at all the good things we can do” “It is useful, (...) we are constantly interrupted throughout the (...) day (...) effectively when we are closed out of here that we are not interrupted (...) so we are up to date and in practice and we can effectively catch up that we have” “what I could do at home for an hour at a time and the task was done, at the store it might take a whole morning, (...) and therefore my vision is completely different now”
Future perspectives	“managers should continue to have, for example, one day of telework per week, this is why, because in the store we are constantly being interrupted” “I think work flexibility could be something to be discussed (...) in the future, I don’t say when, I think our business is a very present business (...) in a reduced style, in a more reduced flexibility I think that It was important too.” “I think it was perfectly feasible if there was a need to work one day a week telecommuting from home (...) I prefer that to coming to the store and then locking myself in the training room” “I am an advocate of working as long as possible in the store (...) but maybe one day a week from time to time, the manager being able to manage this”

productivity [3, 4, 10]. For example, Chinda et al. [3] demonstrate that productivity tends to be higher when workers have high job satisfaction, recognise good safety implementation and receive adequate safety training. Also Shafie et al. [13] indicate that safety is an important factor in ensuring job satisfaction, as workers are satisfied with being able to work safely.

With regard to the teleworking experiences, they were diverse, with some managers liking it and wanting to be able to continue in the future and others who hated it and did not want to be put in that situation again. These testimonies support what the literature shows about the fact that teleworking can have both benefits and difficulties, depending on the specific circumstance of the teleworker [5, 6, 9]. The benefits highlighted include aspects such as saving time, not having to spend time

on transport, having fewer interruptions and easier focus on more complex tasks. These aspects are widely portrayed, for example, in the EU-OSHA report [5] on the subject. In terms of difficulties, many of the complications experienced arose from the exceptional context of confinement, in which workers with dependent children had to combine teleworking with teleschooling at the same time, often without the necessary equipment. Although this is a circumstance that may not be repeated if one of these workers returns to teleworking, the existence of this type of overlap is something that the company must check in advance, otherwise the experience will once again be very negative, cancelling out all the potential advantages that were mentioned above.

In any case, it was clear from the testimonies obtained that the difficulty of reconciling the two spheres of life (personal and professional) in the same space is a definite problem of the teleworking regime. The EU-OSHA [5] itself states that the blurring of boundaries between work and private life can be a greater problem for teleworkers, compounded by the responsibilities of caring for children or other family members. The fact that they may not have a dedicated space to work at home means that carrying out their activities interferes with family dynamics, because as they are developed in shared spaces (e.g. kitchen, living room, bedroom) and require restraining or changing the practices of other family members [5]. This lack of definition of access and use of spatial boundaries can cause friction, especially if other family members are not happy with these limitations, generating situations of tension, dissatisfaction and conflict [5]. Hence the need for a prior assessment of the conditions for the exercise of teleworking by each potential beneficiary worker [9, 12].

Another very clear idea is that the teleworking experience was more positive in the second period of mandatory confinement, due to the learning process from the first moment in the early phase of the pandemic and the greater preparation and organisation that was carried out. As managers are interested in considering this arrangement for the future, but in a fractional way (working remotely 1 to 2 days a week or on certain days of the month), good planning is needed to implement it. The experiences gained in 2020 and 2021 should serve as a basis for learning and the data systematised in the study demonstrate this potential. For this reason, aspects such as those listed will have to be considered, including OSH obligations.

As previously mentioned, the Labour Code lays down a set of requirements concerning to OSH. These demands must also be taken into account in teleworking. However, the results obtained showed that these aspects were not properly considered in the case of this company. Of course, there was the unpredictability of the context and the fact that it was not the company's choice (confinements were imposed by government decree), but for the future these issues will have to be duly implemented. For example, checking the conditions at the place where teleworking is carrying out, conducting the respective risk assessment, communicating the risks to which the teleworker is exposed at that workplace, timely provision of work equipment (namely a computer, telephone, internet connection, chair and desk with ergonomic features

adapted to the teleworker, etc.), annual occupational health monitoring, with assessment of medical aptitude before starting teleworking, the organisation of working hours and ways of controlling activities [2].

These were aspects that were not taken into account in the transition process to teleworking under study. This was largely due to the context of great uncertainty and lack of knowledge about the situation, but for the future this indulgence may no longer apply. Carrying out this study also made the company aware of this reality and of the considerations involved in integrating a teleworking system in the organization. In conclusion, it can be said that the objectives set were achieved, with the company itself recognising the added value of having this data. Although it was not possible to explore the full range of data in this text, due to size constraints, it is believed that it has nevertheless possible to highlight the usefulness of the study and the importance of companies in the same context undertaking the same reflective exercise.

Supports The publication was supported by FCT—Foundation for Science and Technology, within the scope of UIDB/00727/2020.

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Uncovering the Dynamics of Burnout, Stress, Anxiety, and Depression in Office Workers: An Experience Sampling Approach



Simão Ferreira , Inês Silva , Matilde A. Rodrigues , and Nuno Rocha

Abstract Stress, anxiety, depression, and burnout are recognized as prominent mental health challenges within the workplace, and there is evidence to suggest that several psychosocial risk factors may be associated with the occurrence of these mental health problems. However, few studies have relied on the experience sampling method. To address this lack of knowledge, the present study aimed to characterize these mental health challenges in office workers and identify risk factors associated with their occurrence. The study involved a sample of 31 knowledge workers from a large company. To address the variables of interest, questionnaires were administered to the participants. The results revealed that perceived productivity, level of challenge, level of competence, and level of sleepiness were positively correlated with daily stress levels, whereas psychosocial factors such as workload and time available to perform tasks were found to exacerbate stress. These findings highlight the need to consider these risk factors in prevention and intervention programs aimed at promoting mental health in the workplace. In the future, integrating these factors as predictors of mental health problems in automated detection tools for stress, anxiety, burnout, and depression may prove beneficial.

Keywords Psychosocial factors · Emerging risks · Psychosocial risks · Mental health · Office workers

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1 Introduction

Attaining job satisfaction has become increasingly challenging for a significant number of workers. They experience physical and mental fatigue which, coupled with a sense of being unable to cope with the constant changes in the modern workplace, has engendered a negative dynamic between employees and their work environment [11]. Additionally, with companies increasing exporting and expanding their markets, there has been a surge in business volume, particularly in the service sector. This contributes to the challenges that workers face daily. As a result, there has been a constant need to reformulate work organization models and human resource management strategies [4].

Psychosocial risks in workplaces have gained significant attention because of their increasing prevalence [17, 20]. According to the World Health Organization report, about 15% of working-age adults may experience a mental disorder at some point [26]. Notably, levels of Burnout, stress, anxiety, and depression in Portugal have shown a significant rise, as documented in recent research [2]. Studies have strongly related numerous psychosocial risk factors present in working settings to changes in workers' mental health [12, 18]. These factors include excessive workload, time pressure, role conflict, limited participation in decision-making, inadequate cooperation or support from supervisors and colleagues, job dissatisfaction, poor work relationships, inadequate salaries, and exposure to psychological or sexual harassment, as well as violence from third parties [1, 5, 11, 10, 16].

Given the importance of identifying factors that contribute to mental health problems over time, understanding how the work environment impacts worker well-being is crucial. In particular, office workers face a unique set of challenges, as factors such as task type, workload, and daily stress can vary significantly throughout the workday and week [19]. To address this issue, this study employs the experience sampling method to examine the occurrence of depression, anxiety, stress, and burnout in office workers and aims to identify the associated risk factors.

2 Materials and Methods

2.1 Sample

The study sample consisted of 31 office workers from a large company who were over the age of 18 and performed computer tasks for 8 h per day. Informed Consent Forms were signed by all participants who demonstrated cognitive ability to understand and consent to the study details. Voluntary participation was based on individual interest and eligibility based on inclusion criteria.

2.2 Instruments

Initial Questionnaire: The participants filled out an initial questionnaire that included questions about their socio-demographic data (age, gender, BMI, marital status, company position, years of formal education) and health data (amount of coffee, hours of sleep, alcohol consumption).

Bi-Daily Questionnaire: A bi-daily questionnaire appeared as a pop-up window on the employee's computer, with defined and scheduled times throughout the day for the employee to answer. This questionnaire, consisting of 9 questions, aimed to classify the employee's level of stress, perception of productivity, and available time for completing tasks. Furthermore, the questionnaire contained a question with various items to identify the reasons behind the reported levels for the first three factors. The research team developed scales to evaluate these variables, ensuring accuracy and consistency in the data collection process.

The level of stress was obtained through a Likert-type scale of 10°, where the attribution followed the present lines: “0 = No stress (I feel calm and relaxed)” and “10 = Extreme stress”. The worker's perception of productivity was rated using a scale, ranging from “1 = Less than usual” to “3 = More than usual”. Regarding, the time the participant had available for performing the tasks, a scale with 2 levels was constructed, namely “1 = insufficient” and “2 = sufficient”. To further explore the factors behind workers' responses to the bi-daily questionnaire, a 9-item scale was developed to investigate the perceptions of their work environment, including their relationships with colleagues. Additionally, to gain insight into the morning and afternoon work content, participants were asked to rate the level of challenge and competence required for their tasks using a 10-point Likert-type scale ranging from “0 = Low” to “10 = High”.

To check the level of sleepiness throughout the morning and afternoon, an additional scale was added, the Karolinska Sleepiness Scale (KSS), which measures the subjective level of sleepiness at a given time of day [22]. This question was assessed using a 9-point Likert scale, which ranged from 1 = “Extremely alert” to 9 = “Very sleepy, with great effort to stay awake, fighting sleepiness.”

2.3 Data Analysis

The collected data was analyzed using IBM Statistical Package for the Social Sciences® (SPSS) software, version 26.0, in order to provide insights into the study's objectives. Descriptive statistics were used to examine the collected data, with absolute and relative frequencies reported for categorical variables, and mean and standard deviation for continuous variables. Given the non-normal distribution of the data, a Kruskal-Wallis test was conducted to compare independent samples of varying sizes. Additionally, Spearman correlations were used to assess the strength of the association between different variables studied. These analytical techniques

provided a rigorous framework for exploring and interpreting the data collected, thereby contributing to a more comprehensive understanding of the study's findings.

3 Results and Discussion

3.1 *Stress, Sleepiness, Level of Challenge, Productivity, and Competence*

A descriptive analysis of the main variables over the week was performed to gain a better understanding of the data over the course of the weeks. The classification of stress levels over the days of the week can be seen in Fig. 1.

The descriptive analysis of the main variables over the week revealed interesting patterns in stress levels among the participants. The data indicate that stress levels were the lowest on Monday (4.51 ± 2.39) and the highest on Friday (5.51 ± 2.44). Furthermore, statistical analysis revealed significant differences in stress levels across days of the week ($\chi^2(4) = 10.432, p < 0.05$). These findings suggest that the demands and workload of the job may contribute to the observed variation in stress levels. Specifically, respondents may experience high stress levels on Fridays due to the pressure of completing tasks by the end of the week, which often involves multitasking and excessive workload, as reported in previous studies [27].

The study also examined the classification of sleepiness levels throughout the week. The data revealed that participants reported higher levels of sleepiness on

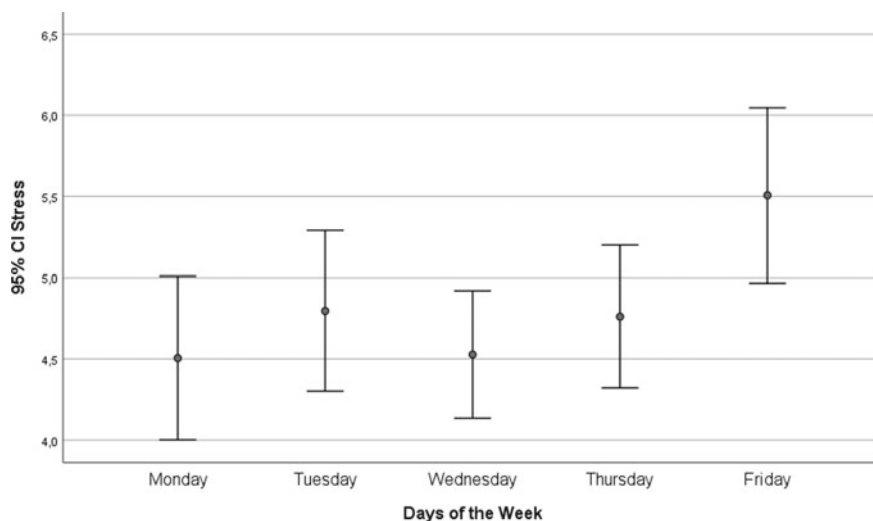


Fig. 1 Stress levels along the days of the week

Monday (3.84 ± 1.671), with values decreasing throughout the week and lower levels reported on Friday (2.88 ± 1.259). These findings suggest that participants become less sleepy and more alert as the week progresses, with statistically significant differences across the days of the week ($\chi^2(4) = 18.007, p < 0.05$). The higher levels of sleepiness observed on Monday could be explained by the fact that respondents may have had different rest schedules during the weekend, as noted in previous studies [24].

In contrast, lower levels of sleepiness observed on Friday could be due to the higher levels of stress identified earlier, which could have increased workers' state of alertness, going along with the previous research [8, 13, 15]. Thus, these findings suggest that the level of sleepiness may be influenced by factors such as weekend rest schedules and work-related stress, which should be taken into account when designing interventions to improve workers well-being.

To gain a deeper insight into the interdependence among the variables, Spearman's correlation analysis was conducted, and the findings are presented in Table 1.

The data reveals a noteworthy positive correlation between the stress level variable and the productivity level ($r = 0.365; p < 0.01$), the level of task challenge ($r = 0.363; p < 0.01$), and the level of required competence ($r = 0.369; p < 0.01$). These results indicate that as the productivity level, level of task challenge, and competences required to complete the task increase, so does the level of daily stress reported by the workers. Beehr and Bhagat's Comprehensive Model, as cited by De Almeida et al. [7], posits that individuals with greater knowledge and expertise in their field are likely to experience less stress than those with less experience. The study revealed a positive correlation between the perceived level of competence required for tasks performed and daily stress levels, which suggests that high task demands may be a critical factor contributing to stress. This finding aligns with the control/demand model, which proposes that individuals who face high demands and low control in their work are at risk of experiencing occupational stress and related health consequences [23]. Notably, workers tend to associate tasks requiring higher skill levels with greater challenges ($r = 0.842; p < 0.01$) and higher levels of productivity ($r = 0.260; p < 0.01$). This observation raises the possibility that some workers may experience healthy stress or eustress situations on Fridays [3, 14]. However, further research is necessary to establish this relationship conclusively.

Table 1 Correlation analysis (Spearman's correlation)

Variables	2	3	4	5
1. Stress	0.365*	0.363*	0.369*	-0.147*
2. Productivity	-	0.283*	0.260*	-0.358*
3. Challenge level	-	-	0.842*	-0.324*
4. Competence level	-	-	-	-0.313*
5. Sleepiness level	-	-	-	-

*Correlation is significant for $p < 0.01$

Regarding sleepiness levels, the results indicate a statistically significant negative correlation ($r = -0.147$; $p < 0.01$), suggesting that lower levels of sleepiness are associated with higher levels of stress. In fact, It has been suggested that heightened levels of stress can lead to a state of alertness, which may explain why workers who report higher levels of stress also report lower levels of sleepiness [13, 15]. Results also show that productivity tends to increase when workers perceive a higher level of challenge ($r = 0.283$, $p < 0.01$) and a higher level of competence required to perform the tasks ($r = 0.260$, $p < 0.01$), and when they report a lower level of sleepiness ($r = -0.358$, $p < 0.01$). The results of this study are consistent with previous research, such as the work of De Almeida et al. [7], which found that a positive correlation exists between personal resources and job demands. This relationship has been shown to not only enhance productivity in the workplace, but also improve the well-being of employees.

3.2 Characterization of Risk Factors

The participants were asked about different factors that might have contributed to the previously reported results, and the results are summarized in Table 2.

The data obtained revealed that workload was considered the main risk factor by the participants, with 51.4% of them identifying it as such. This finding is consistent with previous studies that have highlighted workload as a potential generator of stress, leading to reduced efficiency among workers [18, 21, 28, 29]. The second risk factor identified by the participants was the time available to perform the tasks (39.4%), which is directly related to workload. As indicated by Saveca et al. [21], when workers perceive that the time available to perform their duties is insufficient, coupled with high workload, the likelihood of experiencing stress increases. In fact, research highlights the impact of time pressure on workers’ health and well-being [29, 6]. Participants reported that the significance of their work influenced their stress level and productivity 31.7% of the time. Interruptions related to work

Table 2 Participants perceived stressors

	Yes (%)	No (%)
Available time	39.4	60.6
Interruptions	32.1	67.9
Multi-tasking	37.0	63.0
Leadership	4.9	95.1
Relationship with colleagues	16.7	83.3
Importance of work to you	31.7	68.3
Personal factors	15.0	85.0
Workload	51.4	48.8
Physical environment of the workplace	13.2	86.8

were a factor 32.1% of the time, and multi-tasking was identified 37.0% of the time. Conversely, the impact of other factors, such as relationships with colleagues (16.7%), personal factors (15.0%), physical environment (13.2%), and leadership, were deemed less significant by the participants in terms of their perceived levels of stress and productivity.

Although leadership was identified as the least selected factor by the participants, accounting for only 4.9% of the selections, other studies such as Useche et al. [25] highlight its importance in influencing stress levels, along with interpersonal relationships. However, the characteristics of the job and the organization may explain the discrepancy in results. On the other hand, the physical environment, although not as prominently identified in this study, has frequently been reported as a relevant risk factor in previous studies [18].

While this study focused on certain factors related to stress levels, it is important to note that there are other factors that may also contribute to occupational stress. Santos et al. highlighted the role of aspects such as salary, overtime, and shifts in work organization. Kortum et al. [18] identified the significance of relationships in the workplace, such as harassment, physical and verbal violence, interpersonal conflicts, and job insecurity. Saveca et al. [21] and Duarte et al. [9] found that increasing emotional demands, conflicts between work and private life demands, organizational culture, and function could be potential sources of occupational stress. Živković et al. [29] also identified job demands, interpersonal relationships, lack of support, job role, and job uncertainty as statistically significant predictors of psychosocial risks.

4 Conclusions

The study identified several important findings regarding the relationship between stress and various factors. First, it was found that workers tend to experience higher levels of stress at the end of the week. Additionally, daily stress levels were found to be positively correlated with productivity, level of challenge, and level of competence, while being negatively correlated with the level of sleepiness. The study revealed a significant link between psychosocial risk factors and mental health issues, including stress, anxiety, depression, and burnout. To expand on these findings, future research could replicate the study on a larger scale and for a longer duration, potentially by increasing the number of samples and enabling statistical purposes. Additionally, it would be valuable to create interventions that target occupational stress management, given the study's correlation between psychosocial risk factors and mental health problems. Such interventions could include stress management training, cognitive-behavioral therapy, and mindfulness-based interventions. It's important to note that the study did not examine all possible risk factors due to its specific objectives.

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Work Capacity and Psychosocial Factors in Workers of a Professional School



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Abstract Work has taken a crucial position in the daily life of man, which is reflected in physical health and mental health. According to the Finnish Institute of Occupational Health, The Ability to Work represents how capable the worker is to perform his work with the usual effectiveness. Psychosocial risks are risks resulting from social and psychic mechanisms, which according to the World Labor Organization concern “the relationship between/and the work environment, work content, organizational conditions and skills of the worker, needs, culture, causes of extra work and that can, through perceptions and experience, influence health, work performance and job satisfaction”. There are some professions that are more susceptible, such as teachers who are subject to factors inherent to the profession and the institution where they are allocated. Objective: As a general objective, this investigation aims to evaluate the Work Ability Index (WAI) of the sample under study and to evaluate psychosocial risk factors through the Copenhagen Psychosocial Questionnaire and to know in what sense the relationship between work ability and psychosocial risk

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factors to which they are exposed in the workplace. Material and Methods: For data collection, the Work Ability Index (WAI) and the Copenhagen Psychosocial Questionnaire (COPSOQ) were used. Results: most professors had a “good” to “moderate” WAI condition. Professionals who worked shifts had better WAI compared to those who did not. Older teachers had a better ICT compared to younger ones. Finally, professionals with better WAI also showed lower psychosocial risks (burnout, stress, depressive symptoms) but better results regarding the possibility of personal development, commitment, and predictability.

Keywords Health at work · COPOSOQ · ICT · Psychosocial risks

1 Introduction

Work has become crucial and has taken on a position of great importance in the daily life of man, since it is a source of income, but at the same time it is where we develop part of our social life, all in a complex environment that is reflected in physical health and mental health [1]. We can define work as being a social activity that encompasses the most diverse necessary requirements of workers such as: effort, skills, skills, time, which are reflected through compensation at the economic, material, psychological and social levels [2].

The Finnish Institute of Occupational Health defines the Ability to Work as a representation of how capable the worker is to perform his work with the usual effectiveness, depending on the most varied physical and mental requirements. Work Ability is never constant and can be influenced by factors such as: working conditions, occupational environment and lifestyle [3]. Today, the ability to work is intrinsically linked to work and its balance with our own resources.

Currently, the labor market, is described as unstable and uncertain, does not provide a guarantee of employment for the future, requires a high adaptive flexibility [4]. In addition to these characteristics, it presents other factors such as: giving greater importance regarding information in production processes, constant technological innovation, fewer workers and working conditions, which generally lead to greater mental effort, greater pace and work overload, high levels of attention and concentration, greater responsibility and differentiated schedules [5]. The combination of these characteristics and factors leads to the appearance of risks at the psychosocial level.

For the World Labor Organization, psychosocial risks concern “the relationship between/and the work environment, work content, organizational conditions and worker skills, needs, culture, causes of extra work and that can, through perceptions and experience, influence health, work performance and job satisfaction” [6].

According to Gollac and Bodier [6], psychosocial risk factors in the work context can be inserted into six distinct categories: work intensity and how long work is spent, emotional demands; the difficulty in being autonomous; the lack of quality of social relations in the work context; conflicts of values and insecurity in the workplace.

Consequently, they can lead to increased depression and anxiety, the use of psychoactive substances in the workplace, bullying, intimidation and violence [7].

These are complex and less tangible risks, which hinders their assessment, management and prevention [8]. But even so we can start by raising awareness about what psychosocial risks are, the assessment of the factors that contribute to their appearance, what their consequences are and what are the best methodologies to prevent them.

All this is transversal to the many professions that exist, however some are more susceptible to these problems, such as teachers.

Teachers have to deal with several factors such as: high workload, high number of students, inadequate physical structure of the institution in which they work, individual nature of the activity, singularities of work (work at home, how to prepare classes, correct or elaborate exercises, low salaries and teacher devaluation) [9]. They are also influenced by the physical characteristics of the institution, organizational culture and by the work environment itself [10].

All this culminates with the appearance of health problems, diminution of the quality of life of the professional, quality of education, among other consequences that are mainly reflected in the level of physical and mental health [11].

It is therefore imperative to promote health at work, through the participation of workers in this process, the improvement in organizational terms and the work environment, as well as the promotion of healthy choices on the part of the worker and encouragement of his personal development. By protecting the health of professionals working in various companies and institutions, we reduce absenteeism at work, incapacities for work, health costs are lower, productivity increased, as well as product/service quality [12, 13]. In this sense, as a general objective of the study, it was intended to study the relationship between work ability (WAI) and exposure to psychosocial risk factors (COPSOQ) in professionals at the Professional School.

2 Materials and Methods

As a general objective, this research aims to evaluate the Work Ability Index (WAI) of the sample under study and to evaluate psychosocial risk factors through the Copenhagen Psychosocial Questionnaire (COPSOQ) and to evaluate the relationship between work ability and psychosocial risk factors to which they are exposed in the workplace.

This study becomes an asset for an educational institution, since it will give managers a general perception of workers' satisfaction in terms of working conditions and because it will increase labor productivity, since it will allow the development of measures that encourage teachers more to improve their commitment and quality of the service provided.

Hypotheses or Research Questions

H0: Teachers who perform more overtime have a lower level of work ability.

- H1: Teachers who take shifts are more likely to experience psychosocial changes.
- H2: The age difference of teachers affects their ability to work.
- H3: Psychosocial alterations are affected by the difference in age among teachers.
- H4: The gender gap of teachers affects their ability to work.

Study Design

This paper aims to study the relationship between work ability and exposure to psychosocial risk factors in professionals the one Professional School.

Regarding the type of study, this was an analytical observational, descriptive-correlational type, of cross-sectional timeline. About the Level of Knowledge, the study factor is at level II.

The place of study was in a professional school.

Two types of variables have been defined, considering their characteristics:

Main Variables: Work Ability and Social Risks.

Secondary Variables: Sleep Quality, Workload, Overtime, Age and Gender.

Population and Sample

The Universe of study was the School Professionals.

The inclusion criteria were teachers from the Professional School.

The exclusion criteria were non teachers from the Professional School.

The sampling method to be applied was non-probabilistic type for convenience, consisting of 20 professionals.

Instruments and Data Collection

To ground and discuss the results, the study was complemented with bibliographic research on the topic Psychosocial Factors and Ability to Work.

Data collection was divided into two steps:

1. The sample was selected and the application for authorization was made for the collection of data.
2. A questionnaire was elaborated based on: “Work Ability Index” (WAI)-mean version [14] and the “Copenhagen Psychosocial Questionnaire” (COPSOQ III)-middle version, which was made available to each of the professionals selected to participate in the study.

WAI—Work Ability Index

An instrument that assesses the worker’s perception of how well he or she is in relation to his work, with regard to the requirements of his tasks, his current state of health and his physical and mental capacities [3].

Its use makes us known possible changes that may occur and helps to predict the incidence of early disability and subsidize preventive health measures [15].

The WAI covers 7 distinct areas:

- Ability to work today compared to the best of his life;
- Ability to work compared to work requirements;

- Total number of diseases self-perceived and diagnosed by the doctor;
- Estimated loss at work due to illness;
- Lack of work due to illness;
- Own prognosis on work ability;
- Mental resources.

This index is the sum of all the scores that were obtained in each of the 7 areas of the questionnaire, and it is not possible to leave any item unanswered, if not, it is not possible to obtain the calculation of the scores. In total, the score obtained varies between 7 and 49 points (Table 1).

COPSOQ—Copenhagen Psychosocial Questionnaire

It is a Danish tool focused on the assessment of risks of a psychosocial nature and the creation of preventive measures [16].

This questionnaire consists of about 85 questions, which belong to 31 different scales, representing the following domains:

- Demands at Work;
- Organization and Content at Work;
- Interpersonal Relations and Leadership;
- Interface Work and Private Life;
- Workplace Values;
- Health and Wellness;
- Offensive Behavior.

The scale used to evaluate the answers is of the Likert type of 5 points (1—Never/almost never, 2—rarely, 3—sometimes, 4—often and 5—always).

Thus, the means of the items of each factor should be calculated, assuming the interpretation of this value distinct directions according to the factor/subscale in question.

The means of the items of each factor are calculated, assuming the interpretation of these values according to the factor/subscale in question and are later compared with the normative values for the Portuguese population.

Statistical Analysis

This study was Observational, Descriptive and Cross-sectional.

Table 1 WAI

Stitches	Capacity for work index	Objective of the measures
7–27	Weak	Restore capacity to work
28–36	Moderate	Improving work ability
37–43	Good	Supporting work capacity
44–49	Excellent	Maintaining capacity for work

The statistical approach of the research project was carried out after the collection and later the treatment and analysis of data related to health professionals, with all the information being used for the construction of a database in the specialized software for data processing (IBM SPSS Statistics).

The data obtained were analyzed using specialized software for data processing: IBM SPSS Statistics version 27.

In relation to the descriptive part, frequency analyses (absolute and relative), measures of central tendency (simple arithmetic mean, median and fashion), non-central trend measures (quantities), dispersion measures (standard deviation, variance, amplitude, minimum value and maximum value) were used.

With regard to the inferential part, appropriate statistical tests were applied for each of the research hypotheses, in which the confidence level is 95% for a degree of error of 5%. The statistical tests used can be divided into parametric and non-parametric.

H0: Test Chi Square of Independence.

H1: Wilcoxon Mann–Whitney Test.

H2: Test: Kruskal Wallis.

H3: Test: Kruskal Wallis and Mann Whitney.

H4: Test Chi Square of Independence.

3 Results

3.1 Sociodemographic Characterization of the Population

Until June 20, 2022, 32 questionnaires were collected at the Professional School, of which 20 were fully answered. The majority of the female respondent population (70%) and aged between 40 and 66 years.

Regarding the professional category, respondents are mostly Senior Technicians (50%), with 20 or more years of service (65%).

3.2 Work Ability Index

- Analysis of WAI results

When analyzing Table 2, we understand that the predominant WAI level was the “Good” condition, followed by “Moderate”. Only 1 teacher presented the condition “Excellent”.

The average Work Ability of all respondents was 34.275 ± 7.2 , which is equivalent to the “Moderate” rating.

We proposed to evaluate the levels of work ability according to the participation of the worker in the performance of shifts. Let’s look at the following table.

Table 2 ICT levels

ICT levels	n (%)
Weak (7–27)	3 (15%)
Moderate (28–36)	6 (30%)
Good (37–43)	10 (50%)
Excellent (44–49)	1 (5%)
Total	20 (100%)

Legend: WAI = Work Ability Index; n = Sample number

According to the results presented in Table 3, we found that the WAI revealed to be a significant differentiator ($p < 0.05$) due to the performance of shifts by the workers. Those who indicated performing shifts, on average, presented higher values of the index as a reference compared to workers who did not.

It was also proposed to understand the type of relationship between WAI levels and workers' age. Let's look at the following table.

According to the results obtained Table 4 in, we found that WAI levels did not prove to be differentiating, significantly ($p > 0.05$) depending on the ages of the workers. However, the workers who presented an WAI in the condition of "Excellent" and "Good", were also those who presented a higher average age.

In order to finalize the analysis on the Work Ability Index, we proposed to evaluate the levels of the work ability index vis-à-vis gender (Table 5).

According to the results presented in the table above we found that WAI was not differentiating, significantly (p -value does not meet the assumptions) depending

Table 3 Turns with WAI

		Work ability index		
		n	M $\pm$ DP	P-value
Shifts	Yes	4	41.00 $\pm$ 3.37	0.026
	No	16	32.59 $\pm$ 6.96	
	Total	20	34.28 $\pm$ 7.21	

Legend = sample number; M = mean; SD = standard deviation; Test: Wilcoxon Mann–Whitney

Table 4 WAI levels

		Age		
		n	M $\pm$ DP	P-value
Work ability index levels	Weak	3	47 $\pm$ 2	0.402
	Moderate	6	48 $\pm$ 2	
	Good	10	53 $\pm$ 3	
	Excellent	1	58	

Legend: n = sample number; M = mean; SD = standard deviation; Test: Kruskal Wallis

Table 5 WAI levels with gender

		Gender		
		Male	Female	Total
ICT-levels	Weak	0	3 (100%)	3 (100%)
	Moderate	1 (16.7%)	5 (83.3%)	6 (100%)
	Good	4 (40%)	6 (60%)	10 (100%)
	Excellent	1 (100%)	0	1 (100%)

Legend: WAI = Work Ability Index

on gender. Although there were no differences, it is possible to notice that female workers presented, on average, more satisfactory levels, with the “Good” level being the predominant response, followed by the “Moderate” level.

3.3 *Copenhagen Psychosocial Questionnaire*

- Analysis of COPSOQ results

Through the following table, we present an analysis through the tripartite division of the subscales of the Copenhagen Psychosocial Questionnaire (COPSOQ), where a classification of “traffic light” is assumed. In this case the highest value is considered the worst value (Table 6).

To facilitate the presentation of the results, the subscale was divided into two groups, in which one the highest value corresponds to the worst value and another in which the lowest value is considered the worst value that represents a greater exposure to the various psychosocial risks.

Table 6 COPSOQ subscales (highest value is worst)

COPSOQ subscales	Average $\pm$ SD
Quantitative requirements	3
Rhythm	3
Cognitive requirements	4
Emotional demands	4
Labor roles conflict	3
Labor insecurity	2.73 $\pm$ 0.30
Insecurity with working conditions	2.68 $\pm$ 0.26
Horizontal trust	3
Sleep problems	3
Burnout	4
Stress	3
Depressive symptoms	3

For each subscale, the mean and the standard deviation were determined. In the table we present, according to the interpretation “traffic light”, the colors to which corresponded to the values obtained. The semaphore scale is divided into three: green (≤ 2.33), yellow (between 2.331 and 3.659) and red (≥ 3.66).

Table 5 shows that the subscales “Cognitive Requirements”, (4) “Emotional Demands (4)” and “Burnout (4)”, are the ones with the highest score, i.e., they need the most attention.

As for the remaining subscales, although some have higher values, all were in the yellow area of the traffic light, i.e. they are in a situation of potential risk.

In the next table, we try to analyze the COPSOQ subscales, where the lowest value is considered the worst value (Table 7).

In this table, no critical value was identified. The subscales with the highest scores are in the green area of the traffic light: “Development Possibility (4)”, “Social Support of Colleagues” (4) and “Sense of Belonging to the Community” (4).

One of the proposed questions regarding the Copenhagen Psychosocial Questionnaire was to analyze whether there is a relationship between its subscales in relation to overtime (more than 40 h per week):

Table 7 COPSOQ subscales (lowest value is worst)

COPSOQ subscales	Average +SD
Influence at work	3
Development possibility	4
Control over working time	3
Meaning of work	3
Workplace commitment	3
Predictability	3
Recognition	3
Transparency of labour role	3
Leadership quality	3
Social support of colleagues	4
Social support of superiors	3
Sense of belonging to the community	4
Quality of work	3.05
Vertical trust	3
Organizational justice	3
Satisfaction with work	3
Self-assessment of health	3.25
Efficacy	3

According to the results of Table 8 we can verify that the highest percentages in the following subscales: “Quantitative Requirements” (77.8%), “Rhythm” (88.9%), “Cognitive Requirements” (94.4%), “Emotional Requirements” (100%), “Influence at Work” (83.3%), “Control over Working Time” (72.2%), “Meaning of Work” (94.4%), “Commitment to the Workplace” (66.7%), “Social Support of Superiors” (72.2%), “Horizontal Trust” (72.2%), “Work-Family Conflict” (83.3%), “Job Satisfaction” (66.7%), “Sleep Problems” (66.7%), “Burnout” (77.8%), “Stress” (77.8%) and “Depressive Symptoms” (72.2%). All these equivalent percentages went to the condition “Unfavorable” and were answered by those who do not practice overtime (equivalent to 40 h per week).

In the subscales “Recognition”, “Predictability” and “Quality of Leadership”, “Insecurity with Working Conditions”, it was possible that the highest percentages also belonged to those who do not work more than 40 h per week and who are at the extremes, i.e., “Favorable” and “Unfavorable”.

The condition “Unfavorable” is also independent of whether the worker practices overtime or not, in the subscales “Development Possibility” (90%), “Social Support of Colleagues” (95%) “Sense of Belonging to the Community” (94.4%) and “Quality of Work” (85%).

We looked at whether there was a relationship between the subscales of the Copenhagen Psychosocial Questionnaire and the age of the respondents. The data obtained are presented in the following table.

According to the results of Table 9, we found that no significant differences were observed between COPOSQ and Age.

When analyzing the table, we found that the “Favorable” condition corresponds to the highest mean age in the subscales: “Quantitative Requirements” (54.25 ± 8.06), “Rhythm” (56.00 ± 3.61), “Development Possibility” (51.22 ± 7.72), “Meaning of Work” (53.00 ± 2.83), “Commitment to the Workplace” (51.00 ± 8.41), “Recognition” (51.85 ± 8.19), “Insecurity with Working Conditions” (55.25 ± 8.84), “Insecurity with Working Conditions” (55.00 ± 9.43), “Horizontal Confidence” (60.00 ± 9.54), “Horizontal Trust” (“Work-Family Conflict”) (60.00), “Self-efficacy” (51.22 ± 7.72), “Stress” (54.00 ± 4.58) and “Symptoms Depressive” (57.67 ± 8.50).

In the subscales “Cognitive Requirements” (53.00), “Emotional Demands” (55.00), “Influence at Work” (55.00), “Predictability” (55.20 ± 7.53), “Quality of Leadership” ($54.50 + 4.95$), “Social Support from Colleagues” (Sense of Community Belonging) (60.00), “Organizational Justice” (54.00 ± 1.41), “Job Satisfaction” (53.00 ± 7.00), “Sleep Problems” (55.50 ± 3.54), “Burnout” (55.50 ± 4.80) was the “Intermediate” condition that stood out for having an average age of the highest workers.

With regard to “Work Rhythm”, “Meaning of Work”, “Quality of Work” and “Self-Assessment of Health”, none of the workers considers to be in an “intermediate” condition, and there are not many differences in the extremes, unless on the first subscale (“Favorable” = 56.00 ± 3.61 and “Unfavorable” = 49.94 ± 7.68) and the last scale (“Favorable” = 49.76 ± 5.56 and “Unfavorable” = 57.00 ± 14.73) previously mentioned.

Table 8 COPSOQ subscales with overtime

		Overtime		
		Yes	No	Total
		n(%)	n(%)	n(%)
Quantitative requirements	Favorable	1(50%)	3(16.7%)	4(20%)
	Intermediate	1(50%)	1(5.6%)	2(10%)
	Adverse	0	14(77.8%)	14(70%)
Rhythm	Favorable	1(50%)	2(11.1%)	3(15%)
	Adverse	1(50%)	16(88.9%)	17(85%)
Cognitive requirements	Intermediate	0	1(5.6%)	1(5%)
	Adverse	2(100%)	17(94.4%)	19(95%)
Emotional demands	Intermediate	1(50%)	0	1(5%)
	Adverse	1(50%)	18(100%)	19(95%)
Influence at work	Favorable	0	3(16.7%)	3(15%)
	Intermediate	1(50%)	0	1(5%)
	Adverse	1(50%)	15(83.3%)	16(80%)
Possibility of development	Favorable	0	1(5.6%)	1(5%)
	Intermediate	0	1(5.6%)	1(5%)
	Adverse	2(100%)	16(88.9%)	18(90%)
Control over working time	Favorable	1(50%)	3(16.7)	4(20%)
	Intermediate	0	2(11.1)	2(10%)
	Adverse	1(50%)	13(72.2%)	14(70%)
Meaning of the work	Favorable	1(50%)	1(5.6%)	2(10%)
	Adverse	1(50%)	17(94.4%)	18(90%)
Commitment to the workplace	Favorable	1(50%)	3(16.7%)	4(20%)
	Intermediate	0	3(16.7%)	3(15%)
	Adverse	1(50%)	12(66.7%)	13(65%)
Predictability	Favorable	0	6(33.3%)	6(30%)
	Intermediate	1(50%)	4(22.2%)	5(25%)
	Adverse	1(50%)	8(44.4%)	9(45%)
Recognition	Favorable	0	6(33.3%)	6(30%)
	Intermediate	0	1(5.6%)	1(5%)
	Adverse	2(10%)	11(61.1%)	13(65%)
Quality of leadership	Favorable	1(50%)	5(33.3%)	6(35.3%)
	Intermediate	0	2(13.3%)	2(11.8%)
	Adverse	1(50%)	8(53.3%)	9(52.9%)
Social support from colleagues	Intermediate	1(50%)	0	1(5%)
	Adverse	1(50%)	18(100%)	19(95%)
Social support for superior	Favorable	1(50%)	4(22.2%)	5(25%)

(continued)

Table 8 (continued)

		Overtime		
		Yes	No	Total
		n(%)	n(%)	n(%)
	Intermediate	1(50%)	1(5.6%)	2(10%)
	Adverse	0	13(72.2%)	13(65%)
Sense of belonging to the community	Intermediate	0	1(5.6%)	1(5%)
	Adverse	2(100%)	17(94.4%)	19(95%)
Job insecurity	Favorable	1(50%)	7(38.9%)	8(40%)
	Intermediate	0	4(22.2%)	4(20%)
	Adverse	1(50%)	7(38.9%)	8(40%)
Insecurity with working conditions	Favorable	0	8(44.4%)	8(40%)
	Intermediate	0	1(5.6%)	1(5%)
	Adverse	2(100%)	9(50%)	11(55%)
Horizontal trust	Favorable	1(50%)	2(11.1%)	3(15%)
	Intermediate	0	3(16.7%)	3(15%)
	Adverse	1(50%)	13(72.2%)	14(70%)
Quality of work	Favorable	0	3(16.7%)	3(15%)
	Adverse	2(100%)	15(83.3%)	17(85%)
Vertical confidence	Favorable	1(50%)	4(22.2%)	5(25%)
	Intermediate	0	4(22.2%)	4(20%)
	Adverse	1(50%)	10(55.6%)	11(55%)
Organizational justice	Favorable	0	5(27.8%)	5(25%)
	Intermediate	1(50%)	1(5.6%)	2(10%)
	Adverse	1(50%)	12(66.7%)	13(65%)
Work-family conflict	Favorable	0	1(5.6%)	1(5%)
	Intermediate	1(50%)	2(11.1%)	3(15%)
	Adverse	1(50%)	15(83.3%)	16(80%)
Job satisfaction	Favorable	1(50%)	3(16.7%)	4(20%)
	Intermediate	0	3(16.7%)	3(15%)
	Adverse	1(50%)	12(66.7%)	13(65%)
Self-assessment of health	Favorable	0	3(16.7%)	3(15%)
	Adverse	2(100%)	15(83.3%)	17(85%)
Self-efficiency	Favorable	0	1(5.6%)	1(5%)
	Intermediate	0	1(5.6%)	1(5%)
	Adverse	2(100%)	16(88.9%)	18(90%)
Sleep problems	Favorable	1(50%)	4(22.2%)	5(25%)

(continued)

Table 8 (continued)

		Overtime		
		Yes	No	Total
		n(%)	n(%)	n(%)
Burnout	Intermediate	0	2(11.1%)	2(10%)
	Adverse	1(50%)	12(66.7%)	13(65%)
	Favorable	0	1(5.6%)	1(5%)
	Intermediate	1(50%)	3(16.7%)	4(20%)
Stress	Adverse	1(50%)	14(77.8%)	15(75%)
	Favorable	1(50%)	2(11.1%)	3(15%)
	Intermediate	1(50%)	2(11.1%)	3(15%)
	Adverse	0	14(77.8%)	14(70%)
Depressive symptoms	Favorable	0	3(16.7%)	3(15%)
	Intermediate	1(50%)	2(11.1%)	3(15%)
	Adverse	1(50%)	13(72.2%)	14(70%)

Legend: Favorable = Favorable health situation; Intermediate = Intermediate situation; Unfavorable = Health risk; n = Sample number

Regarding the subscales “Transparency of Labor Role” and “Labor Role Conflicts”, all responses were “Unfavorable”.

The “Control over working time” presents identical values of average age in the condition “Favorable” and “Intermediate” and in the “Unfavorable” there is an increase of this value (52.43 ± 8.04). On the contrary in “Vertical Trust”, the identical values are the “Intermediate” and “Unfavorable” and what stands out is the “Favorable” (52.82 ± 8.33).

When we analyze the “Social Support of Superiors”, the values of the extremes are identical and the highest (Favorable = 50.92 ± 8.69 and Unfavorable = 52.00 ± 5.52).

We would then find out if there was a relationship between the subscales of the Copenhagen Psychosocial Questionnaire and the age of the respondents. The data obtained are presented in the following table.

Analyzing Table 10, we found that only in the “Job Satisfaction” subscale (p-value = 0.023) there were statistically significant differences (p-value ≤ 0.05).

However, in most of the remaining subscales there was a tendency for the “Favorable” condition to be located the highest WAI levels:: “Quantitative Requirements” (36.75 ± 4.72), “Influence at Work” (34.91 ± 7.66), “Development Possibility” (35.81 ± 5.72), “Control over Working Time” (35.29 ± 7.61), “Workplace Commitment” (35.92 ± 7.63), “Predictability” (37.89 ± 3.89), “Recognition” (36.85 ± 5.88), “Leadership Quality” (38.33 ± 4.8), “Labor Insecurity,” “Horizontal Trust” (39.67 ± 2.52), “Vertical Trust” (36.59 ± 6.50), “Organizational Justice” (36.15 ± 7.04), “Work-Family Conflict” (37.00), “Self-efficacy” (35.81 ± 5.72), “Sleep Problems” (36.00 ± 7.08) and “Depressive Symptoms” (41.67 ± 2.89).

Table 9 COPSOQ subscales with age

	Age			P-value
	Favorable M $\pm$ DP	Intermediate M $\pm$ DP	Adverse M $\pm$ DP	
Quantitative requirements	54.25 $\pm$ 8.06	50.50 $\pm$ 6.36	49.93 $\pm$ 7.69	0.563
Rhythm	56.00 $\pm$ 3.61	0	49.94 $\pm$ 7.68	0.099
Cognitive requirements	0	53.00	50.74 $\pm$ 7.67	0.542
Emotional demands		55.00	50.63 $\pm$ 7.62	0.433
Influence at work	51.06 $\pm$ 8.14	55.00	48.33 $\pm$ 4.04	0.677
Possibility of development	51.22 $\pm$ 7.72	44.00	51.00	0.505
Control over working time	47.00 $\pm$ 5.83	47.50 $\pm$ 2.12	52.43 $\pm$ 8.04	0.369
Meaning of the work	53.00 $\pm$ 2.83	0	50.61 $\pm$ 7.84	0.411
Commitment to the workplace	51.00 $\pm$ 8.41	50.67 $\pm$ 8.08	50.50 $\pm$ 5.26	0.972
Predictability	50.11 $\pm$ 7.56	55.20 $\pm$ 7.53	48.33 $\pm$ 6.95	0.262
Recognition	51.85 $\pm$ 8.19	46.00	49.50 $\pm$ 6.47	0.683
Quality of leadership	50.44 $\pm$ 7.62	54.50 $\pm$ 4.95	50.17 $\pm$ 6.21	0.577
Social support from colleagues	50.63 $\pm$ 7.62	55.00	0	0.433
Social support for superior	50.92 $\pm$ 8.69	47.50 $\pm$ 2.12	52.00 $\pm$ 5.52	0.705
Sense of belonging to the community	50.37 $\pm$ 7.36	60.00	0	0.191
Job insecurity	55.25 $\pm$ 8.84	49.25 $\pm$ 7.89	47.25 $\pm$ 2.92	0.127
Insecurity with working conditions	55.00 $\pm$ 9.43	40.00	48.82 $\pm$ 3.74	0.103
Horizontal trust	60.00 $\pm$ 9.54	51.00 $\pm$ 2.00	48.86 $\pm$ 6.60	0.140
Quality of work	50.47 $\pm$ 7.70	0	53.00 $\pm$ 7.00	0.457
Vertical confidence	52.82 $\pm$ 8.33	48.25 $\pm$ 6.65	48.60 $\pm$ 5.94	0.457
Organizational justice	51.38 $\pm$ 8.09	54.00 $\pm$ 1.41	48.20 $\pm$ 7.36	0.440
Work-family conflict	60.00	49.33 $\pm$ 8.14	50.56 $\pm$ 7.47	0.425
Job satisfaction	50.92 $\pm$ 8.48	53.00 $\pm$ 7.00	49.00 $\pm$ 4.97	0.738
Self-assessment of health	49.76 $\pm$ 5.56	0	57.00 $\pm$ 14.73	0.366
Self-efficiency	51.22 $\pm$ 7.72	51.00	44.00	0.505
Sleep problems	53.00 $\pm$ 10.20	55.50 $\pm$ 3.54	49.31 $\pm$ 6.69	0.347
Burnout	40.00	55.50 $\pm$ 4.80	50.33 $\pm$ 7.49	0.091
Stress	54.00 $\pm$ 4.58	51.67 $\pm$ 13.20	50.00 $\pm$ 6.96	0.599
Depressive symptoms	57.67 $\pm$ 8.50	45.00 $\pm$ 4.58	50.64 $\pm$ 6.98	0.132

Legend: Favorable = Favorable health situation; Intermediate = Intermediate situation; Unfavorable = Health risk; n = sample number; M = mean; SD = standard deviation Test: Kruskal Wallis and Mann Whitney

Table 10 COPSOQ subscales with ICT

	Work ability index			P-value
	Favorable M $\pm$ DP	Intermediate M $\pm$ DP	Adverse M $\pm$ DP	
Quantitative requirements	36.75 $\pm$ 4.72	34.75 $\pm$ 6.01	33.50 $\pm$ 8.09	0.851
Rhythm	32.50 $\pm$ 3.91	0	34.59 $\pm$ 7.69	0.426
Cognitive requirements	0	30.00	34.50 $\pm$ 7.33	0.434
Emotional demands	0	30.50	34.47 $\pm$ 7.35	0.543
Influence at work	34.91 $\pm$ 7.66	30.50	32.17 $\pm$ 6.05	0.522
Development possibility	35.81 $\pm$ 5.72	18.50	22.50	0.075
Control over working time	35.29 $\pm$ 7.61	33.75 $\pm$ 8.84	31.00 $\pm$ 5.73	0.381
Meaning of work	35.14 $\pm$ 6.95	0	26.50 $\pm$ 5.66	0.411
Workplace commitment	35.92 $\pm$ 7.63	34.50 $\pm$ 6.14	28.75 $\pm$ 4.25	0.177
Predictability	37.89 $\pm$ 3.89	33.10 $\pm$ 9.22	29.83 $\pm$ 7.53	0.069
Recognition	36.85 $\pm$ 5.88	27.50	29.83 $\pm$ 8.03	0.083
Transparency of labor role	34.28 $\pm$ 7.21	0	0	0
Labor role conflicts	0	0	34.28 $\pm$ 7.21	0
Leadership quality	38.33 $\pm$ 4.85	31.00 $\pm$ 12.02	30.33 $\pm$ 7.54	0.082
Social support of colleagues	34.47 $\pm$ 7.35	30.50	0	0.433
Social support of superiors	34.23 $\pm$ 8.26	31.25 $\pm$ 8.13	35.60 $\pm$ 4.35	0.677
Sense of belonging to the community	34.13 $\pm$ 7.37	37.00	0	0.931
Labor insecurity	35.50 $\pm$ 6.24	38.38 $\pm$ 6.47	31.00 $\pm$ 7.77	0.232
Insecurity with working conditions	37.69 $\pm$ 6.27	37.00	31.55 $\pm$ 7.27	0.202
Horizontal trust	39.67 $\pm$ 2.52	36.83 $\pm$ 5.92	32.57 $\pm$ 7.63	0.197
Quality of work	34.76 $\pm$ 7.55	0	31.50 $\pm$ 4.92	0.265
Vertical trust	36.59 $\pm$ 6.50	35.88 $\pm$ 7.71	27.90 $\pm$ 5.33	0.080
Organizational justice	36.15 $\pm$ 7.04	30.25 $\pm$ 0.35	31.00 $\pm$ 8.07	0.198
Work-family conflict	37.00	32.5 $\pm$ 0.3.91	34.44 $\pm$ 7.91	0.729
Job satisfaction	36.96 $\pm$ 5.75	35.33 $\pm$ 4.73	24.75 $\pm$ 5.32	0.023
Self-assessment of health	33.32 $\pm$ 7.38	0	39.67 $\pm$ 2.52	0.138
Self-efficacy	35.81 $\pm$ 5.72	22.50	18.50	0.075
Sleep problems	36.00 $\pm$ 7.08	34.75 $\pm$ 6.72	33.54 $\pm$ 7.74	0.908
Burnout	37.00	38.13 $\pm$ 6.06	33.07 $\pm$ 7.50	0.540
Stress	38.50 $\pm$ 7.37	38.00 $\pm$ 1.73	32.57 $\pm$ 7.53	0.351
Depressive symptoms	41.67 $\pm$ 2.89	37.67 $\pm$ 1.15	31.96 $\pm$ 7.31	0.089

Legend: Favorable = Favorable health situation; Intermediate = Intermediate situation; Unfavorable = Health risk; n = sample number; M = mean; SD = standard deviation Test: Kruskal Wallis and Mann Whitney

By observing the “Rhythm” and “Meaning of Work”, we infer that there was no “Intermediate” answer.

Regarding the subscales “Transparency of The Labor Role” the totality of responses were “Favorable” and “Labor Role Conflicts”, the totality of the responses were “Unfavorable”.

The “Stress” obtained the highest values of the mean age in “Favorable” (38.50 ± 7.37) and almost identical in “Intermediate” (38.00 ± 1.73).

Regarding the “Social Support of Colleagues” and the “Sense of Belonging to the Community” there were no answers in the parameter “Unfavorable”. On the contrary, the “Cognitive Requirements” and “Emotional Requirements”, where there were no answers in the “Unfavorable”.

4 Discussion

According to the sociodemographic characteristics collected through the questionnaire given to professionals who chose to participate in the study, the mean age was 50.85 years, being mostly a female universe (70%).

The mean WAI obtained was 34.275 (Standard Deviation = 7.2), which is equivalent to the “Moderate” classification. This figure is close to that recorded in a Portuguese study on the assessment of work capacity in police elements (36.94). However, it is lower than the value obtained in a study on working capacity in the population of Outil (40.42) [17].

Regarding the distribution of classification by WAI levels, the workers surveyed presented mostly to the classification “Good” (50%). According to the same study, already referred to the population of Outil, in which most of the population is in the classification “Good” (44.7%).

According to the results obtained in Table 4, we found that ICT levels did not prove to be differentiating, significantly ($p > 0.05$) depending on the ages of the workers. In the older ones, they presented a higher-level WAI in the “Good” condition.

This situation does not happen in the study that relates the assessment of work ability with aging [18] which states that although the difference is not significant, younger workers on average have higher work capacity (39.06 ± 4.59) and in the “Good” condition.

According to the results presented in Table 5, it was found that female workers presented, on average, more satisfactory levels, with the “Good” level being the predominant response, followed by the “Moderate” level.

According to the study by Gomes et al. [19], female workers have worse averages at the WAI level. Several authors explain that it may be related to the burden they have due to domestic work and that it accumulates with its functions [20].

Using descriptive analysis, it was intended to evaluate the different subscales that make up COPSOQ through the mean, which indicated the level of exposure to psychosocial risks of workers.

In the table where the highest value is considered the worst, the values that were considered critical are “Cognitive Requirements”, (4) “Emotional Demands (4)” and “Burnout (4)”.

A study about psychosocial risks in Security Center Operators [21], concludes that the highest values for the same table were “Cognitive Requirements” (3.87) and “In work safety” (3.77) present critical values.

In the table where the lowest value is considered the most critical, no critical value was found. The same happened in the above-mentioned study.

According to the results of Table 8 we can verify that some of the highest percentages belong to the following subscales: “Quantitative Requirements” (77.8%), “Cognitive Requirements” (94.4%), “Emotional Requirements” (18%), “Workplace Commitment” (66.7%), “Social Support of Superiors” (72.2%), “Horizontal Trust” (72.2%), “Work-Family Conflict” (83.3%), and “Burnout” (77.8%), and were answered by those who do not practice overtime.

These results are totally contradicted by a study that addresses psychosocial risk factors and well-being in a hospital in the Azores [22], which stated that these same scales have higher levels in workers working overtime.

When analyzing Table 9, we found that the “Favorable” condition corresponded to the highest mean age in the subscales: “Quantitative Requirements” (54.25 ± 8.06), “Rhythm” (56.00 ± 3.61), “Possibility of Development” (51.22 ± 7.72), “Meaning of Work” (53.00 ± 2.83), “Commitment to the Workplace” (51.00 ± 8.41), “Recognition” (51.85 ± 8.19), “Insecurity with Working Conditions” (55.25 ± 8.84), “Insecurity with Working Conditions” (55.00 ± 9.43), “Horizontal Trust” (60.00 ± 9.54), “Horizontal Trust” (“Work-Family Conflict”) (60.00), “Self-efficacy” (51.22 ± 7.72), “Stress” (54.00 ± 4.58) and “Depressive Symptoms” (57.67 ± 8.50).

As far as age is concerned, Silva et al. [23] concluded that workers with average ages of age represent greater exposure to the scales “Quantitative Requirements”, “Cognitive Requirements”, “Predictability”, “Transparency of labor paper”, “Conflict” “Organizational Justice” and “Stress”. This contradicts the results described above since the most significant scales for those with lower average age are not the same.

Analyzing Table 10, we found that only in the “Job Satisfaction” subscale ($p\text{-value} = 0.023$) there were statistically significant differences ($p\text{-value} \leq 0.05$). Cardoso’s study [12] also verified the existence of a correlation between the scale in question and the WAI.

Scales such as “Commitment to the Workplace” (35.92 ± 7.63), “Predictability” (37.89 ± 3.89) and “Leadership Quality” (38.33 ± 4.8) are the ones with the highest values at the ICT level in the “Favorable condition”. This is in line with what the study says that relates the relationships between age, determinants of work and psychosocial factors with the ability to work in an automotive industry.

5 Conclusions

Our study focused on the possible relationship between psychosocial factors, sociodemographic characteristics, and the ability to work professionals in a school.

We consider it to be an important study, since work in the school context is affected by numerous external and internal factors, and mainly due to the constant changes that teaching suffers.

The mean capacity value obtained was 34.275, corresponding to the “Moderate” classification.

Regarding the comparison of WAI with age, we did not obtain differences regarding the improvement or not of work capacity with increasing age. In gender, the differences found were not considerable, although the female gender obtained higher scores, with most of the “Good” classification.

About COPSOQ subscales, the table where critical values were found were in the table where the highest value is considered the worst. The parameters that required attention were: “Cognitive Requirements”, (4) “Emotional Demands (4)” and “Burnout (4)”.

When we crossed COPSOQ with overtime we didn’t find big differences, so did the age variable, since the Favorable condition was presented more often by people with higher average ages.

Finally, there was a direct relationship due to psychosocial changes to work ability. The same can be proven by the subscale “Job Satisfaction” (p-value = 0.023), although in other scales such as “Commitment to the Workplace” (35.92 ± 7.63), “Predictability” (37.89 ± 3.89) and “Leadership Quality” (38.33 ± 4.8), in the “Favorable” condition, presented higher values in the WAI.

In general, we did not find results requiring immediate intervention, this is perhaps due to the limitation of the study in relation to the sample, limiting the application of some statistical tests.

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State of the Art in Occupational Safety and Health

Hospital Work Environment and Maternity Protection: A Scoping Review on Assessment and Perception of Occupational Risks



Soraya Wingester Vasconcelos , Elizabeth Costa Dias ,
and Alexandra Matias

Abstract Hospital occupational risks can negatively impact workers' health, including reproductive health. The present study carried out a scoping review on assessing and perceiving occupational risks to raise methods and tools replicable in the hospital work environment, focusing on maternity protection. Online databases were used to identify peer-reviewed scientific English articles published from 2011 to 2020, based on PRISMA Extension for Scoping Reviews. Almost half of the included studies (19) are cross-sectional. The distribution of articles by research subjects was as follows: risk perception (9), risk assessment (11), and both together (2); health professionals (13); pregnancy (4); and pregnant health professionals (1). As for occupational risks: physical (6); chemical (4); biological (2); psychosocial (5); psychosocial and physical (5); ergonomic, biomechanical, and organizational (15). The literature provides adaptable methods, instruments, and tools to assess and perceive occupational risks in the hospital sector, focusing on maternity protection. The integration and quality of the methods increase the robustness of occupational risk assessment and perception, allowing more reliable preventive measures to protect workers' reproductive health.

Keywords Occupational health · Pregnant worker · Risk evaluation · Assessment tools · Hospital workplace

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1 Introduction

In 2013, of about 234 million workers, who produce health-related products and provide services, 71 million were in health occupations worldwide. In the health and social sector, the proportion of working women was nearly a third greater than that of women in total employment. Globally, this sector is a crucial source of jobs for women as they account for more than 70% of its workforce [17].

The general and reproductive health of pregnant, lactating, or childbearing-age workers can be negatively impacted by biological, chemical, physical, biomechanical, and psychosocial risks generated in the hospital work environment [31].

Inhaling anesthetic gases, ionizing radiation, anticancer agents, and viruses pose sexual and reproductive health risks, including increased congenital anomalies [30]. In addition, the mobilization of loads, inappropriate postures, and psychosocial risk factors involving shift work, irregular hours, and stress related to the organization of work are also relevant occupational risk factors for pregnancy and the health of women workers in the hospital sector [31].

Maternity protection in hospital work sectors is still challenging. Therefore, the objective of this scoping review was, through the existing literature, to raise and describe the methods, instruments, and tools for evaluating and perceiving occupational risk that could be applied in the hospital work environment, with a focus on maternity protection. Thus, this study sought answers to the following questions: what methods and tools to assess and perceive occupational risks do hospital sectors use? Is there any specific method that considers maternity protection issues, such as occupational exposure of pregnant, lactating, or childbearing-age workers?

2 Materials and Methods

This review used the Extension for Scoping Reviews of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses [34] to search and select studies, as well as present and discuss the results.

2.1 Eligibility Criteria

The inclusion of articles in this review focused on the dimensions of assessment and perception of occupational risks and the instruments and methods used. Quantitative, qualitative, and mixed-method studies were included to consider different aspects of these dimensions. The included citations were peer-reviewed journal articles published between 2011 and 2020 and written in English. The study population had to be workers, including health professionals from different categories.

Articles that did not fit the conceptual framework of the study based on the Population, Concept, and Context (PCC) strategy for scoping review were not included: P—workers, including pregnant, lactating, or childbearing age workers; C—assessment and perception of occupational risks to which workers are exposed; and C—hospital sector. In addition, articles on animal testing, non-occupational practices, patient care, disease prevalence, and treatment, among others, were excluded.

2.2 Information Sources

The bibliographic databases used to search for potentially relevant documents were Scopus, Science Magazine/Academic Search Ultimate, and Web of Science. All citations identified were imported into JabRef 5, a bibliographic reference manager, via BibTex files generated in the databases. Duplicates were removed, first with the help of JabRef, and then manually by dates and titles.

2.3 Search

A preliminary search strategy was developed in the Scopus database, using words related to the subject of the study to help define the keywords and their combinations, Chart 1. The chosen databases underwent the same search strategy as Scopus, and the memory of the research steps is in Table 1.

2.4 Data Charting Process

In line with the purpose of the review, a data charting form was independently developed to determine which variables to extract from the included articles. It was continually updated according to similarities and common themes found in the papers. This tool captured relevant information about the study's main characteristics, methods, and tools used to assess and understand occupational risks, including those mentioned in the narrative, but not applied in any workplace, workforce, or hospital sector.

2.4.1 Data Items

Data extraction was about the demographic characteristics of the article (e.g., country of origin and journal), research characteristics (e.g., subject, question/objectives, design, study population, sample, variables studied, and kind of equipment), and the main findings on risk assessment and perception.

Chart 1 Search memory strategy in SCOPUS of potentially eligible articles. Research period: 8th to 9th of March 2021

Screening criteria: period (2011–2020), type of document (article), type of source (journal), language (English)		
Boolean operators (AND, OR) and truncation in the term pregnan*		
Search within: Article title—Abstract—Keywords (TITLE-ABS-KEY)		
Keyword combination (KWC)		Search of citations
1 KWC	Risk perception AND occupational health AND hospital sectors	(TITLE-ABS-KEY (risk AND perception) AND TITLE-ABS-KEY (occupational AND health) AND TITLE-ABS-KEY (pregnan*)) AND (LIMIT-TO (PUBYEAR, 2020, OR..., OR 2011)) AND (LIMIT-TO (SRCTYPE, “j”)) AND (LIMIT-TO (LANGUAGE, “English”))
2 KWC	Risk perception AND occupational health AND pregnan*	All (absenteeism) OR All (sick AND leave) AND All (hospital AND care AND personnel) AND All (pregnancy) AND (LIMIT-TO (PUBYEAR, 2020, OR..., OR 2011)) AND (LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (SRCTYPE, “j”)) AND (LIMIT-TO (LANGUAGE, “English”))
3 KWC	Risk assessment AND occupational risks AND tools OR instruments AND hospital sector	(TITLE-ABS-KEY (risk AND assessment) AND TITLE-ABS-KEY (occupational AND risks) AND TITLE-ABS-KEY (tools) OR TITLE-ABS-KEY (instruments) AND TITLE-ABS-KEY (hospital AND sectors)) AND (LIMIT-TO (PUBYEAR, 2020, OR ..., OR 2011) AND (LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (SRCTYPE, “j”)) AND (LIMIT-TO (LANGUAGE, “English”))

2.5 *Synthesis of Results*

The synthesis of collected data was organized to present the range of evidence identified to meet the objective of the scoping review. The data inserted into the data charting form was summarized in a table by author/year, studied variables, and types of methods and instruments for risk evaluation. The narrative format was adopted to present the articles’ characteristics and discuss the results. This review discussed the integration and quality of the methods and techniques raised, the possibilities of using them to protect the health of pregnant, lactating, or childbearing age workers, and management support for risk assessment and maternity protection.

Table 1 The memory of steps for importing citations into JabRef, eligibility, selection, and the total of articles. Period: 10 to 16/03/2021

Research step		Total
Import of articles (1133) to be evaluated for eligibility after screening in SCOPUS, Science Magazine/Academic Search Ultimate, and Web of Science	Data import into JabRef, new entries only, and manually removing duplicates	998
1st selection of articles by title and abstract	1st step, by title—inclusion criteria/keywords in the JabRef search system: risk perception, occupational risks, tools, instruments, risk assessment, hospital, and pregnant women. Until exhaustion, then inclusion and exclusion were manual	110
	2nd step—manual selection by title and abstract from the 1st selection, observing the same inclusion and exclusion criteria	
	3rd step—manual selection from 2nd with the same criteria	
2nd selection of articles—snowball technique on the references of selected articles in the databases	Inclusion criteria: English language, publication period (2011 to 2020), and should address the perception and assessment of occupational risks in the hospital sector, focusing on pregnancy and maternity and proposing a new method, technique, or tool	0
Inclusion of eligible articles		110
Exclusion of eligible articles		91
Exclusion of articles at all steps	The article does not fit the conceptual framework or discuss animal testing, non-occupational practices, patient care, disease prevalence, treatment, gender, abuse, disaster, dentistry, violence, and air pollution	979
Inclusion of selected articles		19

3 Results

The study included 19 articles from the 2,370 records identified in multiple databases, as shown in Fig. 1, and there was no inclusion of new ones with the snowball technique. Within the study period, 2011 to 2020, publications concentrated on the years 2018 (4), 2019 (5), and 2020 (4). Of the 12 countries, the United States of America, Turkey, and Italy stood out with 3 articles each, and France with 2. The International Journal of Environmental Research and Public Health (2) and Safety Science (2) stood out among the 17 journals.

Nearly half of the studies were observational and descriptive, with an emphasis on cross-sectional studies (9). Qualitative studies were also relevant, mainly reviews and other narrative and descriptive studies proposing assessment and perception risks methods and management tools.

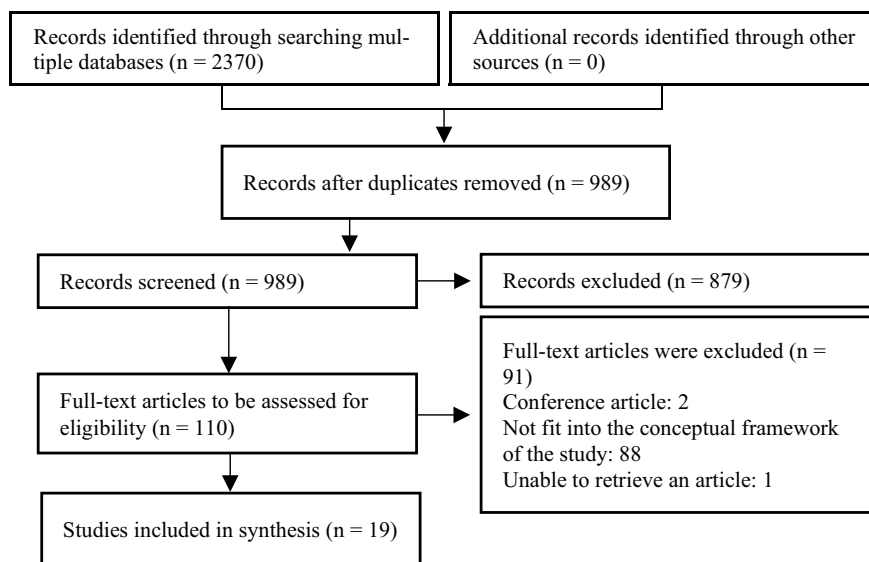


Fig. 1 Search flow diagram of the scoping review

The articles dealing with the hospital sector and the pre-hospital area were 10 and 1, respectively, and all the studies addressed occupational exposure. About the population, 13 studies encompassed healthcare workers (HCW) and 1 the pre-hospital area professionals. A total of 4 articles addressed pregnancy, and only one specifically the pregnant healthcare worker.

As for the researched topics, risk perception was addressed in 9 and risk assessment in 11 articles, and together in only 2; risk management in 6; and feasibility and sensitivity of methods/tools in 8. The number of studies by occupational risk was: 6 (physical hazard), 4 (chemical), 2 (biological), 5 (psychosocial risk factors), 5 (psychosocial and physical risk factors), 15 (ergonomic, biomechanical, and organizational factors). More than half of the articles (13) addressed, in some way, protective and preventive measures. Table 2 lists the articles included by authors/year, variables, method types, and risk evaluation instruments.

4 Discussion

The 19 studies included in this review addressed methods, techniques, and tools for perceiving and assessing occupational risks. However, there is a scarcity of research focused on protecting maternity at work, with few studies on pregnant workers in hospital sectors. Thus, systematic review studies by specific methods, techniques, or tools are necessary to deepen the theme.

Table 2 List of articles included by author/year, title, studied variables, and types of method and instruments for risk evaluation, 2011–2020

Author, year	Title	Studied variables	Method/instrument
Tziaferi et al. (2011)	Risk assessment of physical hazards in greek hospitals combining staff's perception, experts' evaluation and objective measurements	Physical (noise, temperature, humidity, and lighting), electrical, chemical, biological, fire safety, work organization, work with visual monitors, and waste management	Risk perception—the OHS staff questionnaire Risk assessment—the checklist risk assessment matrix (RAM)
Ericsson et al. (2012)	Exposure assessment in different occupational groups at a hospital using quick exposure check (QEC)—a pilot study	Work task (common, strenuous) for the neck/shoulder region and time spent on each work task. Physical and psychosocial work environment	Risk assessment—quick exposure check (QEC). Ergonomic risk assessment tool
Abacıgil et al. (2015)	Perceptions of health personnel about work safety and its relationship with occupational injuries	Age, sex, education, professional category and time of work experience in current position, weekly working hours, and diagnosed chronic disease. Occupational injury in the last 12 months: type and its location, participation in preventive therapy after injuries	Risk perception—a semistructured questionnaire
Giurgiu et al. (2016)	Well-being and occupational risk perception among health care workers: a multicenter study in Morocco and France	Psychosocial risk factors. Risks related to ergonomic, biomechanical, organizational, environmental, toxic and addictive factors	Risk perception—the Moroccan self-administrated questionnaire
D'Ettorre et al. (2016)	Assessment and management of job stress in emergency nurses: a preliminary study	Age, length of service, smoking habit, and alcohol consumption. Psychological stress (depression, anxiety, somatization, aggressiveness, lack of social support—perceived) and objective stress	Risk perception—rapid stress assessment (RSA) scale Risk assessment—tool developed by the Italian Network for the Prevention of Work-related Psychosocial Disorders in Hospital Emergency Departments

(continued)

Table 2 (continued)

Author, year	Title	Studied variables	Method/instrument
Alzubaidi et al. (2017)	Assessment of knowledge and attitude of nurses towards ionizing radiation during radiography in Jeddah City, 2017	Age, education level, and years of experience. Radiation risks and protective measures. Nurses' awareness about ionizing radiation	Risk perception—self-administered questionnaire to assess nurses' knowledge and attitude towards ionizing radiation
Senol et al. (2018)	Evaluation of risk perception and management in emergency medical services providers working in pre-hospital areas in Kayseri, Turkey	Demographic and professional characteristics. Work-related risks: forensic cases, violence, burnout syndrome, risks on site (traffic accidents, fire), disability due to moving and lifting patient/equipment, infectious diseases, trauma and risk of miscarriage in the ambulance during active duty, lack of training in risk assessment and management, high-speed land transport	Risk perception—face-to-face questionnaire to evaluate emergency medical services providers' risk perception and management
Bas (2018)	An integrated OSH risk management approach to surgical flow disruptions in operating rooms	Surgical flow disruptions (SFD). Surgical flow disruptions effects (SFDE). Factors such as technical, human, and environmental (organizational)	Risk assessment—fuzzy cognitive mapping (FCM)—tool for risk prioritization. Human reliability analysis (HRA). Integrated OSH risk management
Oliveira et al. (2018)	Improving occupational health and safety risk evaluation through decision analysis	OSH risks, impact dimensions, descriptor of impact, impacts assessment, value, and probability assessment. Mitigation actions and the impact on each OSH risk	Risk assessment—IRIS approach for improving RMs—value-risk matrix (VRM). Matrix, soft mapping tool, a procedure to model interdependent impacts, analysis technique, and decision support system (DSS)

(continued)

Table 2 (continued)

Author, year	Title	Studied variables	Method/instrument
Tomaschek et al. (2018)	Measuring work-related psychosocial and physical risk factors using workplace observations: a validation study of the Healthy Workplace Screening	Physical factors: posture, anthropometry, tools, and devices. Psychosocial factors: work activity, work organization, and social conditions. Environmental conditions: employment contract and work environment	Risk assessment—The Healthy Workplace Screening. Observation-based job analysis instrument, interview technique, and self-report job analysis instrument
Whitney et al. (2019)	Radiation safety perceptions and practices among pediatric anesthesiologists: a survey of the physician membership of the society for pediatric anesthesia	Demographics. The use of protective lead shielding (aprons, eyewear, thyroid shields, acrylic barriers), institutional safety culture (use of dosimeters, radiation safety courses, feedback on exposure), and the ability to opt out of providing anesthesia in areas of high radiation exposure while pregnant	Risk perception—an electronic e-mail questionnaire
Teyssie et al. (2019)	Perception of environmental risks and behavioral changes during pregnancy: a cross-sectional study of French postpartum women	Sociodemographic situation and data related to pregnancy. Perception of occupational risks to pregnancy and attitudes in the workplace. The preventive measures implemented at home and behavioral changes in personal life. Sources of information on the environment and pregnancy	Risk perception—an anonymous self-administrated survey composed of 30 items of closed questions
Dubray et al. (2019)	Occupational risks evaluation in a centralized antineoplastic agent preparation unit	Hazardous situations with a scale of severity, frequency, effort, and acceptance of risk level	Risk assessment—the global risk analysis (GRA). Integration of risk analysis, severity, frequency, and effort scales. Matrix derived from the scales and map (critical risks)

(continued)

Table 2 (continued)

Author, year	Title	Studied variables	Method/instrument
Zachek et al. (2019)	A screening questionnaire for occupational and hobby exposures during pregnancy	Job characteristics. Workplace and hobby exposures: physical stressors (heavy lifting, prolonged standing, and heavy physical work), organic solvents, ionizing radiation, heavy metals. Use of protective equipment. Symptoms during pregnancy (itchy or tearful eyes, bloody nose, sneezing, coughing, sore throat)	Risk assessment—the pregnancy and work questionnaire
Baracco et al. (2019)	Whole body biomechanical burden of healthcare workers: proposal for a complimentary risk assessment and management tool (HOARA)	Organization of work (total shift duration, number of breaks, and perceived effort cadence). Identification and description of activities. Identification and description of unitary duties (UDs). Job analysis and ergonomic determinants at the UD level. Task analysis and ergonomic determinants of specific activities	Risk assessment—the holistic approach risk assessment helps to define the whole body's biomechanical load risk. Job analysis based on a task time-determining matrix, and global risk index calculation
Lellis et al. (2020)	Occupational risk perceived by pregnant workers: proposal for an assessment tool for health professionals	Identification of pregnant or lactating woman. Habits and behaviors. Information about work. Risk factors: chemical, physical, biological, ergonomic, and accidents. Difficulties faced at work. Need for antenatal leave	Risk perception—The Universidade Estadual de Campinas developed the questionnaire for the qualitative assessment of occupational exposure of interest to the health of pregnant workers based on their perception
Niemeier et al. (2020)	A cumulative risk perspective for occupational health and safety (OHS) professionals	Hazard identification. Dose-response. Exposure. Risk characterization	Risk assessment—cumulative risk assessment (CRA). Integration of: method of cumulative risk assessment, mixtures of substances in the workplace (MIXIE), haz-map, wireless information system for emergency responders (WISER), and online interactive risk assessment (OiRA)

(continued)

Table 2 (continued)

Author, year	Title	Studied variables	Method/instrument
Saranjam et al. (2020)	Hospital occupational safety and health risk assessment	Physical hazards: electrical shock, fire and explosion, feel and sleep hazard, and radiation. Chemical hazards: acid and base materials, alcohol, ether, formaldehyde, and detergents. Biological hazards: needle sticks, hospital waste, and infectious diseases. Ergonomic hazards: musculoskeletal problems and environmental condition. Psychological risks: violence, work shifts, and job stress	Risk assessment—hospital occupational safety and health risk assessment (HOSHRA). Index/checklist
D'Ettorre et al. (2020)	Preliminary risk assessment of workplace violence in hospital emergency departments	Sentinel events. Organizational and environmental factors of workplace violence (WPV) risk	Risk assessment—the emergency department workplace violence-questionnaire (EDWPV-Q)

4.1 Integration and Quality of Methods, Tools, and Techniques

Several articles highlighted the importance of integrating methods, techniques, and instruments [5, 6, 22, 33, 35]. The success of an occupational risk management program, with a consequent reduction in occupational diseases and accidents, involves the integration of objective risk assessments with the different perceptions of the same risks by workers. The workers' input to the risk assessment process is valuable, and finding ways to include their perception of risk helps to provide a complete picture of the workplace situation [4].

For instance, the health professionals' perceptions can be influenced by the communication and risk management adopted, resulting in an exaggerated perception of risks during pandemics and outbreaks of diseases such as Covid-19 and Ebola. Therefore, understanding the workers' perception favors measures that can reduce the risk of infection and the associated anxiety, protecting their physical and psychological well-being [15, 21].

When comparing professionals in the hospital sector of different categories and functions, combining methods and tools is necessary to assess the perception and objective risks of work-related stress (WRS). For example, the Rapid Stress Assessment (RSA) scale with the Prevention of Work-Related Psychosocial Disorder tool,

developed by the Italian Network, effectively showed a higher risk of WRS and higher scores of perceived stresses by emergency nurses than by administrative staff [9].

The Healthy Workplace Screening (*Screening Gesundes Arbeiten*) is a standardized job analysis instrument measuring work-related risk factors, such as physical and psychosocial, on a screening level by combining behavioral observation with a complementary interview technique [29, 33]. Also, differences observed in the perceived risk level of physical hazards, considering the subjective evaluations by staff (The OHS Staff Questionnaire) and the quantitative measurements (The Checklist Risk Assessment Matrix—RAM), usually indicate the need for health and safety training [35].

Using non-conventional methods is more effective when considering the interrelationships between different factors [3]. So, by adapting to occupational risks an integrated Occupational Safety and Health risk management methodology [6], based on the ILO approach and the Fuzzy Cognitive Map [3], it is possible to visualize and prioritize the interdependencies and the cause-effect relationships among different factors such as surgical flow disruptions (SFD), surgical flow disruptions effects, and preventive and protective measures.

A Cumulative Risk Assessment (CRA) can improve the reliability and confidence in occupational health assessments and risk management decisions by focusing holistically on how multiple exposures interact to contribute to a health outcome. Various exposures in the workplace should prompt OHS professionals to consider a CRA perspective using a stressor (exposure)-based approach. On the other hand, observed symptoms or illnesses should encourage a CRA using effects (outcomes)-based approach, especially in multiple exposures [22].

Integrating methods allows for more effective human resources management, especially when assigning workers to specific jobs or tasks. The Holistic Approach Risk Assessment (HOARA) allows assessing health professionals' biomechanical load through the medical and ergonomic branches of the management system [5]. It reaches a much deeper level of detail by looking at the "activities" that are the building blocks of the job. The division into risk areas makes it possible to express judgments of aptitude for work related to individual activities or elementary tasks, allowing the recruitment of the worker for the same function redesigned according to the results of the applied method.

Regarding the quality of the methods, techniques, and tools listed in this review, The Pregnancy and Work Questionnaire is helpful for pregnant women at risk of occupational or hobby-based exposures [14, 37]. This practical, low-cost tool allows for screening obstetric patients for chemical exposures and physical hazards and incorporates exposure assessment for robust evidence of adverse reproductive and developmental outcomes. In clinical settings, it is well accepted, and obstetricians without training in occupational medicine can similarly apply the systematic criteria when evaluating patients for referral [37].

Likewise, the questionnaire developed by the *Universidade Estadual de Campinas* [19] allows healthcare professionals, especially physicians, to assess occupational

exposure to agents [25] and risk factors according to the perception of the pregnant worker. Furthermore, it helps establish conduct and guidelines for patients and employers on possible control and protection measures [19].

Methods, techniques, and tools must also be sensitive to exposure variations to capture differences between occupations and workers within the same job. In addition, they need to be easy to handle, with essential information and clear guidelines for use, as demonstrated in exposure assessment studies in different hospital occupational groups using the Quick Exposure Check [7, 13].

Hospital units can use the Value-Risk Matrix (VRM) to systematically look for potential risks or situations that may cause accidental exposures. This matrix seems to overcome the problems of the classic risk matrix in defining occupational risk categories and allocating resources for mitigation measures. It also proved flexible to model perspectives regarding OSH risk assessment [23].

Finally, The Emergency Department Workplace Violence Questionnaire [8] has proven valuable, structured, and reliable. Besides assessing the risks of violence in the workplace (Type II), it identifies improvements aimed at specific critical issues in emergency services, as seen in the validation study of the Italian version of the WHO questionnaire [18].

4.2 Identified Methods and Equipment and the Possibility of Use to Protect the Health of Pregnant, Lactating, or Childbearing-Age Workers

Although most studies have not focused on maternity protection methods in the workplace, several pointed out occupational risks that can impact female workers' health, pregnancy, and maternity in general, as seen in the literature.

Using the Rapid Stress Assessment (RSA) scale [9] allows for measuring work-related stress (WRS) risks in hospital environments. Applying RSA to an Emergency Service, it is possible to determine professionals at higher risk of WRS and higher stress scores, such as those related to anxiety and depression. Significant work issues can include three work shifts, high exposure to physical and biological risks, variable and non-programmable workloads, use of technologies that demand high responsibility, work close to suffering, and high emotional demand. The scientific literature describes outcomes related to WRS, such as premature birth and miscarriage, macrocephaly, fetal malformation, developmental disorders, low milk supply, and early weaning [25].

Regarding radiation risks and protection strategies, it is possible to assess the perception and practices of pediatric anesthesiologists using an electronic questionnaire [36]. Although some professional categories have a high level of knowledge and attitude toward risks and radiation protection, safety education programs are needed to increase knowledge of risks and adherence to protective measures [11]. Radiation exposure can lead to fetal death, malformations, growth disorders, mutagenesis, and

carcinogenesis [31]. Therefore, the sexual and reproductive health of workers must be protected, especially women, who make up the majority of the health workforce.

A face-to-face questionnaire is also helpful in assessing risk perception and management in pre-hospital services. Through this type of questionnaire, it is possible to determine stressful conditions, such as risks of aggression in forensic cases, as well as some acute and personal safety stressors, such as fire, explosion, secondary accidents, trauma in forensic cases, and incapacity due to inadequate lifting techniques [28]. As the literature shows, traumatic injuries in pregnancy can lead to obstetric complications, such as miscarriage, fetal or neonatal death, retroplacental hematomas, uterine rupture, placental abruption, and premature delivery [11].

An anonymous self-administered survey is also valuable for identifying environmental risk factors, such as chemicals in everyday products, as the environment is a significant factor in a healthy pregnancy. Thus, knowing the environment and its risk factors is fundamental for the pregnant woman to modify her practices at work or home and take preventive measures in consultation with the occupational or perinatal doctor [10, 32].

The Global Risk Analysis [12] is ideal for assessing critical risk categories in a centralized antineoplastic agent preparation facility, such as product, emissions, and residue risks, psychosocial risk factors; and risks related to working equipment. The importance of knowing these risks is the confirmed relationship between anesthetic gases, spontaneous abortion, and congenital malformations; chemotherapy and congenital malformations; and shift work and miscarriage [26].

The Hospital Occupational Safety and Health Risk Assessment (HOSHRA) is an index that categorizes potential risks in hospitals into five categories: physical, chemical, biological, ergonomic, and psychological hazards [27]. HOSHRA covers almost all risks and outcomes to be considered to protect pregnancy and maternity in the workplace, as reported in the literature [25, 26, 30].

Furthermore, it is worth using the questionnaires already mentioned: The Pregnancy and Work Questionnaire [37] for pregnant women at risk of occupational or hobby exposures and the one developed by the *Universidade Estadual de Campinas* [19] to assess the perception of occupational risk in pregnant women.

4.3 The Management Support for Risk Assessment and Maternity Protection

Some studies pointed out the importance of management support for overcoming work-related injuries. The use of several assessment methods and techniques should involve the OHS team, head physicians, and head nurses [8].

Management support should be provided by arranging working hours, prioritizing training activities on safety practices, and identifying problematic dimensions for occupational safety in hospitals [1]. Thus, a map of stressful occupations is relevant for managing occupational risks because it identifies priorities for action [16, 27]. The

OHS management should promote education about workplace risk factors, protective measures, and the culture of radiation safety [33], even during pre-employment orientation [2].

Management support is essential for workplace adaptations, and task assignment adjustments to enable women to work as long as possible while pregnant and breast-feed when returning to their professional activities [24]. It is important to reiterate that preventive measures to protect the worker's health and pregnancy must be done in consultation with an occupational or perinatal physician [20, 32].

5 Conclusions

Although there is a shortage of specific studies, the literature provides some methods, instruments, and tools to assess and perceive occupational risks that, with specific adaptations, can be applied in hospital workplaces to protect maternity.

The integration and quality of methods, techniques, and tools increase the robustness of occupational risk assessments, which favors preventive measures and risk mitigation to protect workers' health, including pregnant, lactating, or childbearing-age women.

Management support is essential to assess and understand the occupational hazards of healthcare workers, increase adherence to preventive measures, and protect their health, including during pandemics and disease outbreaks. Finally, it is necessary to draw up specific norms for preventive care aimed at pregnant workers and establish rules for cooperation between occupational physicians and obstetrician-gynecologists.

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Assessing Mental Workload in Industrial Environments: A Review of Applied Studies



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Abstract Together with physical aspects, cognitive fatigue and overload are important factors for the occurrence of work accidents and underperformance in the workplace. That is why mental workload assessment methods are currently of great interest. Given the changes in the very nature of work from a physical to a more cognitive basis, it is expected that concerns about mental workload will remain high. Different types of mental workload assessment methods exist, many of which were designed to applications in controlled environments. Thus, this study aims to make a systematic review of the literature in order to identify which mental workload assessment methods have been employed in industrial environments. From an initial sample of 1.918 documents, fifteen documents were included in the review containing cognitive assessment methods employed in different sectors. Among the main findings, subjective methods are the most employed across industry sectors with a predominance of NASA-TLX applications. The automotive sector was the target of most studies given the increasing automation levels in this type of industry. Identified research opportunities include the applicability of methods to real environments, the transparency and standardization in the methods selection and combination processes, and the inclusion of psychosocial factors and occupational hazards when establishing methodological approaches.

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Keywords Cognitive ergonomics · Mental fatigue · Industry · Stress · Worker

1 Introduction

Together with physical aspects, cognitive fatigue and overload are important factors for the occurrence of accidents and performance development in the workplace [11]. This is why methods of assessing mental load are currently of great interest, and given the changes in the nature of work itself from a physical to a more cognitive basis, they are expected to remain important [36]. Cognitive overload can be understood as a mismatch between the individual resources available to perform a task and the cognitive resources required [7], whereas mental fatigue causes distractibility and lapses of information processing that, in turn, affect memory performance and attention levels [40]. Mental fatigue has been also linked to higher perceived exertions during physical tasks, which hinders performance [2, 8]. Therefore, given the importance of cognitive ergonomics for the wellbeing, health and safety of workers, different methods have been developed to assess mental workload. According to ISO 10075-3 [16], these methods can be grouped in four categories: physiology, subjective, performance, and job and task analysis. Each category has a particular approach to mental workload assessment, as shown in Table 1. Even though there are other ways to classify mental workload assessment (MWA) methods, as discussed by Galy [13], all methods tend to agree on the nature of ‘measures’ as ‘subjective’, ‘psychophysiological’, and ‘performance-based’. Galy [13] also highlighted the lack of exhaustive measures to assess the different components of mental workload.

On related works, Diaz-Garcia et al. [11] performed a systematic literature review to summarize and classify validated tools used to quantify mental load and fatigue. The authors included 40 scientific works, concluding that 75% of them employed subjective scales in their assessment. However, according to workplace physical and

Table 1 Categories of mental workload assessment methods

#	Category	Description
1	Physiological	These methods provide information about physiological states of employees under given work conditions
2	Subjective	These methods evaluate how workers feel about their work conditions
3	Performance	These methods offer the possibility to evaluate human mental and psychomotor performance under given work conditions, e.g., in order to assess decrements or variations in performance due to the effects of mental workload;
4	Job and Task Analysis	These methods assess task elements, physical and psychosocial work conditions, environmental conditions and the organization of the work process as sources of mental workload

Source Adapted from ISO 10075

psychosocial hazards, as discussed by Oakman et al. [26], or the task under evaluation, certain tools can prove to be more or less appropriate. For instance, Dadashi et al. [9] reviewed cognitive and metabolic workload assessment techniques in the manufacturing context and declared that few methods, among which subjective ones, seem ready for certain real-case applications. Butmee et al. [4] reviewed several methods applied to driving tasks and classified them in subjective, performance analysis, and physiological techniques. The authors declare that, even though NASA-TLX and, more recently, eye-behaviour measures have been commonly used in driving task analysis, no method has been nominated as best suited. Similar reviews have been performed with a focus on health workers [10] and stress management [18]. Also, in a specific study about stress management, Kennedy and Parker [19] have supported the use of biofeedback, i.e., monitoring of physiology measurements such as heart rate variability (HRV), in physiological and subjective stress management. Still, many other works suggest the combination of different methods to comprehensively capture mental and physical workload [4, 10].

Some authors have also proposed frameworks to select appropriate mental workload assessment methods. Miller [24], for instance, proposed a decision tree based on the following criteria: obtrusive (e.g., brain, respiratory and secondary performance measures) versus unobtrusive (e.g., subjective, other physiological, and primary performance measures), data collection form, time consideration, sensitivity, cost of implementation, and reliability. Nonetheless, factors such as data collection, and the time and obtrusive criteria can limit applications in industrial environments. Furthermore, with automation and other industry 4.0 trends, the cognitive workload of industrial workers is expected to follow the upward trend of digitalisation levels [6]. However, from the best of the Authors' knowledge no study has reviewed mental workload assessment methods that are specifically applied to case studies in the industry, as many methods are applied in controlled environments only [22, 30]. Thus, the present study is motivated by this gap and aims to review the literature in order to identify which MWA methods have been employed, with success, in industrial case studies.

2 Materials and Methods

Based on the proposed research objective of investigating the MWA methods applied to the industry, a systematic literature review on the topic of mental workload assessment methods was conducted. Industries in the secondary sector were included in the review with a focus on physical tasks, which means that office work were out of scope. Ten keywords were combined in 29 different ways as shown in Table 2, where the scorecard “*” could represent a single character or a string of characters used to conclude the search word. These 29 combinations were used as queries in the databases PubMed (PM), Science Direct (SD), Scopus (SC), and Web of Science (WoS). Inclusion criteria limited the results to journal articles and conference proceedings written in English and published after 2012. This cut-off date was

considered for two reasons, first, an increase in industry automation, and second, the evolution of mental workload methods.

This search resulted in 4739 documents. The reference manager Mendeley was used to organize documents. After removing duplicates, a total of 1918 documents had their titles and abstracts screened. At this step, 1830 documents were excluded because (1) were not written in English, (2) consisted of review articles, and (3) were out of scope (e.g., theoretical studies, focused on health care, army, aviation, and construction sectors). As eight documents could not be retrieved, the subsequent step consisted of reading the full-text of the remaining 80 documents. At this step, 65 documents were excluded for being out of scope representing studies conducted in laboratory, controlled environments, and sectors that were not of interest (e.g., primary sector and construction). This final full-text screening step resulted in 15 works that were included in the review, as shown in Fig. 1.

Table 2 Search string combinations

Strings
workload AND ergonom* AND cognitive AND assessment AND psychosocial workload AND ergonom* AND cognitive AND assessment
workload AND ergonom* AND cognitive AND psychosocial workload AND ergonom* AND cognitive
workload AND ergonom* AND cognitive AND assessment AND industry workload AND ergonom* AND cognitive AND industry
workload AND ergonom* AND industry
workload AND ergonom* AND cognitive AND tool* AND assessment workload AND ergonom* AND cognitive AND tool*
workload AND ergonom* AND cognitive AND techniqu* AND assessment workload AND ergonom* AND cognitive AND techniqu*
workload AND ergonom* AND cognitive AND method* AND assessment workload AND ergonom* AND cognitive AND method*
workload AND cognitive AND techniqu* AND tool* workload AND cognitive AND techniqu* AND method* workload AND cognitive AND techniqu* AND instrument* workload AND cognitive AND method* AND instrument*
workload AND cognitive AND tool* AND method* AND instrument* workload AND cognitive AND tool* AND method* AND techniqu* workload AND cognitive AND tool* AND method* “mental workload” AND cognitive AND method* AND techniqu* “mental workload” AND cognitive AND tool* AND instrument*
“mental workload” AND “cognitive ergonom*”AND techniqu* AND tool* AND method* “mental workload” AND “cognitive ergonom*” “AND techniqu* AND tool* “mental workload” AND “cognitive ergonom*”AND techniqu*
“mental workload” AND “physical workload” AND tool* AND instrument* AND assessment “mental workload” AND “physical workload” AND method* AND techniqu* AND assessment “mental workload” AND “physical workload” AND method* AND techniqu* “mental workload” AND “physical workload” AND assessment

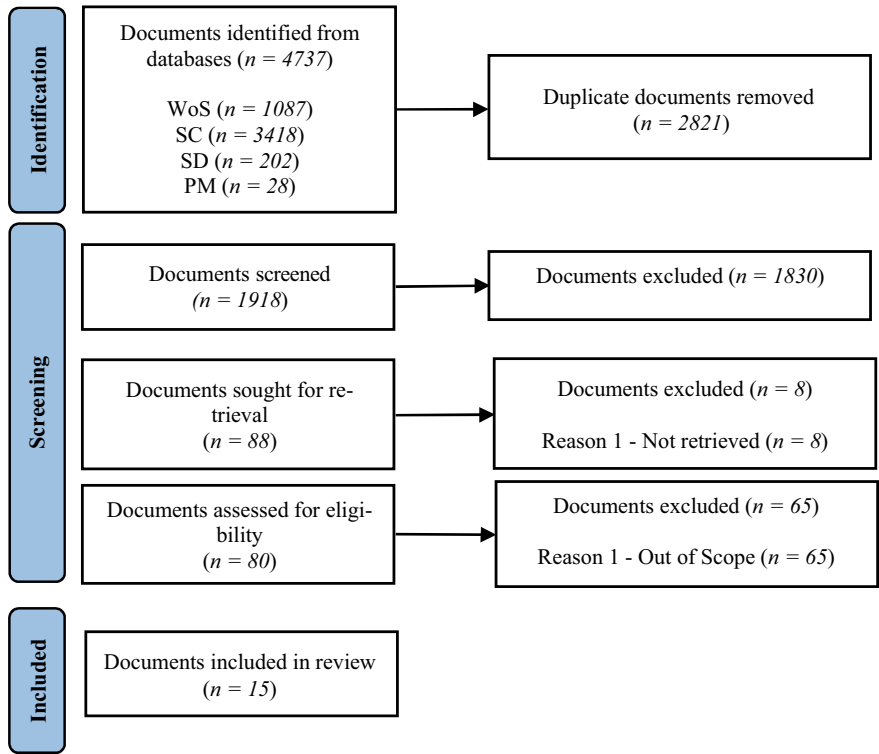


Fig. 1 Literature review process. *Source* Adapted from Page et al. [28]

3 Results

Table 3 displays the main characteristics of the reviewed studies, concerning countries where studies were conducted, the industry type, the sample size of the conducted study, and employed methods. Not only MWA methods are presented in Table 3, but also “physical workload assessment methods” and “other methods”, which were only presented for demonstration purposes. Physical workload assessment methods included Occupational Repetitive Action (OCRA), Ovaco Working Posture Assessment System (OWAS), Rapid Upper Limb Assessment (RULA), and Régie Nationale des Usines Renault (RNUR). Whereas, “other methods” include Rfad [34] and Task Execution Reliability Model (TERM) [21] methods that simultaneously assess physical and mental workload.

Figure 2 displays the number of publications per year. Since databases search occurred in October 2022, the number of publications included in 2022 do not represent the whole year and are likely to increase as the end of the year approaches. As for the location of applied case studies, Europe was the focus of 5 studies (n = 3 in Sweden, n = 1 in Germany, n = 1 in Serbia and Greece). Five studies were performed

Table 3 Characteristics of the reviewed studies (country, industry type, sample size, and employed methods)

References	Country	Industry	Sample size	Methods*	No. of methods
[27]	Brazil	Metallurgical	457	Job Stress Scale (JSS) and Utrecht Work Engagement Scale (UWES) Blood Pressure (BP), Heart rate (HR), Adapted Nordic	2
[32]	India	Textile	219	Musculoskeletal Questionnaire (NMQ), Body Part Discomfort (BPD), and Ovaco Working Posture Assessment System (OWAS)	5
[34]	Brazil	Automotive	Not mentioned	Rfad method	1
[37]	Not mentioned	Automotive	6	Rating Scale Mental Effort (RSME), Electromyography (EMG), Belastungsverlaufstest (BLV) and Ovaco Working Posture Assessment System (OWAS)	4
[25]	India	Metal	26	Index of Cognitive Activity (ICA)	1
[14]	Serbia and Greece	Manufacturing	56	Electro dermal activity (EDA), Electroencephalogram (EEG) and Oximeter and Checklist Individual Strength (CIS)	4
[29]	Brazil	Automotive	Not mentioned	Job Profile Method of Renault (RNUR), NASA Task Load Index (NASA-TLX) and Global Health Questionnaire (GHQ)	3
[15]	Germany	Warehouse	32	Detection Response Task (DRT) and NASA Task Load Index (NASA-TLX)	2

(continued)

Table 3 (continued)

References	Country	Industry	Sample size	Methods*	No. of methods
[38]	Sweden	Manufacturing	Not mentioned	CLAM and NASA-TLX	2
[12]	Iran	Porcelain	120	NASA Task Load Index (NASA-TLX), Occupational Repetitive Action (OCRA), Nordic Musculoskeletal Questionnaire (NMQ)	3
[41]	Indonesia	Textile	10	NASA Task Load Index (NASA-TLX) and Rapid Upper Limb Assessment (RULA)	2
[1]	Sweden	Automotive	75	Interview	1
[33]	Iran	Metal	300	Own developed questionnaire	1
[42]	Sweden	Automotive	50	Interview	1
[21]	Not mentioned	Electronics	149	Task Execution Reliability Model (TERM) and NASA Task Load Index (NASA-TLX) modified version	2

in the Asian continent ($n = 2$ in Iran, $n = 2$ in India, and $n = 1$ in Indonesia), whereas South America, more specifically, Brazil, contributed with three of the publications.

The automotive industry category included studies focused on fatigue recovery and the improvement of production times at an automotive industry in Brazil [34], physiological and subjective workload effects during a typical automotive assembly operation [37], psychophysical demand and workers' perceived workload within assembly cells in an auto parts industry [29], effects on the cognitive performance of industrial assemblers in the context of product design, production setup and assembly in vehicle and automotive component manufacturing companies [1].

"Electronics" comprehend studies focused on evaluating mental and physical workload in a set of assembly workstations in a large computer manufacturing company [21]. In the Metal industry category, Nandakumar et al. [25] evaluated the cognitive workload in a small-scale iron foundry industry. Shakerian et al. [33] tried to identify cognitive unsafe behaviours in front-line industrial workers in a steel manufacturing complex. The study of Padula et al. [27] assessed occupational stress and work engagement in a Metallurgical industry and it was therefore assigned to this category. Fadaei et al. [12] measured the physical and mental workload of workers in the assembly line of porcelain company.

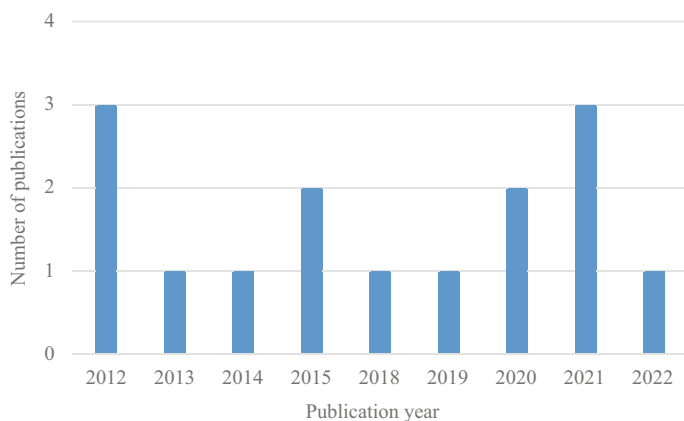


Fig. 2 Number of publications per year

The Textile industry, Sett and Sahu [32] assessed the work stress and the development of work-related musculoskeletal disorders of jute mills workers in India, and Widiastuti et al. [41] measured batik workers' physical and mental workload in Indonesia.

The Warehouse category [15], even though linked to the provision of services, was included in the review for being incorporated in manufacturing processes from a variety of industries, such as paper mills and steel manufacturing. Moreover, the activity performed in the reviewed study was of relevance to an industrial environment. Finally, two works did not mention the investigated sector within the manufacturing industry, but discussed electrophysiological measures for improving industrial workers' wellbeing [14] and developed a tool to reduce cognitive load in assembly workers in Sweden [38]. The Automotive industry was the focus of most of the studies ($n = 5$), followed by the Metal, Manufacturing and Textile ($n = 2$ for each one), Electronics, Warehouse, Porcelain, Metallurgical ($n = 1$, for each one). In relation to the number of methods used per study, these vary from 1 to 5 methods. Most authors used 1 ($n = 5$) or 2 ($n = 5$) methods. Table 4 shows the employed methods grouped according to the type of industry where they were applied.

4 Discussion

In agreement with what was observed by Dias et al. [10], NASA-TLX was the most used method, being applied in 6 of the 8 industry types, namely, Automotive, Electronics, Manufacturing, Porcelain, Textile, and Warehouse. Nonetheless, NASA-TLX as a subjective scale method, suffers from certain lack of convergence with physiological and performance-based measures [23]. On the other hand, it is an easily-applied questionnaire, widely known, that has been used in the validation

Table 4 Methods by type of industry

Industry type	Methods
Automotive	NASA-TLX, RSME, EMG, OWAS, RNUR, GHQ, Interview, BLV, and Rfad
Electronics	NASA-TLX and TERM
Metal	ICA and own developed questionnaire
Metallurgical	JSS and UWES
Manufacturing	NASA-TLX, CLAM, EDA, EEG, Oximeter, and CIS
Porcelain	NASA-TLX, OCRA, and NMQ
Textile	NASA-TLX, BP, HR, NMQ, BPD, OWAS, and RULA
Warehouse	NASA-TLX and DRT

process of other methods (e.g., [3, 38]). Other subjective methods include the JSS, UWES, RSME, and CIS. Physiology methods included EEG, EDA, and HR and they were commonly used in tandem with other methods to measure mental and physical workload. This can be explained by the characteristics and wide application of HR measures as an indicator of individual health [13]. In favour of the application of physiological methods to industrial environments, wearable and light-weight devices are considered promising for cognitive stress monitoring and management (e.g. [35]). However, these devices are subject to further improvement as cost of equipment, sensitivity and data reliability are obstacles for its wide implementation [5, 39]. Moreover, in industrial, as opposed to controlled environments, external factors can generate noise signals that create a bias on physiological measures [31].

Performance and job and task analysis methods were the least found in the reviewed literature. In the performance category, the Detection-Response Task (DRT) method [17] was used by Gross et al. [15] to evaluate the impact of digital devices on the health and safety of forklift truck drivers from a warehouse and logistics company. In this case, DRT was combined with the NASA-TLX subjective method. For job and task analysis, the CLAM and WAI methods were applied. The CLAM method [38] is relatively new, freely available and does not require specialists to collect and analyse data. The literature does not provide reasons for the low applicability of performance methods to real industry environments, but we believe this is due to the method’s nature. Since it monitors the performance of a subject in a primary task when attention is shifted to a secondary cognitive task so, a controlled environment is often required.

In terms of the methods applicability in relation to industry types, it was noticed that there is no pattern besides the fact that NASA-TLX and its variations are used transversally across different industries. This contributed to the fact that subjective methods were the most employed to evaluate mental workload. Moreover, scale-based questionnaires are easier to apply and to analyse than more technological methods, in addition to being low-cost, as not specific equipment is required. Although we can mention these reasons for the wider use of subjective tools, it was not common practice in the reviewed studies to justify the use of selected assessment

methods or their combinations. The automotive sector was the most investigated among reviewed studies, which may be explained by the large automation process that automotive industries have experienced in the past decade [20]. This changed the focus from physical to mental burdens as the industry adapted itself to higher cognitively complex environments [6].

5 Conclusions

The main objective of this study was to identify the mental workload assessment methods used in industrial environments, as most methods are essentially developed to be applied in controlled settings. After a literature review, it was possible to infer those subjective methods are the most employed methods across industry sectors, more specifically the NASA-TLX method. Physiological methods, even though based on quantitative measurement, were not as used as subjective ones. However, it is expected that technological development and machine learning tools will help to overcome the main limitations of these methods in terms of cost, reliability, versatility, and validity. The automotive sector was the target of most studies.

Among the limitations of the present study, we can mention the relatively small number of included studies. However, this can be justified by the fact that many MWA methods require a controlled environment. This points to the first identified research opportunity, which refers to the applicability of methods in real environments. Secondly, the authors call attention to the lack of reasons for selecting specific methods and their combinations, which could even question the suitability of methodological approaches. Even though there is no one-size-fits-all approach, this requires further research on the topic of standardized selection of mental workload assessment methods. Lastly, the absence of a pattern in the type of industry and employed methods shed light to the potential inclusion of psychosocial factors and occupational hazards in the decision of which method or combination of methods to employ.

Acknowledgements This work has been supported by FCT—Fundação para a Ciência e Tecnologia within the R&D Units Project Scope: UIDB/00319/2020.

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Managing Prevention of Psychosocial Risks in Europe—Systematic Review of Good Health and Well-Being Practices in Social Economy



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Abstract Psychosocial risk prevention has become increasingly important in the European landscape. The relevance of analyzing conditioning factors in good psychosocial risk prevention practices is increasing significantly in the face of constant change and psychosocial risks that are difficult to mitigate for current reasons. The aim of this article is to identify, through empirical research, evidence on the factors analyzed as good practices for the prevention of psychosocial risks in Social Economy organizations. This research aims to identify: H1 factors that improve the prevention of psychosocial risks in organizations; H2 which are the most necessary strategies to use in Social Economy organizations. In the methodological development, data were collected through a Systematic Literature Review (SLR) and the PRISMA®—Preferred Reporting Items for Systematic Reviews and Meta-Analyses method was used. In the multilevel analyses, the association between NVivo® software and Design Structure Matrix (DSM) was used, which allowed the verification of variables of the levels. The following main points of consideration were assessed: employee involvement; well-being at work programs; regular check-in; organizational flexibility; specific training; collaboration with specific external entities; employee involvement programs; promotion of work-life balance; building resilience.

Keywords Mental health · Empowerment · Healthcare

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1 Introduction

According to Drucker [7], the most important task of the leader of an organization is to anticipate crises, perhaps more than to conjure them. Ongoing contemporary social problems, such as the 2008 crisis, the impact of public health emergency caused by the Sars-CoV-2 pandemic and the more recent war in Ukraine and subsequent inflation, have caused unprecedented disruptions in the economy and society at large and triggered profound and rapid labor changes that have generated, exacerbated and enhanced psychosocial risks and highlighted the relevance of the health and well-being of workers and the consequential importance of managing psychosocial risks in such contexts. Based on the Diagnosis of NGOs in Portugal (2015), the risk of burnout due to accumulation of functions it was already very high, and the wear and tear or psychological demands of the work developed at all levels of the hierarchy is transversal in Social Economy. Mitigating burnout can not only have a positive impact on the organization, but most importantly the people it serves [26]. Nowadays, organizations recognize the cost of human resource health and that this should be minimized [2]. The general objective of this study is related to the systematic analysis of the state of the art and identification of the main good practices in the mitigation of psychosocial risks in social organizations, determinants of employee health and well-being in the European context. The specific objectives can be presented as follows: (a) Assessing the specificities of psychosocial risk management in this organizations; (b) Presenting the psychosocial risk factors and well-being constraints inherent to good practices in organizations; (c) Identifying and analyzing good practices in psychosocial risk management; (d) Identifying good practices aimed at mitigating psychosocial risks. Thus, the following starting hypotheses were formulated: H1 factors that improve the prevention of psychosocial risks in organizations; H2 which are the most necessary used strategies to use in Social Economy organizations.

This study is relevant in three main aspects: 1. The study of analysis methodologies of psychosocial risk management in social organizations enables its articulation in the third sector. 2. An essential aspect for this study is the comparative analysis with some models implemented in European social organizations, aiming at allowing the understanding of the application of the legislation in force and of the good practices in a European context. 3 It has to do with the importance of managing the wellbeing of human resources in phases of change and/or reformulation, given their primacy in the social area. According to [18] a peculiar characteristic of the human organism when it is dominated by a certain need is that the future philosophy also tends to change.

Note that, according to Csikszentmihalyi [14], there are two main strategies we can adopt to improve quality of life. The first is to try to match external conditions with goals. The second, is to change the way the external conditions are experienced to better match the goals [23], defines well-being in his framework: no single measure defines it exhaustively, but several elements contribute to it and each of them is

measurable. According to [8], an organization can entrench the fixed mindset by conveying to employees that they “either have it” or “don’t have it”: this is called a developmental culture.

2 Methods

2.1 Detailed Methodology

In order to minimize the subjective component, the possible attribution of risks or errors and to be able to replicate the study, the guidelines of the PRISMA method will be followed [4]. A Systematic Reviews and Meta Analyses is based on a question created in a clear way, using systematic methods, explicit to identify, select, and evaluate in a critical way relevant different perspectives, and collect and analyze data from this studies included in the review [20]. The inherent scientific process of systematic review will be PICOS (Population, Interventions, Comparisons, Outcomes and Study design. According to Camilo [3], that implies an a priori definition of the following elements: P Population or problem, which should define the main characteristics of the study participants to be included (e.g. age, gender, socioeconomic status, ethnicity, geographical area or with a specific health or social need, I Interventions or exposures, which include diagnostic, preventive or therapeutic interventions, psychosocial or educational interventions, lifestyle changes or major events, or risk factors; C Comparison, which defines the control group (when comparative studies are to be included); O Results of the intervention or and position; S Research design of the studies to be included (experimental, quasi-experimental, correlational, descriptive) [13].

2.2 Search Criteria

In this research study, the PRISMA protocol Preferred Reporting Items for Systematic Reviews and Meta Analyses [20] was adopted. In the collection of scientific articles, Web Science, Science Direct and Scopus databases were searched. The searches were conducted in the period between the years 2018 to 2023, in order to allow an analysis of the most recent and current research in the Literature. This timeline was selected in order to cover the most current and contemporary social problems possible, such as epidemics, war and current social and political crises. Through the starting question that aims to “*identify, in empirical research, evidence on factors analyzed as good practices for the prevention of psychosocial risks in Social Economy organizations*”. The sample is based on a keyword search in review articles already published in a database on Psychosocial Risks. This sample focuses on questionnaires and observation instruments already published for each country. the keywords or

Table 1 Keywords search

Search categories Keywords (in a European context in the last 5 years)	Nº Art	Countries (in order of number of publications)
“psychosocial risk” AND “Social Economy” OR “non-profit” OR “social organizations” OR “third sector”	1	Italy
“psychosocial risk” AND “Europe”	25	UK, Italy; Netherlands; Spain; Ireland; Germany; Finland; France; Poland
“well-being” AND “work” AND “Europe”	249	UK, Spain; Italy Poland; Germany; Netherlands; Portugal; Belgium and France
“well-being” AND “work” AND “Social Economy” OR “non-profit” OR “social organizations” OR “third sector” AND “Europe”	1	Austria

Source authors

search terms were gauged taking into account PICOS P=Population or population involved; I=Intervention or type of intervention carried out in the research; C=Control or control used as comparative or regency; and O=Outcome or expected results and S=Study Design or Study Design (Table 1).

In the first phase, a search was conducted which ascertained (295) articles distributed as follows: Science Direct (26); Scopus (269). The articles are of typology, review articles, research articles and book chapters from several European countries, namely: England (UK), Spain, Italy, Germany, Netherlands; Ireland; Finland; Belgium; Poland and Portugal. Of the articles checked, 242 were removed for several factors and only (35) dealt with the theme (18) dealt with the specificity of the criteria. The remaining were imported into the Zotero® software (Fig. 1).

2.3 Categorization and Inclusion Criteria

Of the 295 articles assessed, these were not empirical studies; and most deal with the analysis of psychosocial risks outside Europe. Thus, 18 articles remained for analysis by the stages of: (a) preparation; (b) categorization; (c) description and (d) interpretation [3].

- (a) **Preparation** were coded to ensure traceability and entered into Excel® and Zotero®. As criteria of definition of the sample, they were according to the year of publication, organizational areas, most studied factors, and measurement methods. The 18 articles were loaded into NVivo® and Excel® software, according to the PRISMA® method. The NVivo software will also be used to work with the project concept. The project's sources of information, as well as

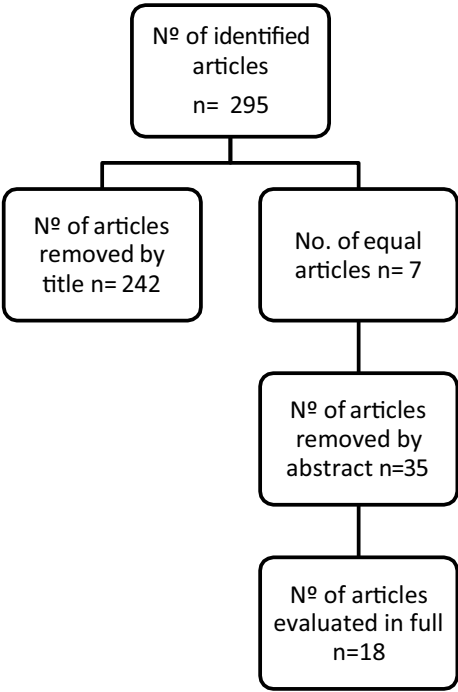


Fig. 1 Inclusion and analysis criteria in the SLR Systematic Literature Review. *Source* authors

- the data generated during the analysis process, as categories of information, are stored in a database [14].
- (b) **Categorization** was made in Zotero® by four major areas of Psychosocial Risk prevention: 1. Well-being in Organizations; 2. Social and Solidarity Economy; 3. Psychosocial Risk Management with analysis in the last 5 years on European territory (Fig. 2).

Criteria of Inclusion type of art.	Ideomatic Criteria	Time criteria	Localisation criteria
• Analysis and review articles; • theses and dissertations and research articles; • Books and chapters.	• English; • French; • Spanish; • Portuguese.	• Last 5 years.	• Countries in the European territory.

Fig. 2 Definition of Inclusion Criteria *Source* authors



Fig. 3 Step-by-step method of Systematic Literature Review *Source* authors

- (c) **Description** were subsequently described using PRISMA® method sheets in order to identify similarities and differences between analysis articles. They were also categorized in DSM (Design Structure Matrix) in order to identify method analysis groups (Fig. 3).

Step 1 and 2 The first stage consists of a general search for articles, in Scopus and Science Direct, and papers, in the Theses and Dissertations, only in English, French, Spanish and Portuguese, and in the last 5 years (2018–2023). The search gave 1055 results in Scopus and 26 results in Science Direct. The same articles are refined search turning in 295 results total, then sorted to ensure that 7 were separated for the repetition.

Step 3 and 4 Subsequently, another filter is added to the search for 288 articles so that it is more refined for peer-reviewed journals, that is, only for articles evaluated by at least two reviewers. Then, a search is made in the titles of the 242 articles and of the works (theses and dissertations) in order to analyze and separate the most relevant ones, so that later a search was made in 34 articles by their Abstracts in order to specify those that should be fully analyzed 18, in the last phase.

- (d) **Interpretation** in this phase was aimed at analysis and interpretation of results to answer the initial questions.

3 Results

For the purpose of analysis the results were organised into five main groups of prevention factors: general factors (such as policy, socio-economic factors, and sociocultural context); social factors (including social trust, social ties and social inclusion); working conditions (such as: flexibility of working hours, working environment, partnerships, work bonding, training and empowerment); safety (which also includes trust); individual factors (such as: physical activity; diet, health status, education, gender, mental well-being and cohabitation).

After the DSM analysis, the considerations were based on the number of authors with the same considerations. It is necessary to ascertain that the studies analyzed were 47% cross-sectional analyses, 41% systematic analyses and 12% multidimensional studies. In the results and considering the percentage of the five groups presented: General Factors 19%; Social Factors 25%; Working Conditions 28%; Security 5%; Individual Factors 23% we can ascertain that there are relationships

between them, which are of significant importance that can be analyzed in the extractions from the articles and cited in Table 2. We can however analyze the significance of each of the conditioning factors for preventive management of psychosocial risks. Primarily it is important to analyze that *"The results show that working time is negatively associated with life satisfaction, [24].* Subsequently, we can ascertain that there are differences between countries that should be considered. *"The factors that could help explain this heterogeneity could be, on the one hand, the socio-cultural context of each country and, on the other hand, the working environment" [16].* We can also analyze five dimensions of social capital that impact happiness: *"institutional trust, social trust, social ties and voluntary association, civility and sense of belonging, and religiosity. Among the results, we find that the five dimensions that build social capital have a positive impact on happiness" [10].* The results indicate that structural empowerment was positively related to psychological empowerment, which in turn is positively related to job satisfaction, work engagement, and social wellbeing. The analysis conducted showed that a country's government and regional public authorities have direct influence and play a central role in the formation of unified regional ecosystems. *"The common economic, social and political situation of a country depends on the government and is influenced by the regional public authorities. Therefore, collaboration and dialogue between such institutions is the important factor that defines how quickly different countries will create unified ecosystems and solve future problems" [6].* The findings highlight the important role of support from colleagues and supervisors in the workplace, which can help reduce stress at work, and improves mental wellbeing. *"Sociological and occupational health researchers should not ignore the role of gender when studying the work environment and jobs in general" [19].* The results show that mental health status is similar in the working poor and in the unemployed, and is worse than in workers outside the risk of poverty. *"This situation calls for a re-evaluation of the value of work at all levels: as the main instrument of social inclusion; as a way of building identity; as a source of social support, and also as a guarantee of well-being and mental health"[15].* The importance of outdoor activities in the natural environment is also demonstrated. *"The use and experience of the natural outdoor environment are important predictors of the beneficial effects of the natural outdoor environment and health" [12].* Finally, it is important to note with regard to areas of work that *"Employees working in human service professions reported higher levels of engagement at work than employees in other industries" [11].*

4 Discussion

The vast majority of the studies presented represent the observation and research of various methods, both quantitative and qualitative analysis. *H1: Factors that improve the prevention of psychosocial risks in organizations?* Considering that there is a relationship between this commitment insofar as, by taking these factors into account, it is possible to assess the needs and involve employees, as well as train human

Table. 2 Factors of prevention and Highlighting points

Typeof Factors	Total No Art	Highlighting points
General Factors	8	“The factors that could help explain this heterogeneity could be, on the one hand, the socio-cultural context of each country and, on the other hand, the working environment” [16] “The common economic, social and political situation of a country depends on the government and is influenced by the regional public authorities. Therefore, collaboration and dialogue between such institutions is the important factor that defines how quickly different countries will create unified ecosystems and solve future problems” [6] “Policies evidently concentrate on prevention while compliance” [27]
Social Factors	11	“The results highlight the importance of the role of support from colleagues and supervisors at the work place, which may help reduce job stress, and improve mental well-being.” [19] “Social support is one of the most important resilience factors” [10]
Working Conditions	12	“The results show that working time is negatively associated with life satisfaction, implying that Europeans generally prefer a shorter working week. Health plays an important role in the working time-satisfaction nexus. Social trust, social inclusion, feelings of security and digitalization show positive and significant effects on life satisfaction” [24] “Providing employees with information, support, resources, and opportunities to learn (the essence of the SE concept), encouraging them to value their work as meaningful and impactful, and showing them that they have adequate autonomy and the necessary skills to be successful (i.e., enhancing their PE) and form an effective integrated strategy to increase their levels of psychological and social well-being” [17] “Employees working in human service professions reported higher levels of engagement at work than employees in other industries” [11] “Job quality was a stronger predictor of higher quality of life and well-being mainly countries with lower average levels of CASP-12”[22] “To some extent, WTC (Work Time Control) attenuates the negative relationship between WTV and health” [1] “The results support the hypothesis that training practices had a more favorable safety culture than nontraining practices” [25]
Security	2	“institutional trust, social trust, social ties and voluntary association, civility and sense of belonging, and religiosity. Among the results, we find that the five dimensions that build social capital have a positive im-pact on happiness” [10]

(continued)

Table. 2 (continued)

Type of Factors	Total No Art	Highlighting points
Individual Factors	10	“This situation calls for a re-evaluation of the value of work at all levels: as the main instrument of social inclusion; as a way of building identity; as a source of social support, and also as a guarantee of well-being and mental health” [15]
		“By feeling listened to, understood, supported and respected, our well-being increases” [10] “The use and experience of the natural outdoor environment are important predictors of the beneficial effects of the natural outdoor environment and health” [12] “Healthy nutrition interventions, sports activities after working hours, back exercises at work, prevention of addictions and procedures to return to work after a long-term sickness” [16] “Since health is an important factor in the relationship between working hours and life satisfaction, good physical and mental health can significantly improve life satisfaction” [24]

Source authors

resources accordingly. The analysis conducted showed that a country's government and regional public authorities have direct influence and play a central role in the formation of unified regional ecosystems. *“Therefore, collaboration and dialogue between such institutions is the important factor that defines how quickly different countries will create unified ecosystems and solve future problems”* [6]. In view of the results obtained among the employees of humanitarian organizations, there is a greater involvement of resources, but the local specificity of this involvement was also assessed. Therefore, despite the national policies implemented, specific adaptation work is always necessary. Subsequently, we can ascertain that there are differences between countries that should be considered. *“The factors that could help explain this heterogeneity could be, on the one hand, the socio-cultural context of each country and, on the other hand, the working environment”* [16]. In view of the results obtained, it can be analyzed that the conditioning factors are: national policies, local specificities, work areas, labor relations and flexibility, social integration and cooperation factors, as well as personal factors (such as leisure and contact with nature). Other factors are pressing for consideration. Primarily it is important to analyze that *“working time is negatively associated with life satisfaction, implying that Europeans generally prefer a shorter working week. Health plays an important role in the working time-satisfaction nexus. Social trust, social inclusion, feelings of security and digitalization show positive and significant effects on life satisfaction”* [24]. It can also be analyzed five dimensions of social capital that impact happiness: *“institutional trust, social trust, social ties and voluntary association, civility and sense of belonging, and religiosity. Among the results, we find that the five dimensions that build social capital have a positive impact on happiness”* [18]. The findings highlight the important role of support from colleagues and supervisors in the workplace,

which can help reduce stress at work, and improves mental wellbeing. *"Sociological and occupational health researchers should not ignore the role of gender when studying the work environment and jobs in general"* [19].

H2: which are the most necessary strategies to use in Social Economy organizations? We can group these into eight innovative prevention factors: (1) Involvement of employees; (2) Well-being at work programs; (3) Regular check-ins; Organizational flexibility; (4) Specific training; (5) Collaboration with specific external entities; (6) Employee involvement programs; (7) Promotion of work-life balance; (8) Construction of resilience and coping strategies. The results indicate that structural empowerment was positively related to psychological empowerment, which in turn is positively related to job satisfaction, work engagement, and social well-being. The results show that mental health status is similar in the working poor and in the unemployed, and is worse than in workers outside the risk of poverty *"a re-evaluation of the value of work at all levels: as the main instrument of social inclusion; as a way of building identity; as a source of social support, and also as a guarantee of well-being and mental health"* [15]. *The importance of outdoor activities in the natural environment is also demonstrated. "the natural outdoor environment are important predictors of the beneficial effects"* [12].

5 Conclusions

This study covered countries such as Portugal, Spain, England, Austria, Finland, Italy, the Netherlands, France, Poland and Belgium. The tools used allowed a thorough and more complete analysis. The researchers analyzed were Systematic Analysis, Multidimensional and Cross sectorial survey. It is important to note with this study that the literary production in the specific field of Social Organizations is very low (2 articles) and that few specificities of this area are assessed, given that there is already a certain singularity which increases the value of a study of this nature *"we know that these institutions constitute an essential element of society (...) we realize that it (non-profit organizations) is a central element of citizenship and quality of life (...)"* [7]. As regards the multilevel approach, the association between the NVivo® and the DSM made it possible to standardize several factors of high interest that allowed for the considerations made. The answer to *H1 factors that improving the prevention of psychosocial risks in organizations*, it is essential to talk about five groups of factors: 1. General Factors; 2. Social Factors; 3. Working Conditions; 4. Security and 5. Individual Factors. European Agency for Safety and Health at Work. & ECORYS (2022) reported that establishments in the human health and social work activities sector are more likely than those in other sectors to use different preventive measures. In terms of measures taken to mitigate psychosocial risks, in the sector in 2014, was confidential counselling for employees, but in 2019, reflects the value of autonomy and allowing employees more control over how they work as a way of reducing stress. Establishments in this sector, compared to establishments in all other sectors, are more likely to have well-developed psychosocial risk management. It is also

important to note with regard that *"Employees working in human service professions reported higher levels of engagement at work than employees in other industries"* [11]. The results of this analysis also indicated that establishments in the sector were more likely than those in other sectors to have a high uptake of measures to prevent psychosocial risks. In answer to *H2. which are the most used strategies in Social Economy organizations*. Thus, the importance of employee involvement is confirmed, but it is necessary to go a step further through wellness programs adapted to the local and organizational culture. Besides the primacy of specific training programs, it is also essential to analyze the team in a holistic way in order to understand the balance between personal and professional life. It is important to consider for future studies a wider range of articles in order to improve the screening of good practices to be implemented.

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Work Ability Determinants in Industry: What Are the Gaps? A Narrative Review



Márcia de A. Pereira , Filomena Carnide , and Teresa Patrone Cotrim

Abstract Preservation of work ability is one of the major challenges of occupational health and ergonomics experts, namely in industrial settings. Work ability encompasses physical, psychosocial and social workers' capabilities, organizational and work environment. These issues are particularly relevant considering the ageing workforce across Europe. This narrative review aims to identify the determinants of work ability among workers in the industry. Papers were selected from electronic databases PubMed, Web of Science and SCOPUS (1990–2023). The inclusion criteria were: English or Portuguese language, full-text availability, peer-reviewed publications, including active workers, and the use of work ability definition according to the Finnish Institute of Occupational Health. Seventeen papers were included in the narrative review. All studies presented a cross-sectional study design. The occupational factors were the organisation and work environment, psychosocial, physical and mental demands. The individual factors analysed included education level, age, gender, work experience, sleep quality, the presence of chronic diseases, and health behaviours. There is a lack of robust, longitudinal studies focused on the evaluation of work ability in industrial settings. Individual and work-related factors are important determinants of work ability, but further studies are needed to clarify the type of associations between them.

Keywords Work environment · Workers' characteristics · WAI · Manufacturing industry

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1 Introduction

Population ageing is considered inevitable, and its consequences will affect all aspects of life, including professional life. In addition, the increase in life expectancy has revealed the need for an extension of working life to guarantee the worker's permanence in the labour market [1]. European Labour Market Policies are already focused on extending working life and maintaining workers' health [2].

Several studies revealed that one of the determinants of early retirement is low work ability in workers over 50 years old [1, 3–5].

In the present review, the definition of work ability used the concept of the Finish Institute of Occupational Health, represented by the worker's ability that results from the interaction between individual resources (health and functional capacity, training, skills, values and attitudes, motivation) and the physical, mental and organizational demands of work (physical and social work environment, contents and work organization) [6, 7].

The interaction of occupational and individual factors can negatively interfere with the health and safety of industrial workers and influence their work ability [8–11]. One of the most relevant determinants is exposure to high physical demands during long periods that can limit work ability [12, 13] in industrial sectors [14–16]. The exposure to high physical and mental demands in the automotive industry [17–20] resulting from work processes influence workers' health. Among work requirements, unfavourable postures, exertion of force [21], fatigue [22], repetitive movements, psychosocial factors [23] and unfavourable work environment (noise, temperature, exposure to chemical agents) [8, 24–26] may also contribute to a variation in work ability [27].

Thus, it is necessary to understand the factors that influence work ability in industry, aiming at its better management and promotion [28, 29] through working life. Accordingly, this narrative review of the literature focused on the determinants of the work ability of workers in the industry and, in particular, in the automotive industry.

2 Methodology

A narrative review of the literature was carried out [30] to obtain a critical synthesis of the studies that describe and analyse associations between occupational and individual factors, with the work ability in the industry and, in particular, in the automobile industry.

The current search was carried out between September 2022 and January 2023 in the electronic databases PubMed, Web of Science and SCOPUS. The descriptors “industry”, “automotive industry”, “car manufacturing” were combined separately with the descriptor “work ability index” through the Boolean operator AND.

The selection of the studies was based on: the language (English or Portuguese); full-text availability; being published in journals, book chapters and books, with peer review, since January 1990; being active workers; and the definition of work ability according to the concept of the Finnish Institute of Occupational Health presented by Tuomi et al. [7]. Studies that did not consider the production worker in the manufacturing industry were excluded.

The article selection process began with removing duplicates, followed by reading the title and abstract. Only the selected articles were fully read.

The first search found 141 articles. Ninety-six articles were removed because they were duplicated and did not meet the inclusion criteria. Next, four articles were excluded because they did not have the full text. So, 41 articles were selected for this narrative review.

After reading the full text of the selected articles, 24 articles were removed. Of these, 19 articles did not integrate results with workers who performed functions exclusively in industrial production; four articles were not in English or Portuguese; and one was excluded because the sample included retired workers.

3 Results

In the present narrative review, the studies investigated the relationship between occupational factors and individual factors with work ability in workers in industrial settings among production workers. The analysis included seventeen articles: fifteen were developed in the manufacturing industry and two in the automotive industry (Table 1). All studies presented an analytical cross-sectional study design.

The occupational factors covered in this review were those of the organisation and the work environment, psychosocial, physical and mental demands. The individual factors analysed included education level, age, gender, work experience, sleep quality, the presence of chronic diseases, and health behaviours, like, physical activity habits.

There were significant relationships between occupational and individual factors and work ability, which can change when adjusted to sociodemographic and health factors [24, 31–33].

The main results are presented globally and by the type of determinants.

3.1 *Global Results of Work Ability in Industry*

Work ability was assessed through the Work Ability Index (WAI) [7], and the disparity of the results may depend on the type of industry, tasks performed, characteristics of the sample and the exposure to occupational determinants. Accordingly, the results obtained through the WAI ranged from unsatisfactory scores in the Iranian textile [34.0 ± 5.8] and food [35.0 ± 5.5] industries [34, 35] to satisfactory scores obtained

Table 1 Summary of the studies in the narrative review in the industrial settings

Autor (year)	Main purpose	Sample	Methods (variables)	Main findings	
				Individual determinants	Work-related determinants
Esmatelpour, Zakerian, Abbasi, Abbasi Balochkhaneh and Mousavi Kordmiri (2022)	To examine the relationship between the work ability index (WAI) in the face of different industrial noise levels directly	Automobile parts manufacturing industry N = 325	SVANTEK-971 Sound analyser (Level of exposure to noise) Demographic information questionnaires (age, work experience, education level) Kessler Psychological Distress Scale (K-10) (mental disorders) WAI (work ability)	The WAI mean score was 32.53 ± 4.55 Age and work experience had negative effects on the work ability	Daily exposure to noise had negative effects on work ability
Azevedo, Chiavegato, Carvalho, Braz, Nunes Cabral and Padula (2021)	To evaluate the association between the total step count (at work and leisure time) with musculoskeletal pain intensity and work ability	Rubber glove industry-Brazil N = 277	Sociodemographic and behavioural health questionnaire (sex, age, ethnicity, marital status, income, weight, height, waist circumference, lifestyle (smoking and alcohol use,)), activities practiced outside work, physical exercise and frequency, duration, time, and type of physical activity practiced Nordic Musculoskeletal Questionnaire (musculoskeletal symptoms in the neck, back, lower and upper limbs) Visual Analog Scale (intensity of symptoms) Accelerometer (Total step count and caloric expenditure) WAI (work ability)	There were no statistically significant differences between the WAI and the intensity of musculoskeletal complaints in the lower limbs	WAI score was higher for white-collar workers (excellent 2.8% and good 95%) when compared with blue-collar workers

(continued)

Table 1 (continued)

Autor (year)	Main purpose	Sample	Methods (variables)	Main findings	Work-related determinants
Mokarami, Kalteh, and Marioryad (2020)	To evaluate the WAI and the effects of sociodemographic and work-related factors among workers of an industrial company in Iran	Cosmetics industry workers-Iran n = 190	Work-related and sociodemographic Questionnaire (Age, sex, marital status, education level, smoking, exercise activity, sleep quality, job tenure, Work schedule, second job, weekly hours, work nature, workload, conflicts between the work and individual, social, and family lives, work-related injuries, job training, and job satisfaction WAI (work ability)	The mean WAI score was 38.4 ± 6.4 The workers who had very good sleep quality and higher educational degrees had the better WAI scores The men's mean score of WAI was 38.0 ± 6.5, and the women's mean score of WAI was 42.1 ± 4.7	The lowest mean scores of WAI were related to the workers with three-shift work schedules
Hasad and Nurka (2020)	To evaluate WAI with individual and work condition factors; and comparatively evaluate the predictors of WAI levels in the field of individual and workplace factors all within the public administration sector and industrial sector employees	Target Population N = 500 workers Sample N = 300 workers N = 171 administrative (57.2%) N = 180 industrial (42.8%)	Sociodemographic Questionnaire (Age, sex, marital status, education level, working field of working activity, current work ability compared with lifetime best, mental, and physical demands of job, work impairment due to dis-ease, sick leave during past 12 months, work ability prognosis for 2 years, and mental functional capacities) WAI (work ability)	There were positive correlations between educational level, physical demands of work and WAI Good prognosis of work ability is the prognosis of WAI in two next years	There are no statistically significant differences in the WAI between administrative sectors (excellent: 36.8%; good: 43.9%) and industrial ones (excellent: 37.5%; good: 44.5%). Protectors of decrease WAI are higher physical and mental demands of work and higher mental demand

(continued)

Table 1 (continued)

Autor (year)	Main purpose	Sample	Methods (variables)	Main findings	Work-related determinants
Kazemi, Zamanian, Khalifeh and Hemmatjo (2019)	To determine the impact of noise and heat as two prevalent work-related risk factors as well as individual characteristics and lifestyle on the WAI	Rubber factory-Iran N = 197	Demographic and lifestyle Questionnaire (height, weight, experience, marital status, physical exercise practice) Physiological strain index Electro-Polar RSI100 (psychological strain index, heart rate and ear canal temperature) TES Noise Dosimeter (noise exposure level) Persian version of the WAI (work ability)	The linear regression model, showed that the variables with higher explanatory power of WAI were age (both with negative relation) and the exercising time (positive relationship)	The level of noise had higher explanatory power of WAI
Moraes, Laat and Silveira (2017)	To evaluate and compare work ability and quality of life	Electric Wire and Cable Industry-Brazil N = 45	WHOQOL-Brief Questionnaire (Physical, psychological, social relations and environmental domains) WAI (work ability)	The mean WAI score was 45.22 (± 2.97)	Quality of life domains and the WAI showed significant correlation with the Physical Domain ($r = 0.63$), followed by Psychological ($r = 0.56$), Environment ($r = 0.45$) and Social Relations Domains ($r = 34$)

(continued)

Table 1 (continued)

Author (year)	Main purpose	Sample	Methods (variables)	Main findings	Work-related determinants
Mokarami, Mortazavi, Asgari, Choobineh and Stallones (2017)	To investigate the simultaneous effects of physical, psychosocial, and other work-related risk factors on the WAI on industrial workers	Industrial workers-Iran N = 280	Persian version of job content questionnaire (P-JCQ) (Dimensions: physical exertion, hazardous conditions, physical isometric loads, skill discretion, co-worker support, supervisor support, decision authority and psychological job demands) Work-related factors questionnaire (job title, work hours per week, job tenure, work nature, overtime, workload, work schedule, second job, conflict between work and family and social lives, occupational training and occupational accidents and injuries) Health-related factors questionnaire (smoking and sleep quality) Sociodemographic questionnaire (age, gender, marital status, and educational level) Persian version of WAI (PWAI) (work ability)	The mean WAI score was 37.3 ± 6.4 The significant predictors of the WAI were: sleep quality, educational level	The significant predictors of the WAI were: work nature, occupational accidents, and injuries, occupational training, skill discretion and supervisor support. Occupational accidents and injuries were the strongest predictors of the WAI score ($\beta = -0.26, p < 0.001$). Of the P-JCQ dimensions, co-worker support, supervisor support and skill discretion were positively correlated to the WAI score Supervisor support showed the highest correlation with the WAI score and the P-JCQ dimensions

(continued)

Table 1 (continued)

Autor (year)	Main purpose	Sample	Methods (variables)	Main findings	Work-related determinants
Tavakoli-Fard, Mortazavi, Kulpayehzadeh and Nojomi (2016)	To determine the association between the HRQoL, work ability, and individual characteristics of female workers of factories	Food supplier industry – Iran N = 328	Short-Form General Health Survey (SF-12) (Physical component (PCS) and mental component (MCS), HRQoL) Sociodemographic questionnaire (age, marital status, education, income, work experience and work shift) P-WAI (work ability) Omnion PA-350-E sphygmomanometer, Cemex BV, Nieuwegein (blood pressure) Accutrend Plus, Roche Diagnostics Nederland BV, Almere, The Netherlands (blood glucose and total cholesterol) Personal characteristics (age, gender, and affiliation duration) were retrieved from company administration. Educational level was assessed in the Workers Health Surveillance	The mean score of WAI was 35.02 ± 5.57 Regarding the association between WAI and demographic variables, a higher education level (WAI 36.47) and permanent work shift (35.31) independently explain higher levels of WAI	There were positive associations between the physical and mental components of HRQoL with WAI;

(continued)

Table 1 (continued)

Autor (year)	Main purpose	Sample	Methods (variables)	Main findings	Work-related determinants
Lian, Xiao, Liu, Ning, Guan, Ge, Li and Liu (2015)	To examine the independent and joint association of objective sleep duration and insomnia with poor work ability, adjusting for various social and work-and health-related factors	State-owned and private manufacturing companies-China N = 2820	Athens Insomnia Scale (Insomnia) Watch-PAT-200@ (Objective sleep duration) Chinese version of the Occupational Stress Inventory (OSIR) Sociodemographic questionnaire (age, gender, educational level, monthly income, marital status, and length of service, educational, marital status, monthly income, length of service, body mass index (BMI), habits and lifestyle (smoking, alcohol, Sleep medication)	Individual determinants Work ability was good in 79.5% of participants Insomnia (24.5%) was associated with a significant risk of poor WAI (OR 1.34) When associated with sleep duration < 5 h, the risk of poor work ability increased by approximately 300% (OR 3.43, 95% CI 1.87–5.23) compared to the group without insomnia and who slept ≥ 7 h	Work-related determinants Work ability was good in 79.5% of participants Insomnia (24.5%) was associated with a significant risk of poor WAI (OR 1.34) When associated with sleep duration < 5 h, the risk of poor work ability increased by approximately 300% (OR 3.43, 95% CI 1.87–5.23) compared to the group without insomnia and who slept ≥ 7 h
Chung, Park, Cho, Park, Kim, Yang and Yang (2015)	To evaluate the correlation of age, work experience, cognition, and work ability in older workers in heavy industry	Employees over 55 years old of a heavy industry-Republic of Korea N = 100	Korean version of the Montreal Cognitive Assessment (Cognitive ability) Sociodemographic questionnaire (gender, age, work experience) WAI (work ability)	The mean WAI score was 39.41 ± 4.47 The WAI had a positive correlation with cognitive function; there was no significant correlation between WAI and age or seniority	(continued)

Table 1 (continued)

Autor (year)	Main purpose	Sample	Methods (variables)	Main findings	
				Individual determinants	Work-related determinants
Safari, Akbari, Kazemi, Mououdi and Mahaki (2013)	To investigate factors which affect work ability and mental workload	Male workers with an average age of 40.2 years from the textile industry -Iran. N = 194	Sociodemographic questionnaire (quality of sleep, age) NASA-TLX Questionnaire (mental workload) Direct measurements of height and weight (BMI) WAI (work ability)	The global WAI score was 34.0 ± 5.8 The WAI was negatively correlated with age The interaction between BMI and age is a predictor of WAI. Older workers with high BMI reported lower WAI scores The results suggest there is a significant synergistic interaction between insomnia and objective short sleep duration that was associated with poor work ability	The WAI was negatively correlated with the mental workload
Börner, Scherf, Leit-ner-Mai and Spanner-Ulmer (2012)	To explore age-differentiated strain of Assembly line workers	Female assembly line workers from the workplace "belt buckle assembly" in automotive industry Germany (N = 54)	Aquila-Complete-System Software (assembly time) MTM (Methods-Time-Measurement) Medical Examination (Age, BMI, arm, shoulder, and hand discomfort) BioharnessTM chest strap from ZephyrTM; NASA Task Load Index (Task load index) Strain-ratingsn Munich Chronotype Questionnaire (individual chronotype) WAI (work ability)	The WAI of younger (37.5 ± 5.43) and older women (38.6 ± 4.99) is "good", with no significant difference within the groups	There is no correlation between average assembly time and WAI

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Table 1 (continued)

Autor (year)	Main purpose	Sample	Methods (variables)	Main findings	
				Individual determinants	Work-related determinants
Padula, Rosina, Caral, de Freitas and Chiavegato (2012)	To analyse the association between the physical activity level and work ability of workers from an institution of higher education and workers from a metallurgical industry	457 workers from the metallurgical industry (101 women and 357 men) 193 higher education teachers (124 women and 69 men) n = 650	Sociodemographic Questionnaire International Physical Activity Questionnaire (IPAQ) (Level of physical activity (Active/ Not Active) WAI (work ability)	In the industry workers, 60.5% had good WAI, 10.5% excellent, 26.9% moderate, and 2.2% weak No significant association was found between the level of physical activity and WAI	
Costa, Freitas, Mendonça, Alem and Coury (2012)	To analyse the association between work ability and quality of life in night shift workers on a production line	Workers from the night shift of a production line of a school and office supplies company (assembly, finishing and packaging of the products)-Brazil N = 100	Sociodemographic questionnaire (sex, age) The Brazilian version of Abbreviated World Health Organization Quality of Life Questionnaire (WHOQOL Brief) (quality of life) WAI (work ability)	Global mean WAI score was 40.27 There were significant differences among men and women in the 20–29 age group, with men presenting a higher mean of WAI ($p = 0.016$)	WAI was also significantly correlated ($p < 0.001$) with the domains of quality of life: physical ($r = 0.61$), psychological ($r = 0.44$), social relationships ($r = 0.42$) and environment ($r = 0.32$) domains

(continued)

Table 1 (continued)

Autor (year)	Main purpose	Sample	Methods (variables)	Main findings	Work-related determinants
Yong et al. (2010)	To evaluate the impact of two different working time system of 12 h on work ability and to compare to the day shift. 278 worked in the 3 × 12 h system N = 321 in 4 × 12 h and N = 325 in day shift system	Male wage employees of a chemistry industry N = 924	Sociodemographic Questionnaire (Working Time System of 12 h; age; living alone, number of children, educational status, and engagement in job rotation plan) Department of Occupational Medicine information (Alcohol drinking behaviour; smoking habits; Physical activity; BMI) WAI (work ability)	Being part of the age groups 30–39 and > = 40 showed an increased risk of lower WAI (OR = 1.54 and OR = 1.66) Obesity (BMI > = 30) increased the risk of worse WAI (OR = 1.54)	No difference in WAI was observed between the three working time systems
Walsh, Corral, Franco, Canetti, Alem and Coury (2004)	To evaluate the influence of pain and individual factors work-related on work ability of workers with and without Work-Related Musculoskeletal Disorders	Workers, female and male (75 without WRMSD, 27 men and 48 Women; And 52 with WRMSD, 4 men and 48 women) of a production line of a school and office supplies company (assembly, finishing and packaging of the products)-Brazil N = 127	Visual Analog Scale (pain perception) Sociodemographic questionnaire (Age; Education level; sickness absenteeism) WAI (work ability)	There were significant differences in WAI between age groups (19–29; 30–39; 40–49), with older groups presenting worse WAI There were also significant differences in WAI between males and females (in men, 35% present good and 52% present excellent WAI; in women, 26% present good and 21% present excellent WAI); in the WAI was affected by sickness absenteeism and pain perception	

in different types of industries and varying from 37.3 [± 6.4] in an Iranian Industry to 45.2 [± 2.9] in a Brazilian Industry [11, 31, 36–38].

The automotive industry, underrepresented in this study, was analyzed only in two studies. Both showed a mean score of WAI of around 37 points [24, 27], corresponding to the lowest value of a good work ability category [7].

3.2 *Determinants of Work Ability in Industry*

Considering the multifactorial nature of work ability, the determinants were divided in two main groups: individual determinants and work-related determinants [39].

3.2.1 *Individual Determinants*

The individual factors that emerge from the literature review as being associated with workers' work ability in the industry were: age [11, 26, 27, 35], education level [11, 26, 32, 35, 37], gender, professional training [40], quality of life [36], health-related factors (quality of sleep and insomnia, chronic diseases and sick leave) [26, 32, 33], and behaviours and lifestyles (smoking and physical exercise).

Age was one of the most relevant and independent individual determinant factors of the decrease in work ability in the industry [11, 16, 24, 26, 27, 32, 34, 36, 41]. Younger workers had a 6% higher likelihood to have a higher work ability level when compared to older workers [11].

The pattern of work ability decline was similar when comparing samples of male and female workers. It means that women were more likely to have lower work ability levels than male workers, regardless of age [36, 37].

The educational level also correlated with the work ability index, where higher education levels corresponded to a better work ability index [26, 32, 37]. The correlations between experience and professional training with WAI were also analyzed. However, the results on the influence of these competence dimensions were inconsistent. In most studies, no significant correlations were observed between experience or professional training with work ability [31, 37].

Work ability was also influenced by the quality of life, especially in women, with particular expression in the physical dimension ($r = 0.61$ – 0.42), followed by the psychological ($r = 0.36$ – 0.44) and social ($r = 0.44$) dimensions ($r = 0.42$) [36, 35].

Regarding health-related factors, the presence of chronic diseases and comorbidities had a negative impact on work ability. This association was also responsible for the higher sick-leave days [32, 16].

In addition to chronic diseases, musculoskeletal pain symptoms in the lower limbs appeared as a determinant of the decline in work ability [37, 42]. However, in one of the studies, this association was not independent of the physical demands of work (distances covered during the work shift), so it is important to retain this result with caution [42].

Sleep quality (total number of daily sleep hours and presence of insomnia) was associated with a decline in work ability [33], meaning that the lower the number of sleep hours, synergistically with the presence of insomnia, the greater the probability of obtaining a lower work ability score [33, 37].

Finally, three studies analyzed the influence of behaviour and lifestyle habits on work ability, showing inconsistent results [26, 37, 43]. Only one study analyzed the influence of smoking on the work ability index, and showed a negative association [37]. The three studies above analyzed the influence of physical activity on work ability. However, only Kazemi et al. [26] found positive associations between the number of hours of exercise and higher scores on work ability.

These results suggest that the influence of individual factors, namely those related to health and individual behaviours, should be investigated by robust study designs, with control for the potential confounding factors and bias sources that may exist, namely the heterogeneity of the physical work demands in industrial settings.

3.2.2 Work-Related Determinants

Regarding work-related determinants, only 7 studies assessed the influence of environmental exposure [24, 26], organizational factors [27, 34, 35, 41], psychosocial factors [37], and high work demands [34, 37] on work ability among industrial manufacturing workers.

Mental demands were assessed in samples of industrial workers and the results showed a negative correlation with WAI, meaning that an increase in mental demands corresponded to a decrease in work ability [34]. Nevertheless, other studies in physical demanding tasks showed that the presence of mental demands, when compared with the physical ones, had a positive influence in work ability [37]. These results indicate the need for additional research to clarify the role of mental demands on blue-collar workers.

Among the organizational factors, the studies focused on the shift work impact on work ability. Differences between performing shift work or not, presented a better WAI on those without shift work [35], and between morning, afternoon and night shifts were assessed, showed workers in morning shifts with a better WAI [34]. But results were not consensual, with other studies showing no differential impact of the working time arrangements based on 12-h shifts on WAI industrial settings [41]. Also, regarding shift work arrangements it is needed further research in manufacturing industry. Only one study in the automotive industry analyzed the association concerning average assembly time and WAI, but the results showed no correlation between them [27].

Some studies identified a positive association between psychosocial factors, such as supervisor support, skill discretion and occupational training, with work ability, meaning that these factors acted as promoters of a better WAI [37].

The presence of occupational accidents had a negative impact on WAI [37], stressing the indirect relevance that safe practices may have in work ability, through the impact on the workers' health.

Concerning environmental exposure in industrial settings, some studies found an association between exposure to heat and noise and work ability, a higher noise exposure [24, 26], and an increase in the heat stress [26] determined a lower WAI. Only noise exposure was assessed in automotive industry [24]. Environmental conditions are of great relevance in industrial settings and can impact individuals' work ability.

4 Conclusions

The role of work ability determinants in industry workers is relevant, as it can impact a company's productivity, efficiency, and overall success. The individual factors contributing to variations in work ability among workers in industrial settings were age, gender, educational level, occupational training, health-related factors and lifestyles. Regarding the main work-related factors, environmental exposure, organizational factors, psychosocial factors, and high work demands were identified as determinants of work ability in the manufacturing industrial sector.

Overall, this narrative review highlighted a lack of robust, longitudinal studies focused on the evaluation of work ability in industrial settings. Individual and work-related factors are important determinants of work ability, but further studies are needed to clarify the type of associations between them.

The number of studies based on individual factors was higher than those concerning work-related factors, which underlines the need for further research assessing the impact of physical work demands and organizational and psychosocial factors on work ability in manufacturing industries.

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Association of Low Back Pain and Fatigue Among Office Workers: A Systematic Review



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Abstract Lower back pain (LBP) is the leading cause of work disability and dayoff requests. Studies have shown that sedentary jobs will champion sedentary behaviours that can increase the risk of LBP development. Several studies confirm the association of posture and different sitting habits with tiredness and fatigue. While studies have been done to understand mental and physical fatigue and LBP separately, limited specific research considers the association between fatigue and LBP in office workers. This systematic review highlights the studies that have found an association between fatigue and LBP in office workers. This study follows the guidelines for systematic reviews as stated in the PRISMA methodology. Four databases (PubMed, Scopus, Web of Science, and Science Direct) were chosen for the search. The total number of articles included for screening in this study was 1427. Twenty-three articles were identified as relevant to the objective of this study. Different methods to measure fatigue among office workers were identified and reported. A comparison was made between such methods in terms of frequency. The study concluded that office workers could benefit from fatigue-reducing techniques to prevent LBP development.

Keywords Lumbar · Posture · PRISMA · Preventive measures · EMG

1 Introduction

When considering the many reasons for work disability and requesting day-offs among workers, lower back pain (LBP) seems to be the most common and the leading cause [18, 41]. Research has shown that office workers are among the most vulnerable to sedentary behaviour associated with LBP [8]. This may be due to what promotes lower back muscle fatigue [18]. Work-induced fatigue can affect office workers, which may exacerbate the development of multiple musculoskeletal disorders [1, 23, 32]. Organizations can lose money, directly and indirectly, due to

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lost working days by their employees [18, 23]. Fatigue is a significant influencing factor, and its relevance to the development of LBP is worth examining. Associations have been demonstrated with the lower limb strength and sitting posture that may influence LBP development [38]. While such association has been shown, a review focusing on it in office workers has not yet been published. This review is concerned with the methodologies used to identify fatigue in office workers which, in one way or another, can lead to LBP development.

This study aims to highlight the association between fatigue and LBP among office workers to find preventive measures. To achieve this objective, the following research questions were developed. How many reports and studies show or suggest such association among office workers? What are the main methodologies that are used to find this association? What are the current limitations in the office environment for a global solution to fatigue-induced LBP?

2 Materials and Methods

The review was done based on the PRISMA statement [27, 28]. The databases used for this study were: Scopus, Web of Science, PubMed, and Science Direct. The original search was conducted in October 2021 and then redone in October 2022. The last time databases were accessed was March 18, 2023. Using the search strategy worksheet available on the Western Libraries website, the following keywords were identified, as seen in Table 1:

Since Science Direct did not accept wildcards, “musculoskeletal” was used instead of “musc*”. PubMed, moreover, did not have a default title/abstract/keyword option for queries such as Scopus but had a default title/abstract option that was chosen for the search. As the abstract could be more wholesome, it was assumed it would cover the keyword search. The same approach was taken regarding the Web of Science directory. This concluded the first search performed.

The Mendeley Desktop citation manager removed some of the duplicates. A collection was created for each search, four folders were created for each searched

Table 1 Search datasheet⁽¹⁾: An example for a search on Scopus could be ((back AND pain) AND (fatigue OR drowsiness OR tiredness) AND (office OR sedentary))

	AND	AND	AND	
	Group 1	Group 2	Group 3	Group 4
OR	Back	Pain	Fatigue	Office
	Musc*	Ache	Drowsiness	Sedentary
	Low	Stiff*	Tiredness	
	Lumbar		Sleep*	

⁽¹⁾<https://guides.lib.uwo.ca/systematicreviews/searchtechniques>

database, and the found articles were imported to each associated folder. The duplicates were automatically shown as one article in different highlighted folders by clicking on the parent collection. Furthermore, the Mendeley duplicate finder was used to merge, if any, duplicate articles into one. Then, one reviewer screened the remaining articles by reading the titles first, and if necessary, keywords and then the abstract. The following exclusion criteria were used: (1) not Journals publications, (2) not from this century as the vast majority of the accessible studies have happened in it; 2000–2023, (3) studies not related to humans, (4) not written in English, (5) workrelated musculoskeletal pain not associated to sitting, in office workers, (6) studies with populations out of the range: $65 > x \geq 18$ years old. The documents found by the search in the databases were then exposed to the exclusion criteria. Other exclusion criteria were used: (1) No specific medical condition that manifests itself, among other things, as pain but is the underlying cause of such pain. This includes cancer, rheumatoid diseases, fibromyalgia, chronic fatigue, muscular sclerosis, cerebral palsy, and Gulf War Illness, among others, (2) pain and fractures as a result of a traumatic injury such as vehicle accidents, (3) non-sedentary work-related musculoskeletal disorders, (4) differently abled conditions, e.g., having lost a limb, paralyze. (5) Pains related to a body part besides the lower back; however, the study will be included if the results regarding lower back pain are reported separately. (6) Studies with questionnaires were excluded unless accompanied by an experimental data-gathering technique, statistical analysis of the gathered data is a separate phase and irrelevant to the inclusion or exclusion of the studies. For instance, a study that accompanied questionnaires with pain measurements using instruments will be included but excluded if only accompanied by Visual Analogue Scale (VAS) for pain measurement. Another example of an excluded study could be one with only questionnaires and a simple logistic regression method for data analysis.

The eligibility criteria were updated by screening the first few articles. However, this was not a significant change but a specific one. The intended eligibility criteria were to remove metabolic diseases, but not all metabolic diseases could be brainstormed initially. It was helpful to update the specific name of the diseases that repeated themselves more than two times. Thus, an Excel file was created mentioning the title of each article and their presence in each database, with one sheet dedicated to rejection reasons and another dedicated to preliminary inclusion. The reviewer would read the abstract, and if there were questions or ambiguities regarding the eligibility, the full-text article was accessed solely for the methodology section. This was helpful as some articles did not specify important information, such as the participants' jobs. Therefore, in addition to the title, keywords and abstract, the methodology was occasionally checked to ensure the eligibility criteria. The included articles were moved to another collection entitled systematic review for further examination. The exclusion reasons were written down in the Excel file as the authors decided on them.

Additional screening was deemed necessary, with the specification of the inclusion criteria. This second screening included looking for specific mentions of fatigue and its association with LBP anywhere in the full text. Also, the abstract and the methodology would be controlled once more to ensure inclusion criteria. The selected articles at this point would be moved to a folder called "SR-further". The articles in this folder

would be checked by reviewing their references and applying all the selection procedures to each reference to saturate the included studies. Then, confirmed included articles would be divided into two important categories, Randomized Controlled Trials (RCTs) and non-RCTs. This is important as it helps extract relevant data in each category and determine how to synthesise the systematic review results based on their categorical differences. This is because the methods available in PRISMA methodology are designed for RCTs, and some of the sections may not be fully applicable to other types of studies [27, 28]. Therefore, according to the Cochrane handbook [15], other sections have been included to be applied, or some modifications to existing sections were suggested.

3 Results and Discussion

Following the methodology, 136 articles were deemed eligible for further screening. Seventeen articles were eligible to be in the mentioned folder. Ultimately, five more articles were added by scanning their references. In total, 23 articles were accepted for the full-text data synthesis. Figure 1 is the PRISMA flowchart demonstrating the included studies.

Only three studies fit the definitions of RCT, and the rest (21) are non-RCTs. A summary can be seen in Table 2.

Based on the available information from individual studies, Microsoft Excel 2016 was used to develop the proper graphs using the extracted data to visually present the findings. Figures 2 and 3 synthesise the answers to the specific research questions below the stated study's objective.

Considering the categorization of Fig. 2, the percentages shown are not reflecting the number of articles but the articles that used specific methodologies. This means that articles that used several methods in their approach are counted more than once. Figure 3 shows the number of articles that used several specific methodologies for a clearer picture. For these graphs, the type of fatigue (objective vs subjective) is irrelevant, and questionnaires were not considered.

To better understand Fig. 3, a summary is provided as follows. It can be seen that no articles have used all four methodologies. While Computer logging has never been used as a single fatigue detection method, sensors or cameras have been used the most without other methods. Alternatively, surface EMG has been used the most in pairing with other methodologies for the same purpose. Computer logging shows a small portion of being paired as a fatigue detection method. Moreover, it is briefly reported that two articles calculated objective fatigue only, and 21 articles paired it with subjective measurements. The most used subjective method was Visual Analogue Scale (VAS), followed by the Nordic Musculoskeletal Disorder questionnaire and the Cornell.

The main purpose of this review study was to highlight fatigue and LBP association in addition to different methodologies for office workers' fatigue detection. Computer logging has received special attention from the reviewing authors as it falls under

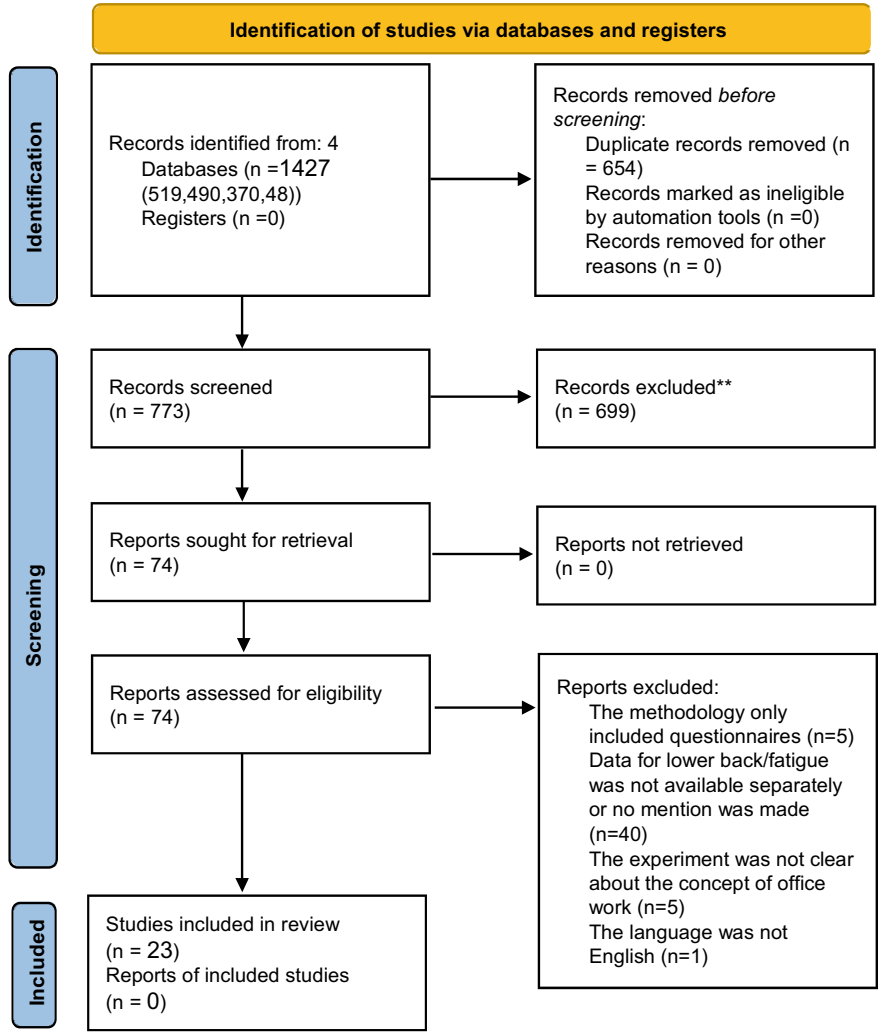


Fig. 1. PRISMA 2020 flow diagram for new systematic reviews, which included searches of databases and registers only.

the ongoing research objectives. Computer logging in this categorization signifies a collection of keyboard and mouse-related actions that the computer operator, in this case, office workers, undertakes. The technology seems to be in its infancy for office workers' fatigue detection. As it is a relatively new methodology, this small portion of pairing is understandable. Furthermore, the fact that it has not been used as a stand-alone method for fatigue detection in office workers provides additional lighting on this new technology which seems to be in its development phase, even

Table 2 Articles' main information and findings

#	Authors – Year	RCT Yes or No	Main Findings
1	[25]	No	Participants lost control over work when standing was not allowed
2	[20]	No	Analysis of Variance used to verify risk factors, and a risk assessment model was developed. MS strain has different effects on different body parts. Foot support can reduce MSD
3	[24]	No	A small number of muscle activities lowers the number of complaints. Rest time has the opposite effect
4	[37]	Yes	Once-per-week massages help decrease MSD and increase Range of Motion (ROM). Immobility leads to muscle shortening
5	[17]	No	Hamstring muscle length and Sciatic nerve tension show more significance with Lower Back Pain regarding Flexion rather than extension
6	[12]	No	Trunk muscle endurance is significantly different in subjects with non-specific LBP Subjects with Chronic LBP may adopt alternative strategies to reduce fatigue in their back muscles
7	[13]	No	The method provides a reliable and valid measure for subacute LBP in office workers
8	[35]	No	Standing break pain relief might be psychological rather than physical. It is unclear if shorter long-term exercise interventions can improve LBP ratings Deep tissue muscles contribute more to LBP
9	[42]	No	All body parts in specific sitting postures will experience discomfort after an hour
10	[2]	No	Patients with chronic LBP sit asymmetrically while showing poorer posture control. Even 10 min of sitting can affect the lower back badly
11	[10]	Yes	Pre-existing LBP affects interventions
12	[10]	No	Specific chair design can decrease lumbar muscle fatigue A decrease in RoM could be associated to muscle fatigue
13	[10]	No	Standing with movement might negatively affect cognitive functions while presenting no effect on sustained attention The suggested protocol proved to be insignificant in discomfort reduction
14	[10]	No	Prolonged sitting negatively affects comfort levels in the lower back Body discomfort is mildly correlated to cognitive function
15	[6]	No	Effects of the sit-stand workstation coupled with high and moderate break-time activities reduce muscle fatigue Shorter standing times were the least favoured among participants
16	[11]	No	The musculoskeletal symptoms and their correlation to office work activities seem very complex
17	[16]	No	No differences in lumbar flexion RoM were found. Disc height is strongly dependent on sitting posture

(continued)

Table 2 (continued)

#	Authors – Year	RCT Yes or No	Main Findings
18	[5]	No	Prolonged sitting decreases cognitive functions and sustained attention A meaningful increase in low back discomfort was observed. Lower limb discomfort and pelvis movement showed no correlations
19	[14]	No	A specific type of active break is suggested to minimize muscle fatigue. Significant correlations were found between EMG and subjective discomfort reports
20	[33]	Yes	A method was developed to reduce stature loss that also helps activate deep trunk muscle
21	[43]	No	Perceived discomfort can be used as a musculoskeletal disorder predictor Postural shifts and discomfort increase during prolonged sitting. Prolonged sitting for 4 h has the most adverse perceived effects on the lower back
22	[40]	No	Trunk posture shifts are most common during prolonged sitting Leg crossing and chair wheels as a footrest are common behaviours to put knees in a flexed position
23	[9]	No	A risk assessment method was developed to identify muscle fatigue and LBP Maximum fatigue is found before lunch break after four working hours

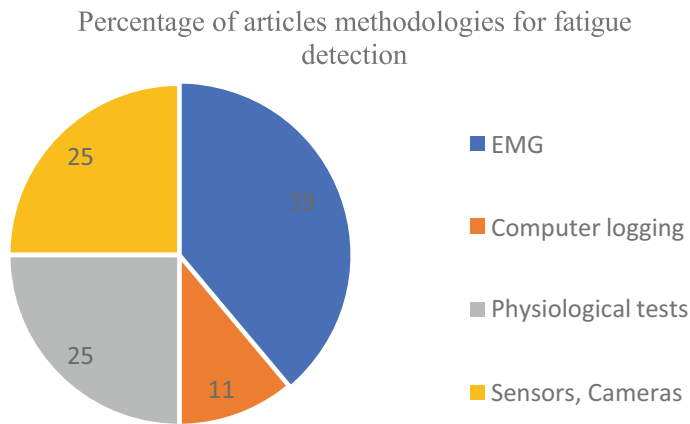


Fig. 2 Summary of the different methods used for fatigue detection

though studies have suggested that using computer logging for fatigue detection is a good machine-learning approach [19, 21, 22, 29, 30, 36, 39, 44].

There is no surprise that surface electromyography (EMG) is a trusted method for fatigue detection. This method has been around since 1890 [31] and has been used by 14 articles in this review. A very important distinction is that ActivPAL3™

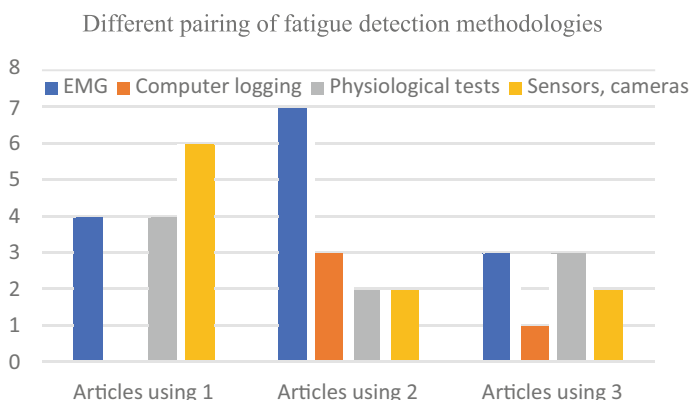


Fig. 3 pairings of muscle fatigue detection.

is categorized with sensors and cameras since it monitors activity in addition to built-in EMG features. This is done because of what the camera captures as posture and movement, and ActivPAL3™ is doing the same. However, an emphasis is made on it being a trademark, and this way is separated from other EMG measurements. Furthermore, it is acknowledged that while different categorization is possible, it would not change the “Computer logging” category results.

One of the main agreements of all the 23 studies included in this review is that subjective measurements are unanimously considered less reliable than their objective counterpart. This is understandable because the studies that only considered subjective measures have been excluded from the study in the screening phase. Also, it was reported multiple times, as a limit, that the number of participants was too small or too specific to be generalized to other groups, whether this particularity is regarding age, weight, or gender.

Another observation was the trial extent of the studies. All articles have only considered short-term effects of fatigue on lower back pain, provided that a 3-month study is included in the short definition. The issue of the extent goes beyond the overall amount of experiments. While two studies have been performed with full-day working hours, the rest seem satisfied with 1, 2, or 4-h testing time. This is justified well by the individual studies, yet the review further summarizes that the most common issue reported by the studies is the human/clinical nature of the experiments. Most participants' responses could be affected if the trial extent is too long.

4 Limitations

Some of the main findings of individual studies were intentionally omitted to include only the most relevant reported data items, meaning that other extractions are certainly possible. Further analysis can be performed based on the extracted data

to draw more comprehensive results. In this review, the authors are set to answer the research questions only. Moreover, statistical work could be performed on many variables described in this study to find meaningful correlations between methodologies. This was omitted as the statistical analysis is out of the scope of this review. As the last limitation of this review, the absence of meta-analysis can be noted. Even though this is a valid argument, due to the nature of most studies included in this review, the routine measures to perform a meta-analysis might have needed multiple alterations and hence avoided.

5 Conclusions

This review asked three research questions and responded by following the PRISMA approach. As a reminder, the research questions were as follows: How many reports and studies show or suggest the existence of such association? What are the main methodologies that are used to find this association? What are the current limitations in the office environment for a global solution to fatigue-induced lower back pain? The first question was answered by performing a search in four databases, screening more than 700 studies, and 73 studies were included for a fulltext analysis, of which 23 were used to synthesise the results. The second question was answered using the methodologies introduced in the 23 studies. Table 7 demonstrates the data extraction for this purpose.

Furthermore, table 2 and the discussion section provide the bigger picture to answer the last research question. The importance of lower back pain prevention among office workers is further highlighted in this review. Additionally, this review sheds light on the necessity of preventive measures for tackling lower back pain among office workers.

Acknowledgements The authors would like to acknowledge the Doctoral Program of Occupational Safety and Health of the University of Porto (grant number demsso.sip.PD9986).

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Inclusive Design and the Use of Assistive Technology in the Classroom: A Systematic Review



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Juliana Fonsêca de Queiroz Marcelino , and Laura Bezerra Martins

Abstract Inclusive Design refers to the development of products that allow people with different abilities to use, promoting social inclusion. Assistive technology can be used by designers and other professionals to promote functionality, encouraging autonomy and independence when it comes to using a product. This study aims to understand adaptations and interventions in the classroom during activities regarding children with cerebral palsy. It is a systematic review according to the PRISMA guideline. 18 articles were included in this study and data was extracted from each of them. The results presented were divided into 3 categories: (a) General Data; (b) Participant Description; (c) Identification of assistive technology. The country with the most articles included was Sweden, followed by Brazil. Participants included children, teenagers, teachers, parents and health professionals, emphasizing the need of different professionals to work together and collaborate in the assistive technology service. Different assistive technologies were included in the analyzed studies and a variety of materials were used to adapt children with PC in the classroom. The results of this research can help designers to use metrics for product usability in order to meet the specific needs of each client and facilitate the process of product development.

Keywords School · PRISMA · Haptic device · Wheelchair · Cerebral palsy

1 Introduction

The term “design” refers to the area that studies the healthy relation between user and products or services with the objective of creating projects that aim to solve existing problems, prevent conflicts or create new market opportunities [1]. Inclusive Design (ID) is immersed into the Design concept and can be addressed in the literature with different terms, such as Design for all or Universal Design. Inclusive Design refers to the development of products that allow usability for different people and

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P. M. Arezes et al. (eds.), *Occupational and Environmental Safety and Health V*, Studies in Systems, Decision and Control 492, https://doi.org/10.1007/978-3-031-38277-2_58

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their specific needs contributing to non-discrimination and social inclusion [2]. The European Institute for Design and Disability (EIDD) Stockholm Declaration, adopted on May 9th 2004 at the Ordinary General Assembly of the European Institute for Inclusive Design in Stockholm states that Design for all aims to enable all people to have equal opportunities to participate in all aspects of society, therefore products, services and built environments must be accessible and usable by everyone in the society. Universal Design, on the other hand, is a project that considers and is intended for all existing users in a society [3]. Carletto and Cambiaghi [3] presents seven principles for Universal Design, they are: Equal use, flexible use, simple and intuitive use, perceivable information, error tolerance, low physical effort, and extensiveness. Designers can use these principles as a guide for new projects or adaptations and evaluations of existing projects so that the products are adjusted to the needs of others [3]. Although the terms are different, the concepts can be treated as synonymous because they refer to the search for access by people with functional differences to places, products and services [4]. These terms follow the usability parameters and are based on “Design centered on the user” that seeks to promote effective social inclusion [3]. Reference [5] conducted a study applying the concept of User-Centered Design to the creation of assistive technology projects for children with cerebral palsy. Participants in the aforementioned study were asked to create their own assistive technology designs that they would use in the classroom, so that their ideas could be applied. Inclusive design also takes into account the needs and preferences of the user from their own perspectives.

When it comes to the inclusion of different people in society, it is important to highlight two concepts that may be associated with Inclusive Design (ID), they are: assistive technology and technical help. Assistive Technology (AT) is any product, equipment, resource or practice that aims to promote the functionality of a person with a disability and increase their participation in society, with the aim of encouraging their autonomy and independence (Decree law no 13.146/2015). The Technical Assistance Committee, in 2009, highlights that the terms “assistive technology” and “technical help” are considered synonymous. However, in official documents, the use of the term “Assistive Technology” is recommended. In recent years, Assistive Technology has been acquiring more and more space in special education, and there is a notorious increase in studies on this topic [6]. For [7], AT in a classroom can range from simple inexpensive products (low-tech AT), to battery operated tools (mid tech) to computerized software (high tech).

Assistive Technology is used by people with different limitations or disabilities, including Cerebral Palsy. Injuries to nerve centers and pathways can cause various neuromotor dysfunctions depending on the location of the damage, impacting motor coordination, compromising the child’s manual skills, and/or cognitive skills [8]. To promote an inclusive space using AT devices, a multidisciplinary approach is often needed. In the study carried out by [9], parents of children with PC and health professionals were asked about the perception of the use of AT in the classroom. It was observed that the participation of parents in the process of implementing AT in the classroom was limited, and when it happened, it significantly improved the child’s acceptance of AT. For [9], the partnership between parents and professionals in the

development of assistive technology is crucial. Reference [10] emphasized that when choosing which technology is appropriate and should be implemented when working with children with PC, the family-centered approach is important, and the preference and selection of the child in question can be valued over the therapist's opinion. This family-centered approach and user-centered design can help the rehabilitation process and acceptance of the child towards assistive technology.

This study aims to understand adaptations and interventions in the classroom during activities regarding children with cerebral palsy.

2 Materials and Methods

2.1 Research Design

This study is a systematic review of the literature according to the Preferred Items for Reporting for Systematic Reviews and Meta-analysis (PRISMA) guideline [11].

2.2 Methods

2.2.1 Eligibility Criteria

Inclusion criteria were articles published in national and international journals, between 2012 and 2022, that addressed the use of AT in the classroom, and that were available in English or Portuguese. Exclusion criteria were articles that addressed AT outside of school, inaccessible for the full-text articles, and any article other than research articles.

2.2.2 Data Extraction

Four searches were performed, 2 in the SCOPUS database and 2 in the Web of Science database. "Search A" used the terms "cerebral palsy" AND "assistive technology" AND "school OR classroom". These terms were used in both databases. "Search B" used the terms "cerebral palsy" AND "assistive technology" AND "writing". These terms were also used in both databases. Scientific articles were selected between the years 2012 and 2022 that answer the following research question: How does adaptation occur in the classroom during the activities of children with cerebral palsy?

2.2.3 Data Analysis

The data of the articles were tabulated in Microsoft Excel spreadsheets, and analyzed qualitatively to generate graphs and tables. Data regarding study information (author and year), participants (sample size, age sex, diagnosis), use of assistive technology (activities that AT was used, types of AT used), assessment instrument, and results were extracted. The results presented will be divided into 3 categories: (a) General Data; (b) Participant Description; (c) Identification of assistive technology.

3 Results

Figure 1 presents the research flowchart based on the PRISMA guideline. After the proposed steps, 18 articles were included for analysis. The 18 articles included in the study were coded to facilitate the identification and description process.

3.1 General Data

Table 1 describes the general data of the articles included in the research. It is possible to observe that Search A in the SCOPUS database resulted in the highest number of articles (15 of the 18 included).

The country with the most articles included was Sweden (5 out of 18) followed by Brazil with 4 out of 18 articles. Two articles from the UK and Canada were included, respectively. Countries with only one article included were Indonesia, Qatar, Portugal, Italy, and Australia. Regarding the year of publication, it is clear that the years with the most publications (4 publications each) were 2013 and 2016, and from 2018 the publications concerning the topic declined.

3.2 Participant Description

Figure 2 describes the participants of the analyzed studies.

It is observed that 6 of the 18 articles included the teacher in data collection and research. In addition to including children, teenagers and adults in the studies, 10 of the 18 articles (55.6%) included the male and female gender in their research, 3 of the 18 (16.7%) included only males, 3 of 18 (16.7%) included only females, and 2 of 18 (11.1%) did not specify the gender of their participants.

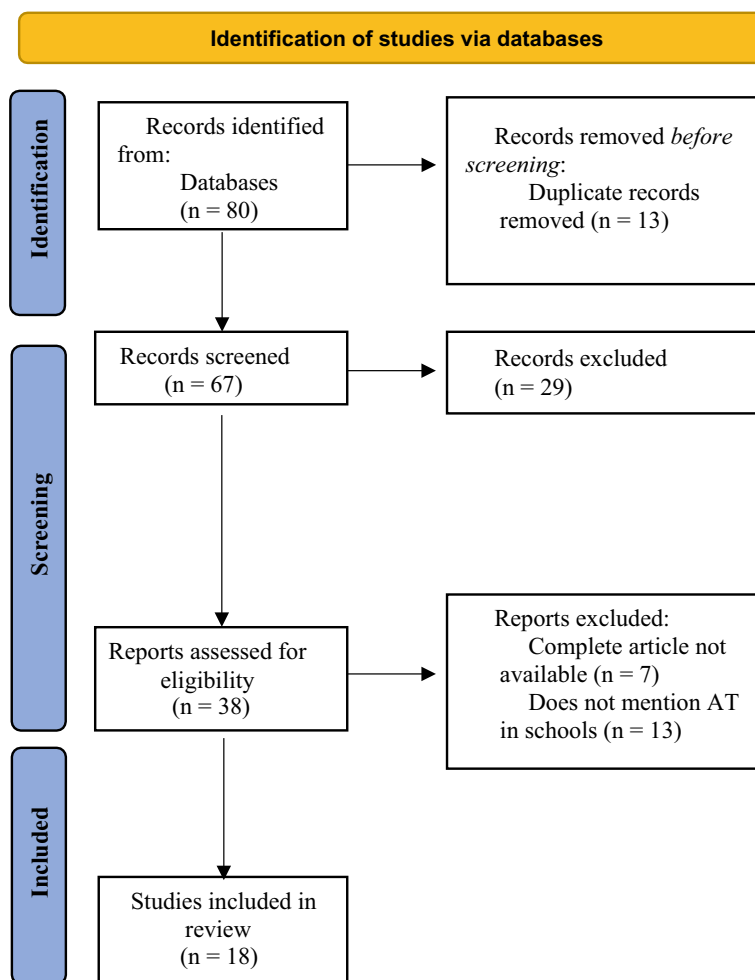


Fig. 1 PRISMA flow diagram describing the process of study selection to be included in the review

3.3 Identification of Assistive Technology

Table 2 presents the assistive technology used in the surveys included.

In Table 2, it is possible to observe that 5 of the 18 articles used low-cost materials as assistive technology. These low-cost materials were generally plywood or simple hardware to adapt small objects. 13 of the 18 articles purchased materials or products already available on the market. It is possible to observe that 8 of the 18 articles sought to use assistive technology to adapt computers in the classroom.

Table 1 General data of the analyzed articles

Code	Database	Title	Authors	Research country
1	Search A-SCOPUS	Assistive technology for children with cerebral palsy in school: Identification of needs	[6]	Brazil
2	Search A-SCOPUS	Assistive Technology of Vocational Skills Learning For Children With Cerebral Palsy	[12]	Indonesia
3	Search A-SCOPUS	Change in manual dexterity of student with cerebral palsy with the use of adequateschool furniture	[13]	Brazil
4	Search A-SCOPUS	Constructionprocess assistivetechnology resource for students with cerebral palsy in multifunctional resources room	[14]	Brazil
5	Search A-SCOPUS	Evaluating methods for engaging children in healthcare technology design	[5]	United Kingdom
6	Search A-SCOPUS	Feasibility of school-basedcomputer-assisted robotic gaming technology for upper limb rehabilitation of children with cerebral palsy	[15]	United Kingdom
7	Search A-SCOPUS	Gaze-based assistive technology in daily activities in children with severe physical impairments–An intervention study	[16]	Sweden
8	Search A-SCOPUS	Opinion of education andhealth professionals on the use of orthostatic boards for students with cerebral palsy	[17]	Brazil
9	Search A-SCOPUS	Programming and controlling robots using scanning on a speech generating communication device: A case study	[18]	Canada
10	Search A-SCOPUS	Teachers' experiences of using eye gaze-controlled computers for pupils with severe motor impairments and without speech	[19]	Sweden

(continued)

Table 1 (continued)

Code	Database	Title	Authors	Research country
11	Search A-SCOPUS	The Impact of Eye-gazeControlled Computer on Communicationand Functional Independence in Children and Young People with Complex Needs–A Multicenter Intervention Study	[20]	Sweden
12	Search A-SCOPUS	Use of computer access technology as an alternative to writing for a preschool child with athetoid cerebral palsy -A case report	[10]	Qatar
13	Search A-SCOPUS	Use of ICT in school: A comparison between studentswithand withoutphysical disabilities	[21]	Sweden
14	Search A-SCOPUS	Using assistive robots to promote inclusive education	[21]	Portugal
15	Search A-SCOPUS	Using robots in "hands-on"academic activities: A case study examining speech-generating device use and required skills	[22]	Canada
16	Search A-Web of Science	Computerand microswitch-based programs to improve academic activities by sixchildrenwith cerebral palsy	[23]	Italy
17	Search A-Web of Science	Improving computer usage for students with physical disabilities through a collaborative approach: A pilot study	[24]	Sweden
18	Search B-SCOPUS	Knowing the person brings light to the gifts: A study of a gifted child with cerebral palsy	[23]	Australia

4 Discussion

Regarding the multidisciplinary approach that most studies mentioned when using assistive technology in the classroom, for [6], it is essential that professionals specialized in various areas of knowledge work alongside people with disabilities to achieve different stages of the assistive technology service. Different professionals can contribute to a better use of AT. To build child empowerment and use of the AT service, an integrated and collaborative practice between professionals, parents and

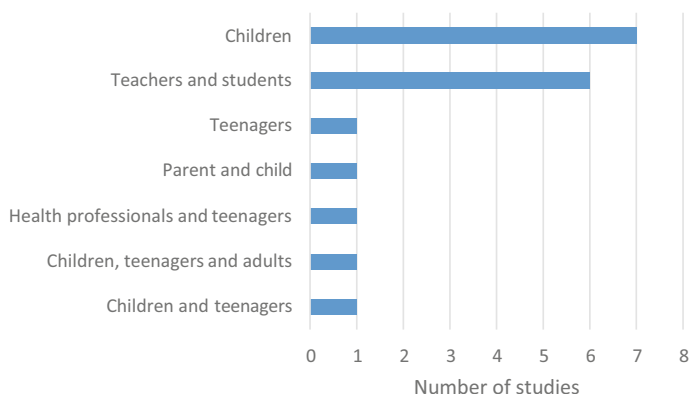


Fig. 2 Participants of the analyzed studies

Table 2 Assistive technology used in the analyzed surveys

Assistive technology	Code	Materials used
Wheelchair positioning and adjustment	1,3	Low-cost material: wood, pillow rolls, cardboard, steel-framed walker
Adaptation of artifacts for feeding	2	Low cost material: thin wood and adaptive grips for feeding utensils
Assistive technology resource for school “resources room”	4	Low-cost cardboard material: craft wood and cardboard
Haptic device for writing	5	Commercially available product (PHANTOM Omni® haptic)
Computer Access Technologies (CATs)	5, 6, 12, 13, 14, 16, 17, 18	Acquisition of rehabilitation joystick available for purchase; Acquisition of software available for purchase (Co-writer, Clicker 5 software package)
Eye tracking device	7, 10, 11	Devices commercially available (Tobii device for eye tracking)
Confection of orthostatic board	8	Low cost material: plywood, foam, simple hardware, screws and knobs
Speech Generating Device (SGD)	9, 14, 15	Commercially available device for speech generation (SGD)
Assistive robotic technology	6, 14	Computer-assisted robotic gaming technology; Commercially available device (Lego® Mindstorms® NXT truck-like robot)

the community is necessary [12]. In the study by [6] teachers attempt to adapt assistive technology in the classroom for better participation of two students with cerebral palsy. Teachers understand the need to adapt the students' wheelchair and writing pad, but due to the lack of specific knowledge in this area, it is analyzed that the adaptations are not ergonomically adjusted to the student. Although the teacher's role is crucial in understanding and developing AT in schools, this professional is described as having inadequate professional training to teach students with disabilities and handle assistive technology in the classroom [12]. Therefore, the integration of Designers, health professionals and education professionals, in a co-design process becomes necessary. The study by [25] states that co-design, that is, the integration of professionals from other areas of knowledge in Design projects, can help the designer in conceptualizing new ideas in assistive technology. The study states that designers should take into account the emotional, cognitive and physical state of a user when planning a new project.

In this study, data confirmed that a variety of different assistive technologies were used to adapt the environment for children with specific needs. These technologies range from low-cost technology to high-cost technology. Regardless of what type of AT is used, the main purpose is to include people with limitations or impairments in daily activities, specifically educational activities. For Spiller (2014), so that students with cerebral palsy can explore the environment and actively participate in activities, adapted resources such as seats and backrests for postural adequacy are necessary. The appropriate resource for the specificities of students with cerebral palsy is essential for their effective participation in the proposed activity and it is the responsibility of the school to offer students with special educational needs adequate resources [26], but many schools do not have the financial resources to provide such materials, thus needing to use low-cost materials for the inclusion of students with CP. The study by Ref. [14] uses low-cost material to develop a play activity adapted for a child with CP. The use of low cost materials may often be the only option due to low budget income in schools regarding children with difficulties or limitations. Besides using low-cost materials, schools can also use computers as adaptive tools to promote inclusion in the classroom. Computers are artifacts that, according to [24], can be used as an assistive technology, helping in different activities such as reading, writing, participation in the classroom and communication. The adaptation of computers for people with CP includes adaptations of manual devices for manipulation (joystick, mouse, keyboard) and implementation of software for communication. Computer Access Technologies (CATs) are a group of assistive technology (AT) devices that allow people with disabilities who have difficulty using a standard keyboard and mouse to use a computer [10]. The use of computers as assistive technology can be a facilitator for children with CP as it can reduce participation restrictions in certain activities, such as playing, education and communication [16]. Although, for Lidström et al. [16], there are some difficulties involving the use of CATs, namely: (a) difficulty in keeping systems in good condition; (b) CATs are seen as complex and problematic innovations for many teachers to use in the classroom, due to lack of time, training and support; (c) Teachers' resistance to changing their teaching style and learning new approaches. Even with certain limitations, according to the present

study, data confirmed that CATs is still the most used technology to adapt the classroom environment for children with limitations. This result may be due to the fact that implementing CATs during the activities can be motivating and engaging to children. Computer-based communication is typically preferred over the traditional paper–pencil writing [10].

The eye-tracking device (ETD) and the speech generating device (SGD) were also contemplated in assistive technologies used in the classroom. Three studies used ETD and another three studies used SGD as assistive technology. For children with severe physical or communication limitations, the only way to operate a computer may be through the eye-gaze technology, which allows the child to interact with the computer screen by moving only the eyes, allowing the child to interact in different activities such as play or communication [16]. Gaze replaces the mouse and keyboard as the computer input devices [19]. Reference [16] suggest that few studies address gaze-based AT, as it is rarely used by children, and more frequently used by adults, and until recently, it has been considered a high-cost technology. The study by [19] aimed to understand teacher's experiences using eye-gaze assistive computers with children with PC. The assistive technology allowed children to participate in more activities in the classroom and make their feelings, wishes and needs known to their teachers.

The study by Ref. [18] demonstrates the use of SGD in educational activities by programming and controlling a robot. The SGD helped the child not only to observe the robotics class but also to participate in the class in an active and integrated way. The use of SGD can be motivating for children with PC, and assist during classroom activities [22].

Two out of 18 studies used robotic technology as AT in the classroom. Like CATs, robotic technology can too be conceived as high-cost and high-tech, thus the reason why few studies use robotics as an intervention in classrooms. For Preston and Weightman [22], computer assisted robotic equipment seek to encourage children to exercise in a therapeutic way, for example, through repetitive reaching movements, in this way, children understand the activity as fun and this has a positive effect on rehabilitation. Reference [22] states that the use of robots while learning in classroom is motivating and help children engage in activities.

5 Conclusions

From the present research, it was possible to identify that assistive technology can be a tool used by different professionals in the school context to include children and teenagers with cerebral palsy in their activities in the classroom. It is important that when using AT, health professionals, teachers, parents, and designers join together in a multidisciplinary approach in order to provide the best possible service to the student with limitations or difficulties in an activity. Studies have shown that assistive technology is used in several countries and that the use of low-cost materials and the application of computer access technologies (CATs) in the classroom occupy

most of the assistive technology approaches in schools. Followed by eye-tracking technology, speech generating devices and robotic technology.

For designers, identifying the target population, the assistive technology used and the different applications in the classroom can facilitate the process of developing new projects. The results of this research can help designers to use metrics for product usability in order to meet the specific needs of each client. The partnership between the areas of Health, Design and Education can bring benefits to users who use assistive technology by creating new technological paths, as well as improving existing devices on the market.

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The Relevance of Psychosocial Factors in Industry—A Narrative Review



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Abstract Psychosocial risk factors in combination with physical risk factors are a transversal work reality in a wide range of industries and occupations. The main objectives of this review were to investigate the relevance of assessing psychosocial factors in the manufacturing and the automotive industries. The methodology encompassed a narrative review of the literature, with research of scientific articles in databases PubMed, Scielo, ScienceDirect, Scopus. In the manufacturing industry were identified high quantitative demands, low control over working, job insecurity, insecurity over working conditions, high cognitive demands, conflicting social relationships, low recognition at work, work-life conflict, among other psychosocial factors associated with musculoskeletal symptoms in the upper limbs, neck and spine. In the automotive industry, high quantitative demands, the low latitude of decision, low control over working, intense pace of work and low quality of leadership were associated with musculoskeletal symptoms in various regions of the upper limbs, neck and spine. There is a gap in the literature regarding the assessment of psychosocial factors in the automotive industry, and a lack of longitudinal studies and more in-depth assessment of psychosocial factors that identify reference values for the automotive industry.

Keyword Psychosocial risks · Organizational factors · Manufacturing industry · Automotive industry

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1 Introduction

In the last decade, there have been many transformations in the world of work with the introduction of new processes, new forms of contracts, new technologies, and socioeconomic, demographic and political changes [5, 6, 8]. All these phenomena had an impact on the intensification of work with a consequent overload for workers; in the rise of temporary workers and job insecurity; in the increasing complexity of job demands; in the absence of autonomy; and discrimination in the workplace; in addition to an ageing workforce [1, 5, 6, 8].

The above context explains the high prevalence of psychosocial risk factors in the European Union (EU) that represents a cost to the health and well-being of workers, which may also result in costs at the organizational level (increase in absenteeism, presentism, accidents and illnesses), and to the whole society [3, 5, 10, 19].

Psychosocial factors at work do not have a consensual theoretical construct. Some existing theories emphasize the work organization, while others highlight the social and economic aspects [4, 24]. In this study, the definition of the ILO was used, which describes psychosocial factors at work as factors likely to influence health, performance and satisfaction, being verified through the perception and experience of the worker concerning his interactions with the environment, content, nature and working conditions, on the one hand, and the capabilities, needs, culture and living conditions outside of work [17].

From this perspective, it is essential to assess psychosocial risk factors to which workers are exposed [12, 17, 19, 24].

Regarding the psychosocial risks, the temporal pressure (61%) is evidenced in European Survey of Enterprises on New and Emerging Risks (ESENER-1) as one of the main concerns of large companies [5], in ESENER-2, one in five companies face pressure to meet deadlines (43%) and this pressure (45%) continues in ESENER-3 [6, 8]. In the ESENER-2, psychosocial risk factors were perceived as the most demanding, and one in five companies reported they did not have adequate information to prevent psychosocial risks efficiently [6]. In ESENER-3, across all workplaces of different sizes, working hours were considered excessively long or irregular (29%) [8].

In the manufacturing and automotive industries, the assessment of psychosocial factors often takes place within the scope of risk assessment of work-related musculoskeletal disorders (WRMSD) [2, 13, 14, 16, 18, 20, 21, 22, 25, 27, 28, 29]. WRMSD are related to physical and mechanical risk factors and to the design of assembly lines and work organization that impose psychosocial demands on workers [16, 22, 29]. If an association between psychosocial factors and the incidence of WRMSD and its symptoms is commonly recognized, on the other hand, the presence of WRMSD can also contribute to mental health disorders, such as depressive symptoms [7, 9]. Therefore, studies have shown that workers' exposure to psychosocial risk factors in combination with physical risk factors is a transversal work reality in a wide range of industries and occupations [2, 13, 14, 16, 18, 20, 21, 22, 25, 27, 28, 29].

From the perspective of the management of Health and Safety at Work, managers should be aware that the combination of musculoskeletal and psychosocial risks must have a global approach to reduce accidents and disability [1].

This study aims to investigate the relevance of assessing psychosocial factors in the manufacturing and automotive industries.

1.1 Materials and Methods

A narrative review of the literature was carried out from December 2022 to January 2023, based on the search for scientific articles in the PubMed, Scielo, ScienceDirect and Scopus databases.

The research question was: Why and how are psychosocial factors evaluated in the manufacturing and automotive industries?

The keywords used to search for articles in the databases were “psychosocial factors”, “psychosocial risks”, “musculoskeletal injuries”, “musculoskeletal disorders”, “musculoskeletal symptoms”, “industry”, “car industry”, “automotive industry”, combined using the Boolean expression AND.

The inclusion criteria were: articles written in English and Portuguese with full text, published in journals or book chapters, indexed, with peer review, available from 2010 to 2022. However, 2 articles prior to this period were included because they were considered relevant to the investigation. The exclusion criteria were: publications focused on other sectors or industries besides manufacturing and automotive.

The selection of articles began with the removal of duplicates, reading the titles and abstracts. The full text of the selected articles was read and analyzed. A total of 25 articles were obtained, of which 13 articles were excluded for not dealing with the manufacturing industry. The final set included 12 articles (09 from the manufacturing industry and 03 from the automotive industry).

2 Results

This section presents the results divided by the type of industry and the psychosocial factors in the manufacturing and automotive industries.

2.1 Psychosocial Factors in the Manufacturing Industry

In the manufacturing industry, several studies have shown that the assessment of psychosocial risk factors was combined with the risk assessment of WRMSD [2, 13, 14, 18, 20, 21, 25, 27, 28], taking into account the presence of organizational factors (overtime, irregular shifts and a typical weekly shifts) [13, 20, 21, 27, 28].

The assessments were based on cross-sectional studies, mostly [13, 14, 20, 21, 25, 27, 28] and only two studies had a longitudinal design [2, 18].

The assessment of psychosocial factors based on the Job Content Questionnaire (JCQ) by Karasek was the most frequent [13, 14, 20, 27]. This questionnaire was used to assess psychosocial and organizational risk factors in association with the evaluation of musculoskeletal symptoms (MSS) in an appliance industry [13], in machinery and assembly line workers in another industry [27], and in different manufacturing industries [14, 20].

Other studies used the Karasek's Job Demand-Control (JDC) questionnaire to assess the association between psychosocial and personality factors with MSS (neck and wrist-hand) in a company with several industrial areas (auto parts, food, pharmaceutical, electronic components and graphics) [21]. The Copenhagen Psychosocial Questionnaire (COPSOQ) was adopted to verify the influence at work in relation to the exposure to physical demands combined with MSS, among workers from an assembly line [2]. The Cohen's Perceived Stress Scale (CPSS) was used in a study aiming to identify the relationship between physical demands and skills with stress and pain among assembly line workers [25].

Other authors developed their questionnaire to assess the association between psychosocial factors (content of work, control at work, social relationships and mental demands), physical workload and musculoskeletal symptoms (neck, shoulder, upper limbs, lumbar region and lower limbs) in a manufacturing industry with several branches (paper, tractors, engines, rifles, meters and similar) [18].

In addition to the questionnaires, the use of qualitative methods was also observed, like the interviews, in the research of the association of psychosocial risk factors (work-family imbalance, exposure to a hostile work environment and job insecurity) with low back pain among production workers [28].

The studies showed associations between psychosocial factors such as high quantitative demands [2, 13, 14, 18, 20, 25, 27], low control over working [13, 14, 18, 21, 27], job insecurity [20, 28], insecurity over working conditions [13, 21], high cognitive demands [18], conflicting social relationships [18], low recognition at work [21], work-life conflict [28], low social support from supervisors [28] and low organizational justice [20] with the musculoskeletal symptoms in various regions of the upper limbs, neck and spine. These psychosocial risk factors contributed to the development of the referred musculoskeletal symptoms.

2.2 Psychosocial Factors in the Automotive Industry

In the automotive industry, the analyzed studies showed the assessment of psychosocial risk factors in combination with physical and organizational risk factors related to WRMSD [16, 22, 29].

All the studies were cross-sectional [16, 22, 29]. The questionnaire JCQ by Karasek was used to compare two production processes (distinct work organization) regarding exposure to physical and psychosocial risk factors in a truck assembly

industry [29]. The questionnaires Job Demand-Control-Support (JDCS) by Johnson et al. and the Effort-Reward Imbalance Questionnaire short version (ERI-S) by Siegrist were used to assess psychosocial risk factors associated with the retirement age, considering the conditions and quality of work as determinants in this process, in an automotive assembly industry [16].

A qualitative study interviewed workers' representatives, assembly line workers and workers with permanent or partial disability due to WRMSD, assessed the psychosocial factors, such as the perception of workers concerning the pace of work and support from leadership, in a truck assembly industry [22].

The studies showed associations between psychosocial risk factors, such as high quantitative demands [16, 22, 29], low latitude of decision [29], low control over working [16] intense pace of work [22] and low quality of leadership [22] with the presence of musculoskeletal symptoms in different regions of the upper limbs, neck and trunk [16, 22, 29].

The results of Pina et al. [22] revealed that psychosocial and organizational factors contributed to difficult the return to compatible work activities in the company to workers with disabilities. The study by Gyllenstein et al. [16] evidenced early retirement at age 62 or earlier based on the influence of psychosocial factors. Early retirement is very relevant in the context of an aging workforce.

However, psychosocial factors can also constitute favorable factors, as in the study by Zare et al. [29], in which good social support helped to reduce tension at work caused by high demands and low decision latitude by workers.

3 Conclusions

This narrative review of the literature showed that the assessment of psychosocial factors in the manufacturing and automotive industries is very relevant. Nevertheless, narrative reviews have several limitations because they do not allow direct comparisons between studies and are more prone to selection bias.

The studies showed the presence of psychosocial risk factors in the manufacturing industry [2, 13, 14, 18, 20, 21, 25, 27, 28] and automotive industry [16, 22, 29] and the necessity of promoting sustainable working conditions for workers [2, 13, 16, 20, 21, 25, 27, 28, 29].

Organizational measures, such as redesigning functions to increase control at work [15], participatory models of leadership involving workers in work-related decisions [11, 15, 23, 26], and good quality of leadership [26] act as moderating variables in the relationship between high work demands and musculoskeletal symptoms [15, 23]. On another perspective, good organizational measures may improve satisfaction, personal development, and general well-being at work, and increase productivity [11].

There is a scarcity of studies on the assessment of psychosocial factors in the automotive industry, mainly longitudinal studies to show the relationships between psychosocial risk factors, WRMSD, early retirement, quality of life at work and

extension of the active working life. There is also a gap in the literature regarding more in-depth assessments of psychosocial factors that allow the identification of reference values for the automotive industry. More studies are needed in order to fill this gap and contribute to the assessment of psychosocial factors in the automotive industry.

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Tools for Fire Safety in Historic Buildings: Review



Milena Campinho, Adeeb Sidani , and António Couto 

Abstract Using technologies such as BIM, HBIM, and VR has great potential in applying and managing fire safety in built heritage. This review aims to update the progress of studies and analyse the innovative firefighting tools and methodologies involved in historic buildings. A total of 78 articles were initially selected, and 33 relevant studies were analysed after critical analysis. The database used was Scopus, with date restrictions from 2016 to 2022. The results indicate that most of the approaches to evaluate the use of innovative tools in analysing fire safety in historic buildings were developed recently. The collected articles presented interventions that can be grouped into two approaches, Evacuation and Risk Assessment. While the studies that involve analysing the behaviour of building occupants during an evacuation process and surveying the physical state of buildings in a fire risk assessment system stand out, other studies have highlighted the need to improve interoperability between software. The continuity and deepening of the theme, with the aim of promoting the safeguarding of buildings and their users, allows the envisioning of a safe future of historical and cultural heritage.

Keywords Old buildings · Fire protection · Building information modelling (BIM) · Virtual reality (VR)

1 Introduction

Research shows that several studies related to the use of innovative tools in analysing fire safety in historic buildings exist, which is fundamental to enabling a safe future for built heritage. For example, in the field of prevention through design (PtD) and deciding the ideal fire evacuation route for a building, the time information and the

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degree of risk must be spatially integrated with a dynamic evaluation model [1]. Similarly, in the field of evacuation management to improve occupant safety during fire evacuations, Building Information Modelling (BIM) was exploited. Thus, enabling the implementation of early fire detection systems, Fire Dynamics Simulator (FDS) and Agent-Based Simulation (ABS) to optimise evacuation routes [3]. On the other-hand, Serious games can be a great way to investigate building occupants' behaviour to improve their evacuation capacity [4]. Consequently, the use of virtual reality (VR) systems and solutions for assessing the building's state of conservation and users' behavioural self-training has assisted the conservation of the architectural heritage [2]. The VR gamification scenarios can expedite the development of situational awareness for the trainees [10]. BIM also facilitates the understanding of the relation between fire safety and sustainable design, it enables the simulation of how fires in buildings will harm the environment and whether sustainable design features will lead to unexpected fire risks [5]. Furthermore, the application of BIM technology during operation and building maintenance periods enriches fire risk assessments throughout their life cycle [6].

Various articles present proposals related to the evacuation of historic buildings, analysing criteria such as routes to be followed, the time required, fire risks, fire propagation and the environment where fire develops. Although some studies on escape routes can be found, a lack of research on the dynamic modification of these routes based on fire spread simulation is currently observed [7]. Knowledge about the effectiveness of an emergency signal needs to be improved, and so are the reasons that lead to its non-observance by evacuees [11]. Immersive Virtual Environments (IVEs), based on VR technologies, provide a promising alternative for conducting indoor wayfinding behaviour studies [28]. Digital tools are widely accepted as the best approach for simulating fire spread and the human response to fire hazards, predicting fire safety performance and aiding in fire evacuation planning [19]. The challenges are the need for IVEs based on the geometric and material conditions of the buildings, potential escape routes, and realistic visualisation of the modelled building, structuring the situation from the point of view of the people at risk [26].

Despite the different criteria investigated, the Risk Assessment of such buildings presents studies such as identifying fire risks in these buildings, their evaluation, protection, and control. Concerning the Internet of Things (IoT) era, many sensor devices are continuously used to measure data related to the real-time conditions of buildings and their surrounding environments [14]. The data points to the need for a series of systems that can integrate and link the information generated during the operation and maintenance phase to allow the sharing of critical information during the fire phase [20]. Data sharing between BIM applications and fire simulation software can help engineers avoid manually re-entering geometric and semantic information into modelling practices [27]. A new fire system optimisation design, combined with BIM, can simulate smoke density, and temperature change, configure the corresponding parameter and design a fire prevention system [31].

The current review based on the PRISMA statement intends to highlight the types of technologies associated with BIM implemented in historic buildings addressing fire safety. In addition, investigate the intervention areas, regulations and standards,

user groups, the VR technologies utilized, and evaluate the systems' effectiveness. Finally, the authors will highlight the knowledge gaps and validate the need for continuity and deepening of research for developing "new" parameters and methodologies for adapting the historical and cultural heritage with the fire safety concept through technologies'.

2 Methodology

The methodology applied to carry out this review is based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [34]. Thus, encompassing 17 points to facilitate the organization and formulating a robust systematic review.

The types of studies involved in this review are any case study or proof of concept that provides information related to BIM-based fire safety solutions in historic buildings. And any study providing methods to evaluate the efficiency, identify the system architecture, techniques and methodology of the designed tools, implementation, and the assessment methods to validate the tools.

Considering participants, and since the current review is a systematic review in the field of engineering and not in the medical field, any stakeholder related to BIM-based fire safety in historic buildings will be included.

Interventions, the methods focusing on BIM for fire safety implemented in historic buildings are of interest to the current systematic review. The research might include evacuation, escape routes, fire resistant material, fire safety planning, evacuation training practices, building monitoring, facility management, risk assessment and building simulations.

With respect to the time restrictions, there was no time limitations, the study included any applied intervention related to BIM for fire safety in historic buildings at any phase of the building management, renovation, or construction. Similarly, no setting restrictions were considered. while, language, only articles in English were considered.

Considering the exclusion criteria, the authors will reject conference articles, review articles, discussion papers, and unpublished work. Studies not related to engineering fields will also be rejected.

In relation to the information source, due to the restricted duration of the research, the search was developed using the Scopus electronic database, considered one of the broadest databases.

The research strategy was as follow, the search was divided into two phases. In the first phase, three keywords for the search were considered, Historic Buildings, Fire safety, and Building Information Modelling. Then synonyms of the chosen keywords were identified, old buildings for historic building, BIM and HBIM for Building information modelling. Thus, the combination of the keywords for the search was the following: (("Historic* Buildings" OR "Old Buildings") AND "Fire Safety" AND ("Building Information Modelling" OR BIM OR HBIM)). Due to the small

number of articles found, a second search phase consisted of adding keywords that were not initially used, as follows: ((“Historic* Buildings” OR “Old Buildings” OR “Building Fires”) AND (“Fire Safety” OR “Fire Protection”) AND (BIM OR HBIM OR VR OR AR)). As expected, the number of articles found in the second search was much higher than in the first. The search was restricted to title, abstract and keywords were the search fields in the database. A filtering process was performed to select studies with the year of publication defined from 2016. Although fire safety and BIM studies were found before 2016, the authors wanted to investigate BIM usage with immersive technologies for fire safety in historic buildings, by which the first related article was found in 2016.

3 Selection of Studies, Characteristics of Included Articles and Quality of Results

To determine the importance of each study, the authors focused on verifying the possibility of applying the proposal for developing “new” parameters and methodologies for adapting the historical heritage with the concept of fire safety, the relevance of the information for promoting the safeguarding of buildings and their users, similar or reference approaches using Technologies BIM, HBIM, VR, and new concepts that can add to the theme.

This process was carried out using a customised Table (see Table 1) to collect information of interest related to the year of publication, the country where the study was carried out, objective, methodology, result, limitations, target groups, equipment, evaluation method and its limitations, in addition to the classification of eligible studies into two categories according to their general content: (1) Evacuation and (2) Risk Assessment.

The following sections describes the Selection of Studies, Characteristics of Included Articles and Quality of Results. Section 4 assesses the articles, describes future research Perspectives, and presents research limitations. Section 5 describes the conclusions of this review.

3.1 Studies Selection

Through searches in the Scopus database, 78 articles were initially collected. Using some filters, restrictions were applied that resulted in the rejection of 45 articles, as follows: year of publication from 2016 to present eight exclusions, type of research article document—two, type of journal source peer-reviewed—0 exclusions, language of articles written in English—0, and out of topic—31 exclusions. Among the 37 articles selected from the two search phases, the authors eliminated four duplicated articles, leaving a total of 33 relevant articles for analysis in the

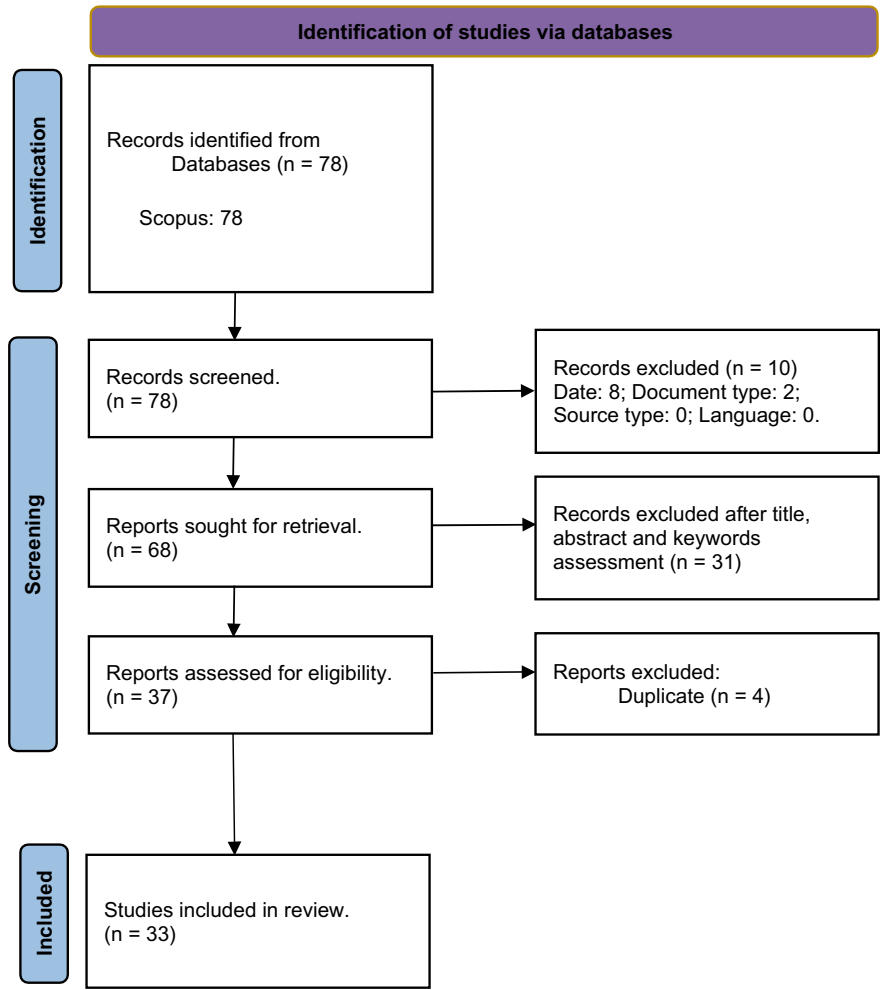


Fig. 1. Search summary, based on PRISMA's flow diagram

current review—in Fig. 1, it is possible to see an overview of the numbers of each stage of the methodology applied in the study.

3.2 *Characteristics of Included Articles*

Regarding the 33 final studies included, the authors found the most significant number of studies in the years 2019, 2020 and 2021: 25 articles (Fig. 2). The number of studies regarding their year of publication, after finding less evidence until the last years to

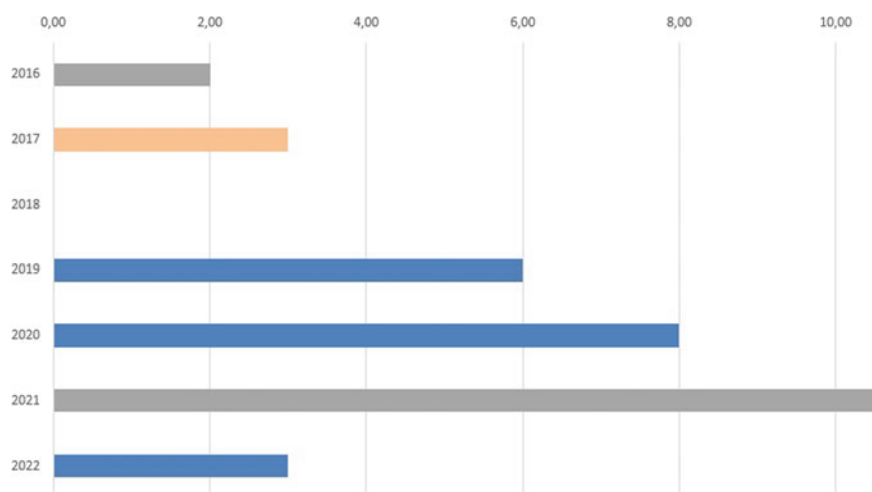


Fig. 2 Selected articles group per year (2016 until 2022)

have the latest Technologies, demonstrates a growth trend of this approach in recent years and allows the validation of the continuity and deepening of the proposals.

Despite the diversity of the 33 selected articles, two research areas could be identified. Among these, 13 studies presented proposals related to the evacuation of historic buildings and 20 addressed issues related to the Risk Assessment of these buildings (see which studies present that information in Table 1). As Fig. 3 illustrates, a more representative quantity can be observed among the Risk Assessment areas.

Grouped by research objective), the authors illustrate (where applicable) the target groups, the equipment used, the type of case study and the analysed variables of the selected studies (Table 1). Among the 33 articles analysed, only four [05, 16, 25, 29] did not use the case study analysis method to test their proposals, and all four related to the research area of risk assessment. Although the studies do not deal specifically with historical buildings, the tools and methodologies applied can be used to develop the theme.

Among the 13 articles in the research area that present proposals related to the evacuation of historic buildings, the most common variables are related to the analysis of the evacuation routes of buildings in eight [04, 07, 11, 12, 13, 22, 26, 28] studies, and the time required for this action, in four [01, 04, 22, 28]. Then, it is possible to compare the different methodologies used with the same objective to be deepened in the future. In most of these cases, the chosen consisted of BIM [04, 07, 12, 13, 22, 26], and the target group was users/owners/experts. This criterion demonstrates the importance of the research on evacuation, not only for owners and experts but mainly for the users.

In the case of the 20 articles related to the Risk Assessment of buildings, despite the different variables analysed, the most common studies are precisely related to the fire risks of these buildings [02, 06, 18, 20, 21, 31]. Among the other 14 articles that

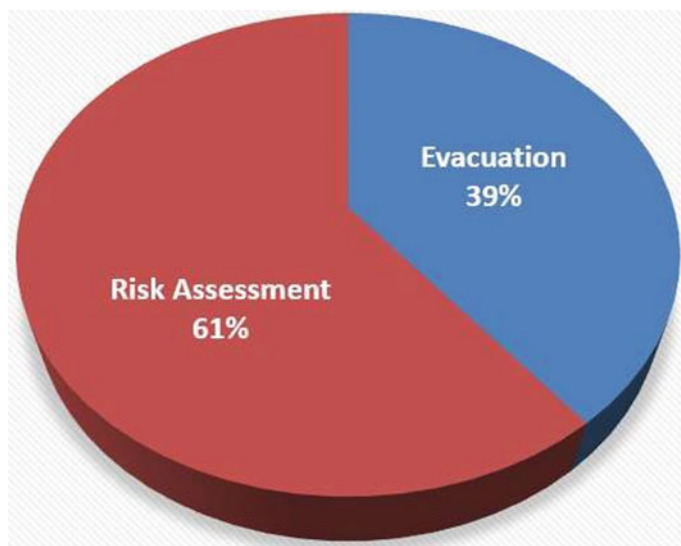


Fig. 3 Classification of Articles based on the field of study

also have the research objective related to Risk Assessment, three variables stand out for being repeated three times each in the results found: Assessment [25, 29, 33], Protection [15, 17, 23] and Control [16, 29, 30]. Despite the diversity of variables presented, it is possible to identify different approaches with the same objective that, in a more careful future analysis, could be used as a basis for developing a new consolidated proposal. In addition, almost all studies were aimed at a target group more focused on owners/experts, except four [02, 15, 18, 33]. Considering that this criterion is specifically focused on the condition of the building, the target group of the studies related to Risk Assessment is essential for owners/experts.

3.3 Quality of Results

After the described filtering process, which resulted in the rejection of 10 articles, as can be seen in Fig. 1, 31 other studies were excluded for being unrelated to the theme. After discarding the four duplicated documents, all selected articles had their abstracts and conclusions read, with the most relevant articles being read in full. The selected studies were generally considered suitable in terms of quality, mainly because they presented relevant, innovative results, despite the weaknesses related to the organisation structure of the texts, most of the time. The quality results were assessed mainly from the collected information on the methodology, result and limitations of the eligible studies, as well as on the possibility of applying the proposal for

Table 1 Characteristics of the studies grouped by their general research objective

Ref	Title	Target group	Equipment (Software/ Hardware)	Case study	Variables	Fields
1	Fire hazard assessment with indoor spaces for evacuation route selection in building fire scenarios	OWNER, DESIGN, USER	GIS	Gymnasium	Risks Time	
3	Fire Simulation and Optimal Evacuation Based on BIM Technology	OWNER, DESIGN, USER	BIM e Pyrosim	Building	Inductors, Propagation, Environment	
4	Virtual fire evacuation drills through a web-based serious game	USER, DESIGN	BIM, CFD e FDS	Dormitory	Time, Routes, Risks	
7	A dynamic fire escape path planning method with BIM	OWNER, DESIGN, USER	FDS e BIM	Prototype	Propagation, Routes	
9	Fire evacuation in complex underground space of personnel	OWNER, DESIGN, USER	BIM e GIS	Building	Indicators, Visualisation	
10	Development of BIM, IoT and AR/VR technologies for fire safety and upskilling	OWNER, DESIGN, USER	BIM, IoT e AR/VR	Prototype	Functionality	1-Evacuation
11	Investigating the influence of route turning angle on compliance behaviours and evacuation performance in a virtual-reality-based experiment	OWNER, DESIGN, USER		Shopping Center	Behaviour, Routes	

(continued)

Table 1 (continued)

Ref	Title	Target group	Equipment (Software/Hardware)	Case study	Variables	Fields
12	Improved Risk Assessment for Fire Evacuation Supported by BIM	OWNER, DESIGN, USER	BIM	Shopping Center	Risks, Routes	
13	A bim-based smart system for fire evacuation	OWNER, DESIGN, USER	BIM e IoT	University	Detection, Environment, Routes	
19	A BIM-based simulation framework for fire safety management and investigation of the critical factors affecting human evacuation performance	OWNER, DESIGN, USER	BIM e FDS	Building	Propagation, Indicators	
22	BIM-based building fire emergency management: Combining building users' behaviour decisions	OWNER, DESIGN, USER	BIM	Simulation	Routes, Time	
26	BIM-based immersive indoor graph networks for emergencies in buildings	OWNER, DESIGN, USER	BIM	Simulation	Environment, Routes	
28	A VR-based study of indoor fire evacuation after active or passive spatial exploration	OWNER, DESIGN, USER	VR	Museum	Behaviour, Routes, Time	

(continued)

Table 1 (continued)

Ref	Title	Target group	Equipment (Software/ Hardware)	Case study	Variables	Fields
2	Dissemination, assessment and management of historic buildings by thematic virtual tours and 3d models [divulgación, evaluación y gestión de edificios históricos Mediante visitas virtuales temáticas y modelos 3d]	OWNER, DESIGN, USER	WEB-GIS	Castle	Disclosure, performance, Risk	2-Risk Assessment
5	An article on green firefighting equipment in Taiwan	OWNER, DESIGN	-	-	Resistance, Sustainability, Socio-economic	
6	Fire risk assessment for building operation and maintenance based on BIM technology	OWNER, DESIGN	BIM	Building	Risks	
8	Building cultural Heritage resilience through remote sensing: An integrated approach using multi-temporal site monitoring, notification, and web-gl visualisation	OWNER, DESIGN	SLAM, GIS e WebGL	Building	Dados legados, Ambiental	
14	Trustworthy Building Fire Detection Framework with Simulation-Based Learning	OWNER, DESIGN		Building	Séries temporais	

(continued)

Table 1 (continued)

Ref	Title	Target group	Equipment (Software/Hardware)	Case study	Variables	Fields
15	Application of BIM Technology in the Fire Protection System of Ancient Buildings in the Intelligent Era	OWNER, DESIGN, USER		Building	Proteção	
16	Research on Building Fire Risk Management Based on BIM	OWNER, DESIGN	BIM	-	Digitisation, Control	
17	Integrating BIM and IoT Technologies in Innovative Fire Management Systems	OWNER, DESIGN	BIM e IoT	Prototype	Protection	
18	Design and Implementation of a BIM-based Fire Risk Assessment System	DESIGN, USER	Microsoft Visual Studio, C# e BIM	Building	Risks	
20	Developing a building fire information management system based on 3D object visualization	OWNER, DESIGN	BIM	Prototype	Detection, Risks	
21	On Intelligent Fire Drawings Review Based on BIM and Knowledge Graph	OWNER, DESIGN	BIM	Building	Risk	
23	Fire Safety of Historical Buildings: Principles and Methodological Approach	OWNER, DESIGN		University	Protection, Restoration	

(continued)

Table 1 (continued)

Ref	Title	Target group	Equipment (Software/ Hardware)	Case study	Variables	Fields
24	Combinatorial spatial data model for building fire simulation and analysis	OWNER, DESIGN	FDS e GIS	Building	Environment	
25	The evaluation of building fire emergency response capability based on the CMM	OWNER, DESIGN	CMM e BIM	-	Evaluation	
27	Research on IFC- And FDS-Based Information Sharing for Building Fire Safety Analysis	OWNER, DESIGN	BIM, IFC e FDS	Gymnasium	Geometry	
29	BIM integrated smart monitoring technique for building fire prevention and disaster relief	OWNER, DESIGN	BIM	-	Evaluation, Detection, Control	
30	Modelling technology for building fire scenes with the virtual geographic environment	OWNER, DESIGN	VGE	Building	Environment, Control, Population	
31	Design and simulation of building fire protection system based on BIM technology	OWNER, DESIGN	BIM e IFC	Building	Risk	

(continued)

Table 1 (continued)

Ref	Title	Target group	Equipment (Software/Hardware)	Case study	Variables	Fields
32	Smoke simulation for large buildings in CFAST: Using BIM to facilitate simulation process	OWNER, DESIGN	CFAST	Algorithms	Propagation	
33	HBIM and fire prevention in historical building heritage management	DESIGN	IFC Model Checking	School	Evaluation, Automation	

developing “new” parameters and methodologies for adapting the historical heritage with the concept of fire safety.

4 Discussion—State of the Art

This review focused on analysing innovative tools and methodologies against fire in historic buildings, with the primary objective of updating the progress of studies carried out so far. In the analysis of the research results, a strong connection was verified between the use of BIM/HBIM/VR tools and Fire Safety in Buildings, the main focus of the research, resulting in 33 articles relevant to the investigation. Among the selected articles, subdivided into two trend groupings of studies with the same research objectives (Fig. 3), it can be highlighted.

4.1 Group 1—Proposals Related to Evacuation in Historic Buildings

Among the 13 articles in this research area, all of them used the case study method to test their proposals, with testing in buildings, in general, being adopted more frequently, with three results [03, 09, 19], followed by shopping centre/prototype/simulation, in two each [11, 12]/[07, 10]/[22, 26], and by museum/university/gym/dormitory with 01 results each [28]/[13]/technologies applied can be used to develop the theme. In order to achieve greater efficiency in the process of evacuating buildings, many studies have presented proposals focusing on criteria such as the analysis of the evacuation paths of buildings in eight [04, 07, 11, 12, 13, 22, 26, 28], the

time necessary for this action, in four [01, 04, 22, 28], fire hazards [01,04,12], fire propagation [03, 07, 19], the environment where it develops [03, 13, 26], among others—the identification of these criteria is an important reference for the continuity and deepening of the research to adapt the historical heritage with the concept of fire safety.

4.1.1 Behaviour of Occupants

Among the studies that adopted the behaviour analysis of building occupants—Serious games for virtual fire evacuation drills [04], Prototyping based upon the rationale of situational awareness [10], Method for assessing human evacuation behaviours [11], Fire emergency management system [22] e People’s wayfinding performance during an emergency [28], it can conclude that despite identifying a considerable advance in this approach, mainly regarding the improvement of users’ skills, situational awareness, interaction with signals, behavioural performance and decision making, with positive results in the interaction of intelligent technology with fire software, the continuity and further research will allow the identification of knowledge gaps and the validation the proposed tools.

4.1.2 Other Results

In addition to the works that adopted occupant behaviour analysis, other results focused on analysing the ideal escape route for buildings through different study factors presented as a differential during the evacuation process: Evacuation route selection algorithm [01], Approach to dynamic simulation and evacuation optimisation [03], Method of real-time dynamic escape path prediction [07], The research on personnel evacuation [09], Local security index at a specific point in time [12], Smart fire evacuation system [13], Simulation framework [19] and Approach to “Immersive Safety Engineering Environment” [26].

In this sense, some proposals consist of different approaches, methods and research to reach the ideal choice Time calculation and comparison of different evacuation routes [03], The dynamic fire escape path can be visualised for the evacuees [07], Technologies complement each other for quantitative analysis of qualitative indicators [09] and Calculation depending on visual assessment of actual building conditions [26]—and others in evaluation models to achieve this objective—Time and degree of risk must be integrated with a dynamic valuation model [01], Time and degree of risk must be integrated with a dynamic valuation model [12], Detect fire early, analyse the environmental data and optimal evacuation paths [13] and Simulation can optimise the building design and investigate the evacuation efficiency [19]. Consolidating an ideal tool requires the continuity of the studies found so that the results obtained in unifying a complete proposal with BIM/HBIM/VR/AR technologies can be used.

4.2 Group 2—*Building Risk Assessment*

Among the 20 articles that have a research objective related to this area, it can be highlighted that most used the case study method to test their proposals, except for four [05,16,25,29], being adopted more frequently the testing in buildings in general, nine results [06, 08, 14, 15, 18, 21, 24, 30, 31], followed by prototype/ university or school, in two each [17, 20]/[23, 33], and by castle/ gym/ algorithm with 01 results each [02]/[27]/[32]. Despite the different criteria addressed, the variables that stood out for being repeated more often in the results found are related precisely to the fire risks of these buildings [02,06,18,20,21,31], their evaluation [25, 29, 33], protection [15, 17, 23] and control [16, 29, 30]. In addition, almost all studies focused on owners/ experts as target groups, except four [02, 15, 18, 33] (Table 1).

4.2.1 Physical State of the Building

Among the studies that adopted the survey of the physical state of the building – Smart, low-cost and user-friendly tools [02], Laser scanning to enhance the preservation [08], Trustworthy building fire detection framework [14], Building's fire information management [20] and Intelligent Fire Prevention and Disaster Relief System [29], it can be highlighted that this adequate and updated survey has an essential role in a successful risk assessment. Documentation of the physical state in a realistic way, 3D of historic buildings with surface change detection, quick access to relevant information, and 3D visualisation to support the assessment and planning of fire safety, among others, are actual results to support fire safety in historic buildings. The use of new tools points to the trend of continuity and deepening of the proposals, as well as the development of more complete ones that unify positive aspects of the presented alternatives.

4.2.2 Other Results

Among the other studies that adopted the fire risk analysis of buildings – The relationship between green buildings and fire safety [05], Assessment method to scientifically calculate the fire risk value [06], Explores how to use scientific and effective thinking in ancient buildings [15], Improved efficiency of fire management in buildings [16], Proposal for fire prevention and emergency management has been presented [17], Method to establish fire risk assessment index system [18], Intelligent review method of building fire design [21], Define and implement the goal of fire safety [23], New spatial data model named the Combinatorial Spatial Data Model [24], The evaluation system of building fire emergency response capability maturity [25], Information sharing for building fire safety analysis [27], Modelling building fire scene with Integrated Virtual Geographic Environment [30], Discuss the BIM technology application in the field of fire protection system [31], Selection

algorithm that allows simulating the 30 most critical rooms in a building [32] and Methodological approach to the management and preservation of historical building [33], it can be highlighted how building fires will harm the environment and whether sustainable design features will lead to unexpected fire hazards [05], the application of BIM technology during the operation and maintenance periods, enrich the fire risk assessment [06], data sharing avoids manual reinsertion of both geometric and semantic information into modelling practices [27], the fire system optimisation can simulate the smoke density and the temperature change, set up the corresponding parameter and design prevention system [31].

Thus, it can be observed that the different risk analysis approaches extend from the concern about the impact of the insertion of new resources in the buildings, evaluating these also during the periods of operation and maintenance, until the development of data sharing, in order to arrive at the optimisation of the fire system. The diversity of proposals presented demonstrates some of the possibilities of using innovative tools for the risk assessment of buildings.

4.3 Future Research Perspectives

There is a recent trend of studies involving proposals related to Evacuation in Historic Buildings and their Risk Assessment to promote the safeguarding of buildings and their users through tools. Future perspectives should explore the continuity and deepening of this research. In addition, most investigations conducted their analyses through case studies, which shows that larger samples should also be the focus of future research.

4.4 Limitations of the Review

The possible exclusion of some articles due to non-compliance with some applied criteria, such as English language and type of document, may have left out data sources. In addition, given the variety between the studies, it was necessary to perform a statistical analysis combining the research areas for a clearer understanding of the results, the definition of which may have disregarded specific relevant points of some articles.

5 Conclusions

The different studies addressed in this review showed that research on the use of tools in the analysis of fire safety in buildings is evolving with a tendency for growth of this approach in upcoming years. While research on areas that involve analysing

the behaviour of building occupants during an evacuation process and surveying the physical state of buildings in a fire risk assessment system stand out, other studies have highlighted the need to improve interoperability between software.

There are many advantages in the possibility of obtaining all the information of a building and managing it, in a single place, with different disciplines, having found many articles that presented great potential for management and application of Fire Safety in built heritage with the use of technologies, BIM/HBIM/VR. The results allow the validation of the need for continuity and deepening of the proposals, with the aim to develop “new” parameters and methodologies for adapting the historical and cultural heritage with the concept of fire safety through the use of tools.

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Digital Twin Applications in the Extractive Industry—A Short Review



J. Duarte  and J. Santos Baptista 

Abstract Introduction: The technological development brought up by Industry 4.0 has wholly revolutionised the industrial sector, promptly opening doors to improving operational efficiency and occupational safety. Trying to understand where the extractive industry stands, this short review aimed to find evidence of the sector's digital twin and digitalisation applications and their integration level. Methodology: The Preferred Reporting Items for Systematic reviews and MetaAnalyses (PRISMA) Statement was used as guidelines to conduct and report the research. Three multidisciplinary databases were selected (Scopus, Web of Science and Science Direct). The research combinations comprised “digital twin” and the varied expressions one might use for the mining sector. The selected works were qualitatively assessed regarding technical context, working methodology and main results. Results and discussion: From the initial 1,590 identified articles, only 23 were found eligible and included in this short review. The results show that occupational safety is not even on the list of priorities of the sector. However, it is indirectly addressed while trying to ensure operation optimisation. Conclusions: Though the results express the use of digital twins, it does not go beyond a digital model in most cases.

Keywords Digital model · Digitalisation · Mining · Management · Optimisation

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1 Introduction

The recent years have faced the digital revolution of the industrial process known as the fourth industrial revolution or Industry 4.0 (I4.0). The traditional industrial grounds shifted to a smart factory environment, with the help of digitalisation conceptions and automation toward excellence in operation [1]. The physical world's day-to-day operations are converted into their virtual replica; this latter model plans and monitors operation. With the introduction of digitalisation techniques, complex problem-solving is easily deconstructed. These solutions find applications in several sectors, such as manufacturing [2], energy [3], food supply [4], construction [5], the automotive industry [6], health care, and embedded services [7], to mention a few.

The structure of an I4.0 system can be fragmented into four layers: physical dimension (mobile devices, robots, equipment), network (device connectivity), cloud (related to how data is stored, *big data*) and final application [8]. Cyber-physical systems (networked and communicating with each other through the Internet of Things) monitor processes in the physical world and create a virtual copy of these records that are transported to a computational model. The result of the clash between the real world and the virtual translates into a “digital twin” (DT).

By definition, digital twins are “digital replication of physical objects, models and systems in the virtual world” [9]. DT acts as a digital shadow of physical reality. For this reason, they are often used to test and simulate scenarios, anticipating potential technical and operational problems in real-time; simultaneously, it helps improve general worker safety. However, the concept application is far more challenging and implies high implementation costs and data processing.

In the mining framework, the resource's finitude requires much planning capacity. The fact that mines and quarries are dynamic sites with complex technical features, and regardless of the effort made by the sector to improve its technique, it is managed as a high-risk industry. All these factors aligned make the figure of DT an attractive solution to longstanding predicaments. A literature review study addressing the application of sensing technology in this field [10] concluded that the primary goal for the future of the industry will include developing a decision support system for real-time production control and optimisation.

This technological revolution can change how mining is done, moving from human-dependent operations to autonomous or semi-autonomous intelligent mines [11, 12] increase outcome quality, transparency and collaboration [13]. Moreover, full processes automation is expected to prevent thousands of injuries and deaths due to occupational accidents [14]. In this sense, one should expect increased mining efficiency, productivity, and occupational safety levels. Yet, is it attainable? Trying to understand where the sector stands, this short review aimed to find evidence of the digital twin and digitalisation applications within the extractive industry and their current integration level.

2 Methodology

The research was conducted using as guidance the Preferred Reporting Items for Systematic reviews and MetaAnalyses (PRISMA) Statement [15]. The PRISMA statement comprises three major phases: identification, screening of information and eligibility study.

Three multidisciplinary databases were selected for the identification phase: Scopus, Web of Science and Science Direct. The keywords related to the aim of the short review were defined and divided into two dimensions: the first one was the work basis “digital twin”, and the second term was related to the field (extractive industry). Their combinations were inserted into the fields “Abstract/Title/Keywords” of each scientific database. The Boolean expression that reflects the web search is as follows.

“digital twin” AND (quarry OR “open pit” OR “open cast” OR “surface min” OR “underground min*” OR “min”).*

The wildcard “*” opens the research expression to every possible word ending.

In this case, “min*” could be either “mine” or “mining”.

Information screening must be transverse despite the chosen database/journal selection. Therefore, a set of exclusion but traceable criteria was defined before records selection:

- (1) Date of publication
- (2) Type of document
- (3) Language.

The publication period considered for this research ranged between 2018 and 2023 since there was an apparent “boom” in the field in the past few years, which would lead to an information overload, most outside the intended scope. Regarding the document type, scientific journal articles and conference proceedings were considered. Proceeding articles are not a consensual work typology. Determining whether the respective conference has peer review or content control exclusively is impossible by looking at the database research. Though this type of article was included in the research, its analysis was executed cautiously. Finally, the criteria related to publication language: only English-written works were considered for analysis in this study. Duplicate records were removed at this point.

After the screening phase, the selected records were assessed for determination of possible inclusion in the short review. The first step between screening and eligibility is analysing the articles’ title and abstract to determine whether the work scope matches the study objective. Once this stage is completed, the full text is retrieved and appraised. An Excel datasheet was used to assist with the data collection and completion. General article information (author, year of publication, title, source, and country), study context (type of quarry/mine, exploited commodity, cycle phase, problem to be solved), and work methodology (DT integration level, proposed methodology, equipment used, software) and main results were retrieved.

To be included in the short review, articles should be within the context of the extractive industry (EI) (underground or surface exploitation), and their working grounds should be practical (in opposition to theoretical frameworks) despite the implementation level of their digital twin models.

3 Results and Discussion

Following the methodological steps, 1,590 records were identified. After applying the exclusion criteria, 43 articles were removed due to publication date, 156 were excluded due to the type of document and 89 regarding publication language. Duplicate records, 44, were also excluded in this phase.

Screening the title and abstract of the remaining 1,258 records and putting their work aim and methodology under analysis led to excluding 1,193 papers. The eligibility phase comprised the assessment of 65 papers. Five were excluded due to the impossibility of retrieving their full text after contacting the respective authors. Other 37 papers were excluded for the following reasons: theoretical framework, falls out of the scope of the EI, article somewhat mentions DT but instead focuses on machine learning algorithms or were not scientific works (published in journals or proceedings). Overall, 23 papers met all the above criteria and were included in this short review. The summary of the research process can be seen in Fig. 1.

Of the 23 included papers, eight were published as conference proceedings [17–23] and 15 as research articles in scientific peer-reviewed journals [9, 24–37].

Before linking the DT topic with the EI process, it is important to contextualise the cycle technically. Generally speaking, the EI set of operations can be divided into four stages: exploration, exploitation, and site reclamation. For short review purposes, the exploitation phase will be addressed into exploitation as such and ore processing.

During the exploration phase, it is crucial to determine the project's feasibility. In simple terms: where the commodity is located and how to extract it. This phase alone involves intricate decision-making aspects, especially in underground mining, where first and foremost, the resources are not as easily accessible and where the hazard is not always perceivable. The only included study that fit under this cycle phase [26] had as an objective to build a digital model of a complex geological structure (a vital safety aspect) and use it to prevent coal mine disasters. To achieve that, the authors collected field data and built the fault model of the coal mine. Though it served its purpose and provided a more profound knowledge of the site, it cannot be said that the final digital model is an actual digital twin since it is missing the input link with the physical world.

Then, exploitation. Each exploitation has its fingertip: underground or surface, per se, has perks and inconveniences. On the one hand, the already mentioned inability to see what lies beneath poses several safety hazards besides the technical challenges. On the other, land degradation is 2–11 times bigger in surface mining, not to mention other impacts that might not be circumscribed to the site, such as dust

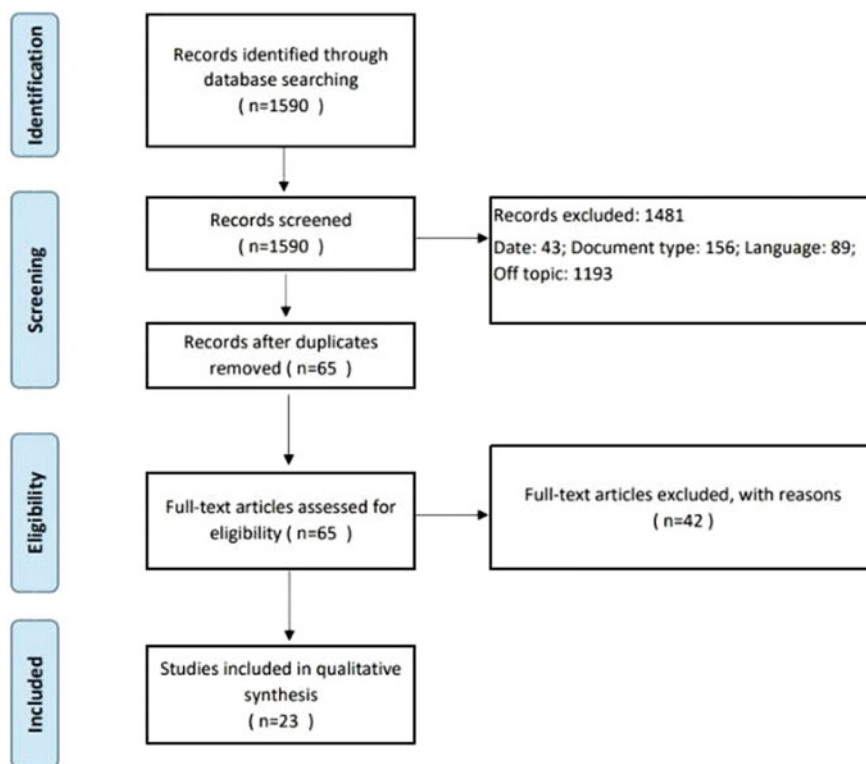


Fig. 1 Research flowdiagram, adapted from PRISMA [16]

and noise affecting workers and the surrounding communities [38]. The extraction methodology depends on the commodity of interest, creating the hows and which market value dictates the ifs.

Figure 2 resumes the relationship between the commodity and country of the included studies. The relative size of each colour is linked with the number of studies reporting that particular product. “Coal” positions itself at the poll top, either from China, India or Russia. Coal bursts related to complex geological structures account for 70% of the total accidents in this industry [26]. That, adding up to the fact that most coal extraction operations occur in underground environments (the reality of 100% of the included studies), requires top-notch technological and multilevel approaches to deal with the problem correctly.

Five of the 13 papers reporting exploitation matters did not mention the commodity [18, 21, 25, 33, 34]. Of those, four [18, 21, 33, 34] were dealing with management issues (process or system control in terms of mine planning and operation control) and the other one [25] with unitary process optimisation. Except for two case studies in which technological achievement did not surpass the model phase, every other digital twin was fed with real-time data.

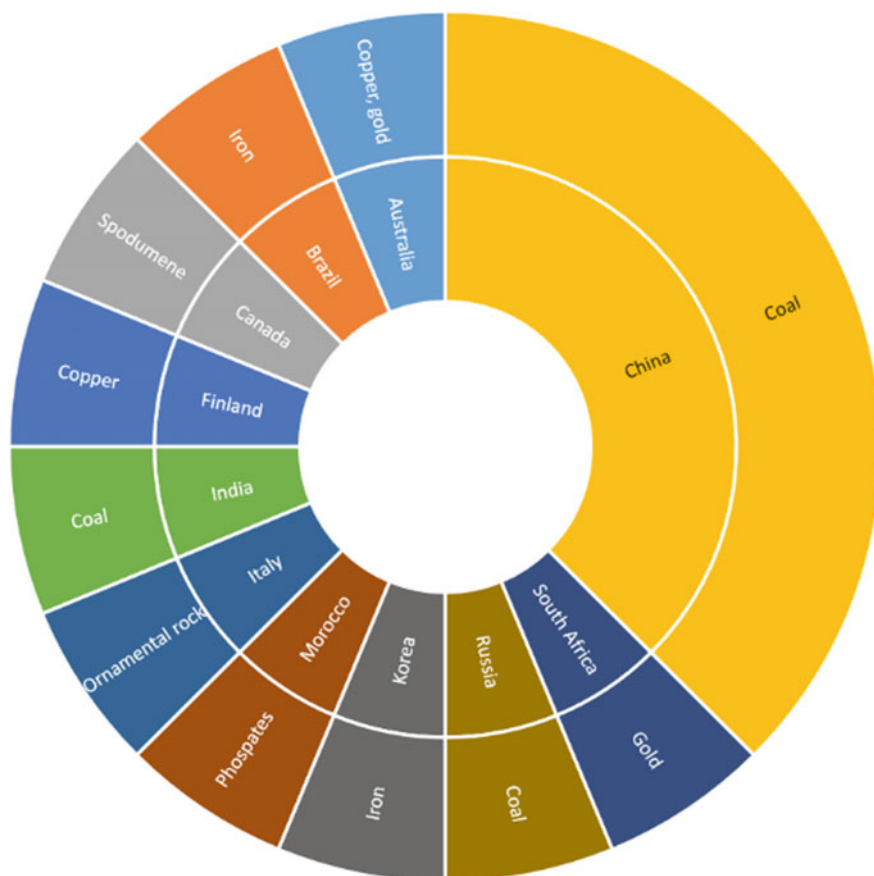


Fig. 2 Exploited commodity per country per number of studies

The digitalisation process occurred at three levels: product (equipment), process (unitary task) and system (overall process) to solve either management or optimisation concerns. Two particular works deserve attention for their input on the digitalisation chapter, both while trying to address critical equipment conditions. After creating the DT model of a drill used in coal exploitation, in the study of Li [22] layered it with a backpropagation (BP) neural network algorithm to train it. The BP works on the grounds of pattern recognition and prediction models. The process can split into the following stages:

- (1) Digital model construction using geometric data (mostly)
- (2) Collection of historical data related to the desired output and feeding it to the BP algorithm
- (3) Link the BP algorithm with the digital model
- (4) Update the model with real-time data.

The training pattern is used in the DT, in which the algorithm compares the predicted outputs, puts them against the expected outputs and calculates the derived error. Then, the error is used to adjust the weights of the algorithm which is expected to minimise it, repeating the process. The results achieved almost 98% accuracy just after the fifth optimisation cycle, which is of great importance since the real-time monitorisation of this equipment in such operation plays a key role in the safety of workers and production. Zhang et al. [20] built the DT of a longwall shearer. They applied a backpropagation through time (BPTT) algorithm that helped achieve a decision-making model regarding equipment safety and maintenance. This algorithm picks the previous one and decomposes a step: it works the sequence data in a time series manner, increasing the number of steps.

Material processing is the phase that handles the extracted raw material, working on its beneficiation to commercialise it. This phase, yet again, is related to the type of material and its economic value. Nine articles focused on two main problems related to mineral processing: process digitalisation [24, 36] and seven on optimisation problems [17, 19, 23, 29, 30, 32, 35]. Optimisation problems related to equipment in this context either try to improve production ratios or maintenance issues. What is meant by production ratios is the continuous improvement of the existing models to achieve higher ore recovery ratios. Maintenance actions are commonly reactive, but that means it stops production. Alternatively, preventive maintenance constitutes the most reliable option to keep the cycle running. Excessive maintenance has increased costs with no significant advantage in failure/fault prevention [39]. What Huang et al. [29] tried to accomplish was the next step in preventive maintenance: predictive maintenance. By feeding the digital model with real-time data and using an improved sparrow search algorithm (that tries to find the feasible solution within a set of possibilities) with random forest (that combines the multiple decision trees output until reaching a single result), known as ISSA-RF, which analysis it continuously, the general equipment status is looked at preventing faults and failures.

The fourth and final step that should be accounted for during the EI cycle is the environmental recovery, which was left out to dry in this case. Nothing in the analysed literature even touched on this topic, leaving the question: is it not being paid the proper attention to, or is it being included, as it should, in the exploitation process?

In Fig. 3 it is summarised the number of studies about their primary purpose, with the main digitalisation tools used for optimisation and management problems. The analysis of the included studies showed that operation safety aspects, if addressed, also contribute to improving overall worker protection in the underground environment. Nonetheless, this relation is indirect as worker safety and integrity are not even in the equation. Another important remark is related to the concept of the digital twin itself: despite the majority of articles (18 out of 23) referring to their work as a “digital twin” of an equipment/process/system, only four worked up to the concept [19, 20, 22, 29]. Thus, the digital twin and digital model concepts are interchangeable in the literature despite the DT requiring a real-time connection with the physical object, process or system. These four studies have another point in common: they all reported the “high fidelity” of the DT in terms of system representation, with a great link to the real world. In the study of Li et al. [22], it was even possible to achieve

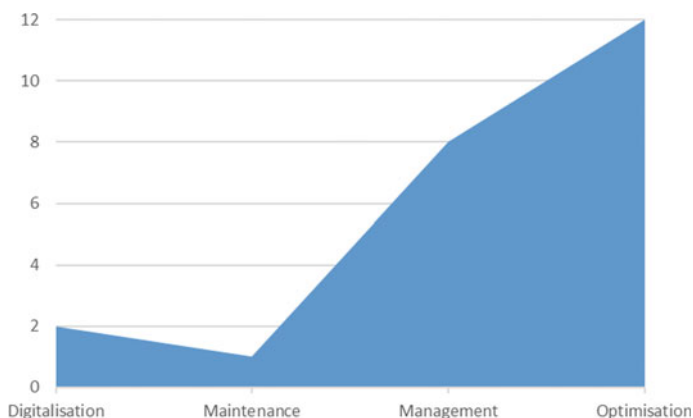


Fig. 3 Number of studies according to general purpose

a 98% accuracy diagnosis model. In the remaining three cases, it was reported that the models did not reach their full potential. However, the DT was already realised as a working basis that solved the immediate operative necessities.

4 Conclusions

The shift caused by Industry 4.0 added the automation level to the already digitalised industrial world. This paradigm change was felt across industries, and the mining sector was not the exception. Known as one of the highest hazardous fields with several dynamic technical challenges, the extractive industry is currently on the edge of its first steps in this technological revolution. Bearing this in mind, this short review aimed to find evidence of the digital twin and digitalisation applications and their current integration level in the sector.

The results showed that most articles pursued optimised solutions to not-so-new problems regarding equipment maintenance and ore processing model optimisation. Due to their potential, the digital models were often used to test and simulate scenarios, anticipating potential machine complications and optimised operational solutions. Most of the time, the core objective underneath the developed work was assuring operational excellence. Notably, since most of these works were related to the underground setting (the most demanding of both scenarios in terms of exploitation), by guaranteeing the optimal technical conditions, workers' safety was also being taken care of without being the actual focus.

An important consideration regarding the integration level of such models is that the concept of digital twin and digital model seem interchangeable in the literature despite the entirely different integration levels. Nonetheless, three of the included studies deserve particular attention since they represent the step ahead in automation:

by integrating machine learning techniques into their works, the authors improved their systems. They added the prediction layer to the decision-making process. While much road has to be paved regarding occupational safety, the mining industry is no longer an ancient sector as it has officially entered the Mining 4.0 era.

Acknowledgements The authors would like to acknowledge the Faculty of Engineering of University of Porto for the funding of this work.

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Work Accidents Related to Heavy Equipment in the Open Pit Extractive Industry: A Systematic Review



Jane Souza, Jacqueline Castelo Branco , and J. Santos Baptista 

Abstract Open pit extractive industry (OPEI) is one of the most dangerous industries, with high rates of accidents associated with the production process and working conditions. This work aims to perform a systematic literature review to identify and characterise the accidents that occurred in OPEI. The review followed the PRISMA Statement approach. Ten databases were consulted with the following combination of keywords: “accident”, “hazard”, “mine”, “extractive industry”, “open pit”, “open cast”, “quarry”, and “equipment”. Papers prior to 2018 not published in journals and languages other than English were excluded. Only papers addressing occupational accidents with mobile equipment in OPEI were included. From the research 4,521 papers were obtained. After applying the defined exclusion and inclusion criteria, 12 papers were considered for detailed analysis in this review. The main accidents reported were slips, trips and falls at the same level, at different levels, and/or from the equipment. The main reported causes were loss of control of the equipment, insufficient lighting, lack of road and inadequate equipment maintenance. Implementing risk management processes that are adequate and adapted to the conditions associated with the production process is essential.

Keywords Extractive industry · Mobile equipment · Mining · Quarrying · Accidents

1 Introduction

The Open Pit Extractive Industry (OPEI) is one of the most dangerous industries. This recognition is justified by the high accident rates associated with the production process and working conditions. Much of these rates are related to the use of heavy

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mobile equipment [12, 16, 18]. Due to the association between the operator, equipment and the environment, the number and severity of accidents in mining operations are higher than in other industries [20].

Data from the International Labour Organization in 2021 showed 26,194 non-fatal and 118 fatal accidents recorded in the OPEI. Some studies in the literature report that OPEI contributes approximately 10% of the worldwide mortality related to occupational accidents [5, 11, 23]. Lack of safety procedures and inadequate safety management can lead to behaviours that increase the probability of accidents [20]. In addition, the operators' behaviour is a factor that can increase the accident rates [4].

From the numerous accident reports involving mobile equipment in the OPEI the most cited were trucks, dumpers, loaders, excavators, and tractors [1, 20]. The reduced operator visibility for the operator, the debris on ladders, the design of the access to the equipment, and the design of the equipment itself, do not facilitate the adoption of best practices and, consequently, accident prevention [15, 18].

From this perspective, this study aims to update the systematic review developed by Duarte et al. [4] on mining equipment involved in occupational accidents, their main causes and risk mitigation measures adopted.

2 Materials and Methods

This paper was conducted based on a systematic review protocol by Duarte et al. [3], which aimed to search for evidence of occupational accidents in the OPEI between 2010 and 2018, for this reason, the research was updated to obtain more current data. The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement was applied [14].

The scientific literature search was based on the following databases: Scopus, Engineering Village (INSPEC), Academic Search Ultimate, Web of Science, Current Contents, IEEE Xplore, Taylor & Francis, Emerald, Ingenta, Directory of Open Access Journals (DOAJ), which are the main databases of multidisciplinary and engineering areas.

The search strategy was based on the following keywords “accident” and “hazard” combined with “mine”, “quarry”, “open pit mining”, and also “equipment”, separated by the Boolean operator AND. The following exclusion criteria were adopted: date, papers published before 2018 were excluded; document type, papers not published in peer-reviewed journals and written in English were excluded.

Studies reporting accidents involving heavy mobile equipment and establishing causes and factors associated with OPEI were included. The Mendeley reference manager was used to manage the references and remove duplicates.

The snowballing technique proposed by Wohlin [24] was also applied. This technique makes it possible to find new references from the initially included articles. Only papers that complied with the eligibility criteria were considered.

3 Results

In the search, 4,521 papers were obtained. After applying the first screening criteria, 3,277 were excluded by date, 343 by type of document, 20 by type of source, and 141 by language (Fig. 1). Subsequently, full papers’ were read to apply the eligibility criteria, evaluating if the papers presented analysis and causes of accidents. After removing the duplicates and adding the papers from the snowballing technique, 12 papers made up the final sample of this systematic review (Fig. 1).

When performing the analysis of the results obtained, it was observed that most of the papers were extracted from Mine Safety and Health Administration (MSHA) [8, 15, 21] National Institute of Occupational Safety and Health (NIOSH) [18], Administrations of state occupational safety of local countries [6, 22]. Mostly these were case studies with mobile equipment operators, which were prevalent [2, 9, 13, 17, 19].

Several types of equipment were identified: haul trucks, forklifts, loaders, belt conveyors, tractors, load haul dumpers (LHD), drills, bucket wheel excavators, excavators, trailer trucks, and crawler tractors. Table 1 summarises the equipment mentioned, associating it with the type of accident and related causes.

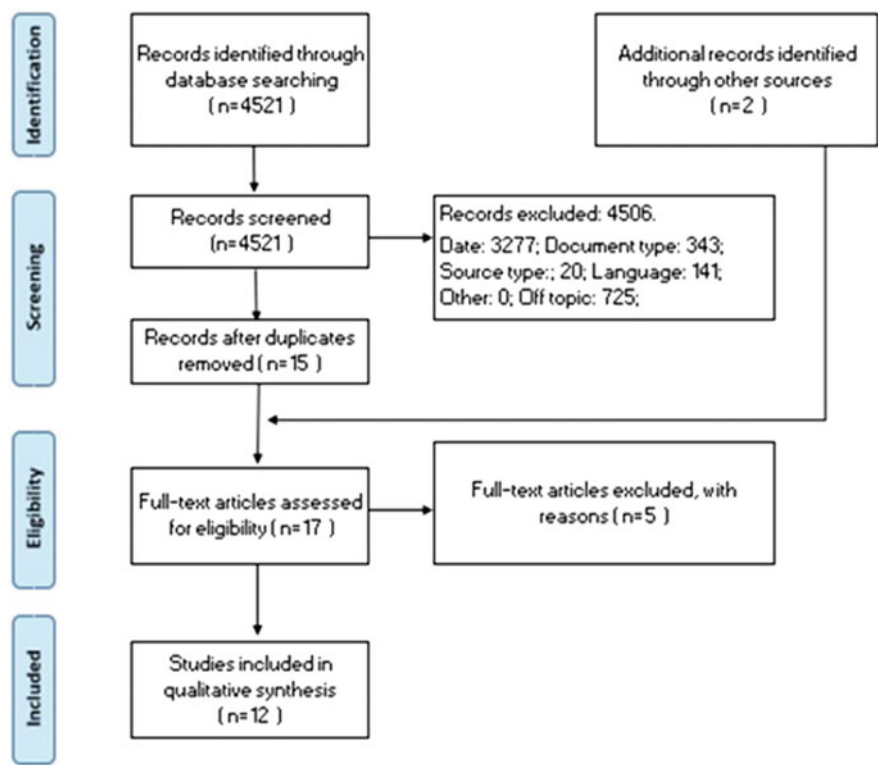


Fig. 1 Research flow diagram [14]

Table 1 Type of accident and main causes by equipment

Equipment	Type of accident	Causes of accidents		
		Human error	Maintenance	Project
Transport truck/dumper	Falling equipment [2]; vehicle/object collision [8, 23], vehicle crash/slide [23], slipping, tripping and falling [13, 21], Slipping and falling [22], collision with pedestrian [8], rollover [21]	Lack of skill [2]; loss of control of equipment [23], lack of rules [6], Weak awareness [6], lack of compliance with warnings [8], inadequate training [8], lack of safety equipment (belt) [8], fatigue and long working day [21], excessive load [9]	Inadequate maintenance [2, 6, 9, 13], equipment control failure [2], mechanical failure of components [2, 8, 21], lack of road maintenance [2, 8, 19, 21], improper mechanical procedures [8]	Insufficient lighting [13, 19], inadequate design [19]
Wheel loaders	Slips, trips and falls [13, 15, 19], collision between equipment and individuals [8]	Loss of stability [15], lack of warning compliance on signs [8], inadequate training [8], lack of safety equipment (belt) [8]	Contaminants in equipment access ladders [15, 19], improper mechanical procedures [8]	Insufficient lighting [13, 19], inadequate equipment design [15, 19],
Tractor	Slip and fall [22]	Not mentioned	Not mentioned	Not mentioned
Jackleg drill	Slipping and falling [22]	Not mentioned	Not mentioned	Not mentioned
Bucket wheel excavator	Not mentioned	Failures to comply with safety procedures [9],	Not mentioned	Not mentioned
Backhoe loader	Vehicle/object collision [23], vehicle crash/slide [23]	Loss of control of the equipment [23],	Not mentioned	Not mentioned
Haul truck	Vehicle/object collision [23], vehicle crash/slide [23],	Loss of control of the equipment [23],	Not mentioned	Not mentioned
Crawler tractor	Vehicle/object collision [23], vehicle crash/slide [23]	Loss of control of the equipment [23]	Not mentioned	Not mentioned

4 Discussion

The analysed papers showed that heavy mobile equipment was associated with the most common occupational accidents in OPEL.

Figures 2 and 3 demonstrate the results obtained from these studies, which report the total number of accidents by type, the most frequent of which were the equipment operators slipping, tripping and falling, followed by vehicle/object collision, slipping and slipping and slipping and slipping and falling (Fig. 2) [13, 21, 22].

Twenty types of accident causes were identified, with loss of control of the equipment, inadequate maintenance, lack of maintenance of circulation routes and inadequate lighting as the most common. In sequence, mechanical failure, inefficient mechanical procedure, the presence of debris on the equipment access stairs, lack of visibility, lack of compliance with signal warnings, inadequate training and the lack of personal protective equipment (PPE), such as the safety belt (Fig. 3) were the most frequent.

The study conducted by Kecojevic et al. [8] also mentioned that the primary causes of accidents are lack of compliance with the rules, loss of balance, excessive load, fatigue and long working day, poor awareness, and failure to control the equipment, lack of skill and inadequate design.

The equipment with the highest accident rates were transport trucks, present in 26% of the analysed articles [2, 8, 13, 17, 21–23].

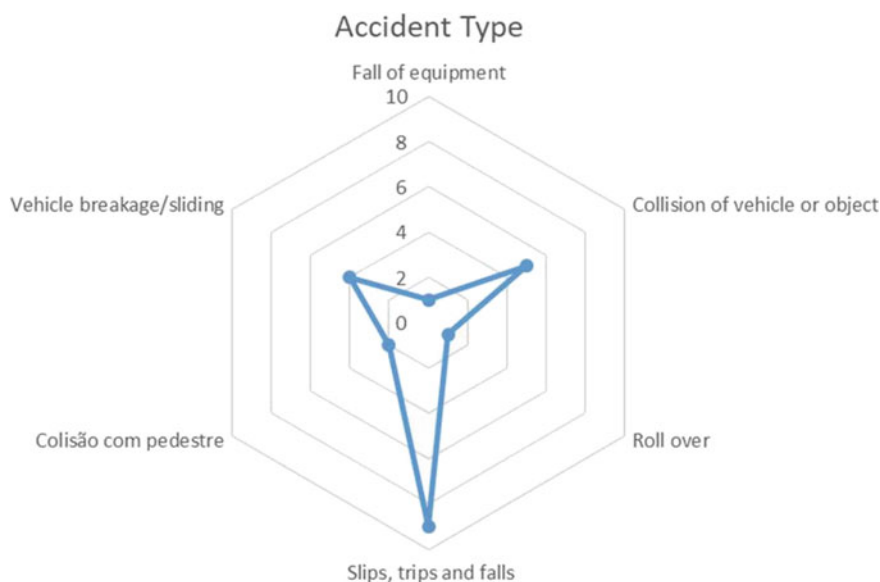


Fig. 2 Number and type of accident [14]

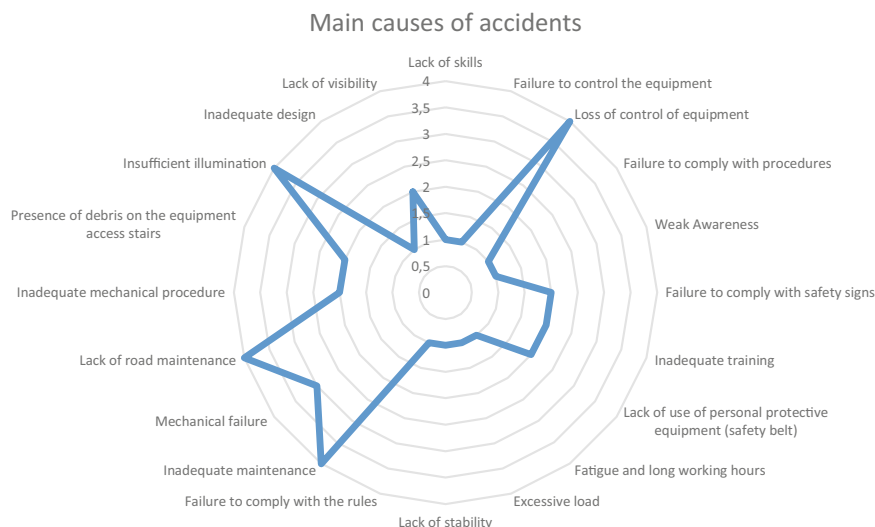


Fig. 3 Main causes of accidents

In sequence, the wheel loader stood out with 15% [8, 13, 15, 17]. General mobile equipment (not specified) adds up to 11% [6, 16, 19]. Finally, tractors, excavators, trailer trucks, and drills add up to 7% [8, 17, 22, 23].

Of the twelve articles included in this systematic review, seven make a complete relationship between the types of accidents associated with their causes [2, 8, 13, 15, 19, 21, 23]. Two articles mentioned only the types of accidents [6, 9]. One of the studies only analysed the causes of accidents in the OPEI sector [22], and two reported the factors associated with the development of accidents with mobile equipment [13, 17].

Among the 12 studies analysed, two did not mention the type of accident outcome, whether there were injuries or fatalities [2, 17]. Two studies reported injuries and fatalities as outcomes [9, 22]. Another seven studies reported only the injuries [6, 13, 15, 16, 19, 21, 23]. Only the study by Kecojevic et al. [8] addressed fatalities specifically.

When performing the analysis of the total number of accidents by type, it was possible to observe that the highest frequency are the equipment operator's slips, trips and falls, collisions between vehicles or objects, followed by equipment falling or slipping [8, 23].

However, it is interesting to note that slips and trips in some locations are not considered occupational accidents but are near misses. Some studies point out that these events are associated with insufficient lighting in the workplace [13, 16].

According to the study conducted by Pollard et al. [19], equipment operators report that the lack of adequate lighting becomes an essential element for accidents to occur during operation, whether the accident occurs during the entry or exit of the equipment. In addition, these accidents resulting from the lack of lighting generate a financial cost to the open-pit mining industry of approximately US\$ 3 million per year [16].

Compared to the study prepared by Duarte et al. [3], it was found that the accidents that most occurred were collisions between vehicles, falling equipment, and rollovers. Accordingly, it is evidenced that even with the passage of years, accident types such as collisions between vehicles are still a stalemate for the open pit extractive industry.

Regarding the causes of accidents, the studies analysed in this systematic review reported that the ones that stood out were the loss of equipment control, inadequate maintenance, failure to carry out road and track maintenance, insufficient lighting and mechanical failures of the equipment. The reported causes were related to mobile equipment, including transport trucks, wheel loaders, tractors, drills, excavators, trailer trucks, and LHDs.

In contrast, Duarte et al. [4] highlighted that the leading causes were the company not providing the maintenance procedures for the operator to perform a safe journey, failures in the equipment controls, lack of visibility, and the mechanical components not adapted to the climate. These causes occurred in equipment such as tractors, dumpers, diggers, forklifts, transport trucks, drills, LHDs, and wheel loaders.

Some authors as Fa et al. [6], Kirin et al. [9], and Patyk and Nowak-Senderowska [17], referred to the operator's behaviour and perception as the main cause of accidents. From this perspective, it is notorious that when performing operation activities, workers do not have adequate knowledge about the risks of accidents at the workplace. Therefore, training actions for operators must be implemented and intensified.

When performing the association between accidents and equipment involved, the studies point out that injuries and fatalities were more present in the activities performed with dump trucks [8, 23]. The reviewed studies focus on the causes of accidents related to human error. This means there must be a recycling of the operators' know-how about the risks of their work activity.

5 Conclusions

Despite the obtained results, it is evident that there are still few published studies that make a direct relationship between accidents and the possible root cause. Seven of the twelve studies included in this systematic review made some kind of causal association between the equipment and the accidents. In this way, this review intended to collect information on heavy mobile equipment related to occupational accidents that resulted in injuries and fatalities, mainly by listing the causes and possible explanations.

This research indicates that fatal accidents related to heavy equipment in the open-pit extractive industry occurred mainly in transport trucks and tractors operations.

Concerning injuries, the involvement of transport trucks and loaders was predominant, followed by mobile equipment in general.

It was possible to conclude that the main causes of accidents are related to inadequate working conditions, such as lack of proper lighting, maintenance of roads, and insufficient maintenance of equipment.

Most authors refer to the importance of adequate risk treatment measures to help reduce the causes of the reported accidents. For example, measures adopted in the mining sites' design phase and the equipment (cabin access and safety devices) should be implemented at the design stage.

Adopting operational procedures, maintenance, and the speeds of the roads, considering the specificities of each workplace (conditions of the roads, visibilities of the operator) and maintenance plan helps reduce the probability of operators' mistakes.

The causes of mechanical failure, lack of visibility, inadequate training, contaminants in the ladders, inappropriate mechanical procedures, lack of PPI, and lack or non-compliance with the safety warning signal have been mentioned.

Among the preventive measures that can be suggested is highlighted the improvement in the general maintenance of work environments, especially in equipment and circulation routes, with the removal of contaminants and improvement in lighting. Besides, as a relevant preventive measure, creating more effective safety training, using recent technology for education, such as virtual reality, and better mapping the most common accident situations, focusing efforts on preventing them.

Acknowledgements The authors would like to acknowledge the Doctoral Program of Occupational Safety and Health of the University of Porto (grant number demsso.jps.PD9986).

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A Systematic Review on Occupational Noise Among the Sailors: Measurement, Standards, and Control



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Abstract This literature review aims to provide an up-to-date literature review and evaluation of the evidence base that compares occupational noise measurements on ships, standards, and noise control recommendations. This study consisted of literature from multiple databases, including Scopus, Pubmed, Web of Science, Ebsco Host, and Science Direct. We followed the PRISMA guidelines to review papers from 1987 to 2022. We discovered 401 articles, which 30 of them were chosen for this review paper. A Sound Level Meter and/or Dosimeter can be used to measure noise levels on fishing boats, ferryboats, navy vessels, container ships, and floating storage and offloading vessels (FSO). The shipyards must also carry out noise measurements to determine noise exposure in ship life. Task-based measurement (TBM), full-day measurement (FDM), and the job-based method (JBM) are the available noise measurement techniques. The simplified International Maritime Organization (sIMO) method suggested by ISO 9612 can also be applied to measure levels of noise on big commercial ships. It provides recommendations for noise control efforts, including elimination, substitution, engineering, administration, and ear protection, based on international regulations.

Keywords Noise · Assessment · Regulation · Recommendation · Seafarers

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1 Introduction

Shipping is the most efficient and cost-effective mode of transport, carrying 80% of the world's trade-in volume and over 70% of the world's trade-in value, but it also has harmful consequences. Due to the complex socio-technical structure of human variables and the fact that the ship operation system is designed with human behavior in mind, it is imperative to comprehend the human factor to prevent seafaring fatalities. The negative impact of human factors on maritime accidents has garnered considerable attention and sparked vigorous debate in the marine industry [24].

Noise pollution is one of the newly emerging environmental issues associated with ships [26]. Globally, workplace noise is a widespread concern [25]. Environmental and occupational noise is a typical annoyance that negatively impacts employee health [19]. Noise exposure is one of the most prevalent occupational risk factors, and is connected with hearing loss, hypertension, heart-disease, irritability, and sleep difficulties. Hearing damage can be detected early, before irreversible hearing loss results from continued exposure [6]. Such impairment to the hearing system makes it difficult to communicate with the surrounding environment and comprehend the spoken communication of others, particularly in noisy surroundings. Consequently, it can potentially raise the risk of workplace accidents [1, 16, 17].

The Occupational Safety and Health Administration (OSHA) estimates that hearing loss disability costs \$242 million annually [28]. There are numerous sorts of noise on ships, including engine, ventilation, and compressor noise [22]. Few recent studies have revealed the noise levels of the ocean, with the majority concentrating on merchant and container ships [34].

Occupational noise affects the health of sailors [25]. Marine engineers remained the occupation with the highest incidence of Hearing Impairment [14]. High noise levels result in hearing loss and overall health problems, including genetic, physical, and psychological disorders that affect several systems, including the circulatory, digestive, endocrine, metabolic, and immune systems [2]. Hearing loss may have a negative impact on workplaces where correct communication between employees or knowledge of auditory warnings from equipment may be required to avert accidents that would otherwise result in harm and property damage [32].

The International Maritime Organization (IMO) framework for order to protect individuals against harmful noise pressure levels in vessels; the considered acceptable noise levels are 85 dBA in work environments, 75 dBA in the motor control room, 65 dBA in command and navigation space, and 60 dBA in common areas. According to this recommendation, the cumulative 24 h exposure limit cannot exceed 80 dB [6].

The present article aims to provide an updated review of the literature and evaluation of the evidence base that will compare occupational noise measurements on ships/boats/vessels, standards, and practices to tackle occupational ocean noise pollution.

2 Methodology

The present study followed PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement 2009 [15] to do a literature review of the published papers on occupational noise on boats/ships/vessels. The flowchart of the literature search process was depicted in Fig. 1. Based on the flowchart, the first step involved specifying keywords and the search's scope. This investigation retrieved relevant English-language studies by searching five databases: Scopus, Pubmed, Web of Science, Ebsco Host, and Science Direct. Several keywords were selected to be explored in these databases ("occupational noise") AND (ship OR boat OR vessel) AND (seafarers OR sailors OR "ships crew"). The search fields were limited to the paper's title and keywords. For this study, research conducted between 1987 and December 2022 were reviewed. The search returned 35, 305, 20, 21, and 20 articles for the searched keyword. Next, redundant results, editorials, conference papers, book reviews, and article critiques were eliminated. Then, through abstract reading and full-text scanning, irrelevant articles were excluded. Studies unrelated to occupational noise on ships were also eliminated. Finally, a total of 30 articles were selected to be included in this review paper, while 34 other articles were rejected. The authors did not review the 34 articles for various reasons, including the fact that the articles were reviews, comments, letters to the editor, or technical notes. In addition, it required additional access to reports and papers that did not correlate with the objectives of this study (noise measurements are not conducted on ships/ were shown in other industries and subjects other than seafarers).

3 Results

3.1 Noise Measuring

Table 1 shows 23 articles published between 1985 and 2022 examined ship noise. In addition to fishing vessels, naval vessels/warships, and ferryboats, there were also container ships. Even research was being conducted offshore on floating storage and offloading vessels (FSO). The analysis performed by the researchers to measure ship noise in the reviewed articles utilized two measuring devices: a Sound Level Meter (SLM) and a Noise Dosimeter. The two measuring instruments were also of different varieties.

There were a total of eight articles that explained noise measurements using an SLM, while seven articles utilized a Noise Dosimeter. In addition, eight reports stated that noise measurements used two devices, both SLM and Dosimeter. In general, the results of noise measurements above the Threshold Limit Value adhere to the limitation of regulation noise exposure on ships.

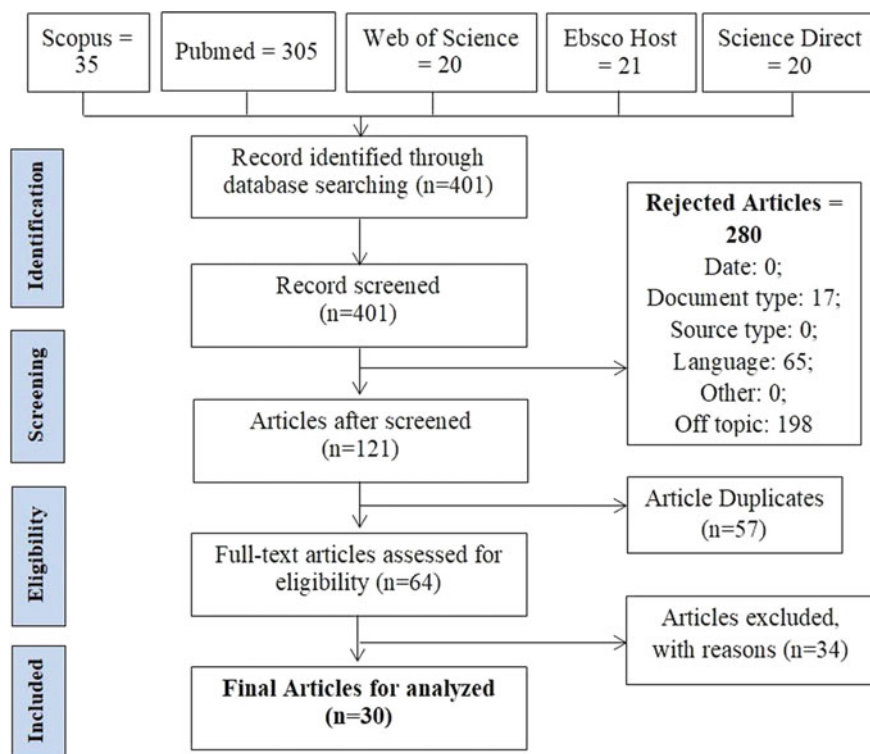


Fig. 1 PRISMA flow diagram

4 Noise Standards

According to Table 2, there were several institutions regulated a variety of noise threshold values for ships including, Occupational Safety and Health Administration (OSHA), US Coast Guard (USCG), National Institute for Occupational Safety and Health (NIOSH), American Conference of Governmental Industrial Hygienists (ACGIH), American Department of Defense (DoD), American Conference of Industrial Hygienists (ACGIH), the International Convention for the Safety of Life at Sea (SOLAS), World Health Organization (WHO), International Labour Organization (ILO), and International Maritime Organization (IMO).

In addition, there were also rules for limiting noise exposure regulated by countries in Europe, for example Directive 2003/10/EC of the European Parliament, The Norwegian Navy Standard Requirements and Regulations (NRAR), and The Great Britain Merchant Shipping and Fishing Vessels (Control of Noise at Work) Regulations 2007. The National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA), Australia's independent expert regulator for health and safety, and Canadian Center for Occupational Health and Safety (CCOHS) were

Table 1 Noise measurements

No.	Author	Location of noise measuring	Noise measurement tools	Measuring method	Results
1	[36]	The Shipbuilding (S) were 162 participants) and a Machine shop department (M) were 95 workers of the Dutch navy shipyard	Personal dosimeters type Genrad 1954 (specification ANSI SI 4-1971) and SLM (type Brühl and Kjaer 2204 and 2219)	Measure noise for 8 h	LAeq in S was 98 dBA (91–111, 30 shifts), whereas in M was 85.5 dBA (8291, 24 shifts)
2	[18]	US Fishing vessel Two large catcher/processor (C/P) with 220 workers	A Type I SLM (SVAN 912AE, Svantek, Warszawa, Poland) and Noise Dosimeters (Q-300, Quest Technologies, Inc., Oconomowoc, WI, USA)	24 h of measurements were conducted at 106 locations and 28 employees conducted personal noise measurements	The Avg, W level was 93.9 dBA, and 93% of the measured exceeded the OSHA 12 h exposure limit (87 dBA). The Leq, W was 95.3 dBA, and all work shifts exceeded the NIOSH 12h exposure limit (83 dBA)
3	[23]	Brazilian Fishing boat (141 male fisherman)	SLM (Bruel & Kjaer, model 2230) and A type 2 noise dosimeter (Bruel & Kjaer, model 4431)	The engineer held the SLM next to the employee's ear in the horizontal plane of the ear canal Four individual exposure measurements were the microphones clipped to the fishermen's lapels, near their ears	The results for vessels without a motor ranged from 38 to 58 dBA, whereas those with a motor ranged from 90 to 108 dBA. SLM measurements conducted in five distinct seating locations of the 9HP engine boat yielded results ranging between 86 and 105 dB
4	[19]	Ferryboat	SLM Brüel & Kjaer modular precise analyzer, model 2250	Five positions were outlined with the minimum measurement period duration was sixty seconds	Measurement results were 83.5 dB < noise exposure exceeded (max 85 dB). The peak sound pressure level was 120 dB < permissible value (137 dB)

(continued)

Table 1 (continued)

No.	Author	Location of noise measuring	Noise measurement tools	Measuring method	Results
5	[37]	Fishing vessels	SLM (Type 1200, Quest Technologies) and Personal dosimetry (Type 4428, Brüel & Kjær)	Twelve locations were selected (5 min measurement each location). Five crew members were chosen for personal dosimetry (full day of work)	The average daily noise exposure exceeded the NIOSH (>85 dB). Other crew members, however, were exposed to noise levels below the limit value (81.6–83.5 dBA to 8-h work)
6	[11]	Thai Naval Officers of Coastal Patrol Crafts	SLM (1/3 octave band real-time analyzer (RION NL-21)	Four common gunboats were chosen for noise measurements (the main deck, control room, engine room, and rest area)	In the engine room, the equivalent A-weighted noise level (LAeq) was 100.6 dB, while at other stations it was less than 85 dB
7	[34]	A four Royal Norwegian Navy Vessel	A Brüel and Kjaer SLM (Hand-held Analyzer Type 2250)	At each measurement location, measurements were taken for 15 s	All vessel classes, with the exception of coast guard vessels, exceeded the RNoN recommended noise level of >85dBA
8	[22]	UK Warship (Royal Navy vessel HMS Grimsby)	A SLM with high-pressure microphones (G.R.A.S. type 40BH and G.R.A.S. type 26AC preamplifiers)	During the survey, 850 rounds were fired in total. Four locations on the ship were used for measurements. Microphones equipped with foam windshields were positioned 1.5 m above the ship's deck and oriented at 90° to the Heavy Machine Gun's direct line of fire	The most significant peak sound pressure level assessed on the bridge wing was 160.7 dBC, while the highest peak evaluated on the bridge (port door) was 122.7 dBC. The bridge wing had the highest sound dose range at 127.8 dBA, while the bridge (starboard door) had the highest sound exposure level at 88.8 dBA

(continued)

Table 1 (continued)

No.	Author	Location of noise measuring	Noise measurement tools	Measuring method	Results
9	[9]	Royal Norwegian Navy (RNoN) vessels (24 navy vessels and 116 personnel)	Personal noise dosimeters (Brüel and Kjaer Type 4445 or 4448, Nærum, Denmark)	The cognitive performance of each participant was evaluated twice on the same day, with a minimum of 4 h in between. The noise dosimeter was attached to the participant's right shoulder until the conclusion of the test	The noise exposure was measured and divided into four groups for analysis: <72.6 dBA, 72.6–77.0 dBA, 77.1–85.2 dBA, and >85.2 dBA Individual noise exposure in the 4 h preceding the second test ranged from 67.2 to 99.1 dBA, with a median of 77.0 dBA
10	[13]	Fishing vessel at gulf Coast in Louisiana and Texas with 227 fisherman	SLM (ANSI S1.4-1983 R1997) and Quest Q-300 Type 2 dosimeters (meeting the requirements of ANSI S1.251991 and 4-1983)	On each vessel, dosimetry measurements were recorded for 30 min	Most of these fishermen worked longer than 16-h shifts for an extended period. In the engine rooms, noise levels between 94.8 and 105.0 dBA were measured to be hazardous
11	[33]	A total 21 Royal Norwegian Navy vessel (RNoN) = 72 sailors	Brüel and Kjaer Noise dosimeter Type 4445	A total of 83 sleep periods from 68 sailors were included in the analysis	There was considerable variation in noise exposure during sleep, with 17 of the sleep periods exceeding the maximum level recommended by applicable maritime regulations for cabin noise
12	[12]	Ship Recycling yard	SLM (Brüel Kjaer Hand Held Analyser Type 2250) and Noise Dosimeter (with the IEC 61,252:1993)	Several measurement strategies according to ISO 9612–2009: Task-based, job based, and full-day measurements	The results of this study indicated that all torch cutters exceeded the EU's Physical Agents (Noise) Directive's noise exposure limit values of 87 dBA and 140 dBC

(continued)

Table 1 (continued)

No.	Author	Location of noise measuring	Noise measurement tools	Measuring method	Results
13	[31]	US Navy Vessel (USS Ronald Reagan)	3MQuest NoisePro type II noise dosimeters (Quest Technologies, Oconomowoc, WI)	The monitored areas were separated into two categories: (1) leisure areas such as gyms, dining areas, chapels/ internet cafes, fantail social areas, and lounges; and (2) berthing (sleeping areas) for 24-h surveillance	The fantail social area had the highest Leq (flt ops), Leq (non-flt ops), and Leq(24-h), ranging from 97.7 to 105.4 dBA. In berthing (sleeping areas), the Leq(24-h) and Leq (flight ops) values ranged from 70.3 to 70.8 dBA. Similar to berthing, the lowest Leq (non-flight ops) ranged between 39 and 64.9 dBA
14	[30]	US Navy Vessel (USS Ronald Reagan)	3MQuest NoisePro type II noise dosimeters (Quest Technologies, Oconomowoc, WI)	After the 24-h monitoring period, proper dosimeter usage was confirmed	The majority of the employees exceeded the 24-h noise limit of 80 dBA. More than half of the participants exceeded the 85 dBA on-duty 8-h TWA noise limit, while the 70 dBA off-duty threshold was deemed effective quiet for TTS recovery
15	[29]	US Navy Vessel (USS Nimitzclass aircraft carrier, USS Harry S. Truman)	3 M™ SoundPro® DL and SE Type 1 SLMs with 1/1 octave band analyzers (Quest Technologies, Oconomowoc, WI, USA)	Random SLM was distributed across every layover area to demonstrate levels of noise	72% of all area Leq measured values surpassed the 70 dBA. All noise readings exceeded the threshold established by the WHO for the onset of sleep problems
16	[28]	US navy vessel (USS George Washington)	A 3 M Quest Technology NoisePro DLX (Oconomowoc, WI) or 3 M Quest Technology Edge eg5 (Oconomowoc, WI) personal noise dosimeter	Noise levels were measured as a Lavg/Leq for 24 h	Noise exposure levels surpassed the 80 dBA 24-h noise limit, the 83 dBA 12-h on-duty noise limit, and the 70 dBA 12-h off-duty threshold classified as effective quiet to allow for temporary threshold shift recovery as established by ACGIH

(continued)

Table 1 (continued)

No.	Author	Location of noise measuring	Noise measurement tools	Measuring method	Results
17	[21]	Container ship in Germany (104 sailors from six container ship (4 small container and 2 large container ships)	A Sound Dosimeter (Type 4445 (class 2) from Bruel & Kjaer, Nærum, Denmark, and SLM (type 2250 (class 1) from Bruel & Kjaer	Throughout multiple sailing episodes, the noise levels in the following working/living areas were evaluated (2 min measurement period)	The engine room had the highest noise level, with up to 110 dB. During the harbor stay, the most significant areas were the engine room (average 104 dBA; range 99–108 dBA) and the engine control room (average 68 dBA) (range 56–74 dBA)
18	[2]	Fishing vessels (466 Brazilian from 15 vessels)	The SPL assessment phase in the vessels (SLM Bruel & Kjaer 2230), and selected fisherman on board of each vessel for hearing evaluation phase with dosimeter measurements (Bruel & Kjaer 4431)	The SPL measurements were taken at sea, during regular work and rest activities, and before setting sail. The noise dosimetry measurements were taken during the catch operations, fish selection, ice storage, meal times, rest periods, and the return of the fishing vessel	The compartment with the highest SPL was the engine room, where the ship's captain works. According to Brazilian law and its technical regulations, as well as those of other nations, the results of this study demonstrated that the noise exposure tolerance limits were excessive
19	[25]	Two Romanian Ferryboat	The Blue Solo 01 dB SLM, according to IEC 61,672-1:2002	The measurement were daily noise exposure, exposure points (job/task) and exposure points per hour with three scenarios: ship started from shore, a boat running and mooring maneuver, and the generator idle (in the engine and command rooms)	The noise level in the engine room exceeded 90–100 dB, while the noise level in the control cabin was 75–80 dB

(continued)

Table 1 (continued)

No.	Author	Location of noise measuring	Noise measurement tools	Measuring method	Results
20	[3]	11 Canadian fishing vessel	Brüel & Kjær Type 4448 personal noise dosimeters	The harvesters wore noise dosimeters on their most exposed shoulder to perform personal noise dosimetry throughout the fishing trip	The presented data emphasized the risk of hazardous noise exposure (noise exposure levels LEX;8 h above 85 dBA) for personnel of vessels in the second group, particularly crew members
21	[4]	Canadian Fishing vessel with a length of 19.81 m	SLM was used to measure the sound pressure levels (a Class 1 PCB Piezotronic mod. 378B02 ICP)	Noise measurements during sea trials and while the ship was docked. SPL was recorded at multiple deck locations	LAeq (T) in the Corridor (81.3 dBA) and in the Mess room (74.5 dBA) were above the IMO maximum acceptable level of 65 dBA
22	[27]	Floating storage and offloading vessels (FSO) at UK sector on North Sea and FSO located offshore Australia	A Bruel & Kjaer type 2270 SLM	Measurements were conducted for a minimum of 30 s, but longer times were used when the noise was variable	Noise exposure in cabins fluctuated between 42 and 49 dBA (>NOPSEMA guideline recommendation of 40 dBA). The average noise levels at the operator's ears ranged from 90 to 101 dBA. This indicated that damage of unprotected ears to 101 dBA was limited to 12 min per 8-h shift in order to prevent exceeding the 85 dBA exposure limit
23	[5]	Canadian Fishing vessel (36 fish harvesters working on 12 small fishing vessels)	Brüel & Kjær Type 4448 personal noise dosimeters	The samples were obtained by randomly extracting twenty 15-min-long noise level measurements from the dosimeter logs	The results indicated that LA exceeded 85 dBA during travel to and from the fishing grounds, putting fish harvesters at risk during this task

Table 2 Noise standards

No.	Author	Noise Standards
1	[18]	The noise threshold values for 8 h, 12 h, and 24 h are as follows: OSHA (90, 87, 82 dBA), USCG(90, 87, 82 dBA), NIOSH (85, 83, 80 dBA), and IMO(85, 83, 80 dBA)
2	[37]	NIOSH suggests of 85 dBA for an 8-h work shift. On board ships, the IMO recommends the same criterion
3	[34]	The NRAR noise levels above 80 dBA are deemed excessive; above 85 dBA, hearing protection devices (HPD) are required, and above 115 dBA, a 10-min maximum stay is allowed (for inspection)
4	[22]	The Merchant Shipping and Fishing Vessels (Control of Noise at Work) Regulations 2007 rules from Great Britain recommend exposure limit values are: a daily or weekly LEP, $w = 87\text{dBA}$, and the peak sound pressure level is $\text{LC}_{\text{peak}} = 140\text{ dBA}$
5	[30]	ACGIH and IMO indicate when workers are restricted for the TLVs, including 85 dBA for 8 h, 82 dBA for 16 h, and 80 dBA for 24 h As a time-weighted average over 8 h, the Department of Defense (DoD) OEL is 85 dBA (TWA) The 24-h equivalent continuous noise level (Leq) recommended by the World Health Organization is 70 dB The OSHA permissible exposure limit (PEL) is a time-weighted average of 90 dB over 8 h (TWA). The implementation of HCP is required when 8-h TWAs exceed 85 dBA
6	[21]	The SOLAS, 1974, The Code on Noise Levels On Board Ships (MSC 91, from 2012) adopted a new SOLAS regulation II -1/ 3–12 mandating that seafarers are not subjected to a Lex (24 h) greater than 80 dBA. No crew member should be unprotected when peak noise levels exceed 135 dB
7	[2]	The ACGIH establishes a daily noise exposure limit of 80 dBA, and the IMO regulations applicable to vessels state that 24 -h equivalent noise exposure levels cannot exceed 80 dBA
8	[25]	The European Parliament and the Council (Directive (EU) 2016/1629) follows exposure limit values: LEX, 8 h = 87dBA
9	[5]	The requirements for dangerous noise exposure 2012; Canadian Center for Occupational Health and Safety (CCOHS): $\text{LEX}, 8h \leq 85\text{ dB(A)}$ —continuous noise; and $\text{LC}, \leq 140\text{ dBC}$ —impulsive noise American Conference of Industrial Hygienists (ACGIH) establishes 85 dBA as the threshold for occupational noise exposure as a regulatory standard for the prevention of noise-induced hearing loss (NIHL)

(continued)

Table 2 (continued)

No.	Author	Noise Standards
10	[27]	The exposure standard specified in Control of Noise at Work Regulations (2005) based on European Union Directive 2003/10/EC (2003) and NOPSEMA Regulations (2006) is 85 dBA averaged over 8 h for noise exposure (LAeq,8 h) or 140 dBC for peak noise (LCpeak)
11	[8]	The IMO standard to protect individuals from harmful noise pressure levels aboard ships sets the permissible noise exposure at 85 dBA in work environments, 75 dBA in the engine control room, 65 dBA in command and navigation space, and 60 dBA in rest rooms. According to this standard, the 24-h cumulative exposure limit cannot exceed 80 dBA
12	[14]	The international regulations on noise levels on board ships (IMO Resolution A 468 XII of 1981) exposure limit should not exceed 85 dBA per 24 h and maximum 110 dBC

other international organizations discussing noise exposure. The standards stipulated that the noise level during eight work hours would not exceed 85 dB.

4.1 Noise Control Recommendation

The review results based on Table 3 revealed that, there were five noise control stages: elimination, substitution, engineering, administrative, and the use of personal protective equipment (PPE) (ear plugs or muffs). Other hearing protection that could be carry out included conducting medical examinations regularly (including ear examinations), retirement or job changes, and making modifications on PPE. Apart from PPE, improvements may be made to lower noise intensity, and it is also employed as a way of communication between workers. As an evaluation of the impact of noise, hearing loss research could be conducted in great detail.

5 Discussion

5.1 Noise Measuring

The Sound Level Meter (SLM) and the Personal Noise Dosimeter are two instruments that can be used to measure noise. The SLM is a device used to measure noise in the overall location/work area, whereas the dosimeter measures the noise exposure received by each worker. SLM is placed in the land surrounding the office, and positions were selected to provide comprehensive coverage of noise sources

Table 3 Noise control recommendation

No.	Author	Study area	Noise control recommendation
1	[18]	US fishing vessel	Infrastructure improvements (engineering or administrative noise controls or increasing the use of ear defenders during work shifts)
2	[23]	Brazilian fishing boat	The diffusion of information on the control of noise emissions from ship engines, audiometric care, and hearing loss prevention services
3	[19]	Ferryboat	Installing another type of reflective muffler on the ferry's propulsion system, performing periodic physical checks (every six months), using wireless communication sets, and wearing earplugs or muffs
4	[37]	Fishing vessel at Egypt	Replacing the engine, use of sound-absorbing materials in the engine room and silencers in the exhaust stack, and machine enclosure/isolation, noise monitoring, a safety training program, job rotation, periodic medical exams, audiometry test, and utilize earplugs or muffs
5	[34]	Norwegian navy vessel	Applying NIOSH recommendations
6	[11]	Thailand navy vessel	Utilizing hearing protection
7	[10]	Norwegian Navy vessel	Noise assessments and a hearing conservation intervention must be created
8	[22]	UK navy vessel	A type of hearing protection would be required for the weapon's operator
9	[9]	Norwegian navy vessel	Noise-reduction (e.g., attenuation of noise sources, correct and increased use of HPD) and performance-shaping measures should be considered by the government (e.g., training, task organization, and improved bridge systems)
10	[13]	Fishing vessel	Engineering (sound-dampening engine mounts, engine enclosures, sound curtains, and maintenance/lubrication of machine), administrative (regulations limit engine room time and increase the distance between the crew and the source of noise), and wear earplugs or muffs
11	[12]	Ship recycling yard	Creating low-cost, realistic technical controls and sufficient, usable hearing protection systems also requires innovation
12	[30]	US Navy vessel	Engineering (sound-absorbing walls and ceilings, dividers, and acoustic panels throughout the ship) administrative measures (reduction of work shifts to 8 h, would provide an opportunity to limit personal noise exposure and facilitate auditory recovery), PPE, including double sound insulation
13	[29]	US Navy vessel	Improving quality of life, boosting operational performance, ship design and noise control measures

(continued)

Table 3 (continued)

No.	Author	Study area	Noise control recommendation
14	[2]	Brazilian fishing vessels	Annual audiometric testing, wearing earplugs, and noise levels should be limited, particularly in sleeping areas, to enhance the crew's quality of rest
15	[7]	The Greek navy ship's	Implementing hearing conservation programs, and using preventative measures
16	[25]	Romanian Ferryboats	The use of sound-absorbing materials or to invest in the purchase of new ships
17	[5]	Canadian fishing vessels	The use of appropriate hearing safety devices, the creation of feasible solutions to reduce damaging noise levels on current and future vessels; and the development and implementation of programs
18	[27]	Floating storage and offloading vessels (FSO) at UK	Isolating workers, utilizing a quieter process or activity devoid of vibroacoustic impacts, such as an alternative surface preparation technique, and altering the timing of the action to reduce exposure
19	[8]	Iranian speed vessel	Utilizing highly effective sound-absorbing materials with sound insulation and absorption materials. Examining based on hearing ability and age. Personnel assigned to these vessels are eligible for retirement or an early job change

and locations where noise-exposed workers frequently positioned themselves. The dosimeters' microphones are placed on the shoulders of subjects and shielded with windscreens (near the ear) [18]. Although the two measuring instruments are distinct, the measurement outcomes are comparable. Levin et al. [13] found that using the SLM resulted in engine room noise levels ranging from 95.1 to 102.5 dBA, whereas utilizing the dosimeter resulted in noise levels ranging from 94.8 to 105.0 dBA [13]. In the study of [2], however, the results of noise measurements with the SLM and Dosimeter differed by ± 10 dBA. With SLM, the noise level ranged between 99.5 and 107 dBA, whereas the dosimeter ranges between 89.8 and 92.6 dBA [2].

Paini et al. [23] measured the noise levels of small-scale fishing vessels powered by 9-18 horsepower (HP) engines and operated by one or two fishermen. The results of sound level measurements for ships without an engine ranged between 38 and 58 dB and 90 and 108 dB for vessels with an engine. Additional area sound level measurements conducted in five different seating locations in the 9HP engine boat ranged from 86 to 105 dBA [23]. In the study by [37], noise levels on fishing vessels were measured using the SLM tool and ranged from 84.7 to 93.5 dBA. Considering the 45-300 HP engines used in the machines is surprising. The noise levels were lower than those of [23] because the ship's surface area was larger (10–25 m in length), so the noise was reduced. Dosimeter measurements from personnel ranged from 81.6 to 83.5 dB. Although these exposure levels were lower than the NIOSH recommended thresholds, the NIHL should not be ruled out as a risk to the health of the average crew for many factors [37].

The results of noise measurements conducted on warships in various nations are also diverse. Even though the results are dissimilar, the noise level is above the set threshold according to the established rules. Therefore, workers on navy/warship vessels are also susceptible to hearing loss [11]. The engine room on each ship is the noisiest location. As with container ships, the noise intensity is 104 dBA [21], 90–100 dBA on ferryboats [25], and 90–100 dBA on Floating Storage and Offloading vessels (FSO) [27].

Shipyards are another industry related to noise on ships. At the shipyard, ships are manufactured, repaired, and recycled. The noise exposure (LAeq) in Shipbuilding was 98 dB, while in the Machine shop it was 85.5 dB [36]. According to research published at the ship recycling yard, the employees are at risk for work related noise-induced hearing loss due to their prolonged exposure to hazardous sound levels. This research discussed that those who utilized torch-cutting equipment were particularly vulnerable. Additionally, the study demonstrated that ship recycling yards need to implement more appropriate hearing protection measures [12].

Most of the reported research on the assessment of noise exposure of fish harvesters utilized the task-based measurement (TBM) method, where sound levels are monitored time spent in each work position [3, 34, 37]. Alternatively, full-day measurement (FDM) can be used to determine the average daytime sound levels. Harvesters wear personal noise dosimeters during normal fishing activities and workdays to monitor noise levels [13, 23]. The third method for assessing noise exposure is the job-based method (JBM), which identifies jobs as the total occupational activity a worker performs throughout the workday. Each position's exposure level was extrapolated from a random sample of noise measurements taken throughout the working day [5]. The Maritime Safety Committee of the International Maritime Organization (IMO), the foremost international body regulating safety at sea, recommends using International Organization for Standardization (ISO) 9612 methods for exposure assessment. Additionally, the IMO outlines a simplified IMO (sIMO) method for determining the noise levels of crews, using noise exposure measured in various ship spaces during shipping and threshold levels. This code is not applicable to small boats but is used to evaluate noise exposure on larger commercial vessels [35].

5.2 Noise Standards

A globally recognized official institution establishes the noise standards, including NIOSH, OSHA, WHO and ILO. However, noise on ships is specifically regulated by SOLAS and IMO. The noise exposure limit for 8 h of work is 85 dB. This applies to all types of employment, not just maritime employment. Most of the articles reviewed based on Table 2 indicate that for 8 h of work, the permissible threshold value cannot exceed 85 dBA. Nonetheless, according to the European Parliament and the Council, the 8 h threshold value is 87 dB [25]. The peak sound pressure level is L_{cpeak} 140 dBC according to UK regulations [22], NOPSEMA (Australia's regulator for health and safety) [27], and Canadian framework [5]. However, International Convention

for the Safety of Life at Sea (SOLAS) mentions a different reference for L_{cpeak} , namely 135 dBC [21].

Neitzel et al. [18] cite specific rules governing noise limits for ship workers in their research (especially on fishing vessels). The four laws include three directives from the United States government and one rule from the IMO. Classification of working time begins with 8 h, 12 h, and 24 h. OSHA and USCG state that for each of these noise exposures sequentially, it does not exceed 90 dBA, 87 dBA, and 82 dBA, whereas NIOSH and IMO state that for each type of noise exposure, it does not exceed 85 dBA, 83 dBA, and 80 dBA [18]. The ACGIH, CCOHS, and SOLAS also recommends a 24 h noise exposure limit of 80 dB [5, 21, 30].

Additionally, research conducted by [8] explained in detail the ship's room noise limits. According to the IMO standard to protect individuals from harmful noise pressure levels in vessels, the permissible noise exposure is equal to 85 dBA in work environments, approximately 75 dBA in the engine control room, 65 dBA in control and navigation space, and about 60 dBA in laying down rooms [8]. The IMO regulations are 5 dB louder than the Norwegian regulations (NRAR). The NRAR even specifies the threshold value for other shipboard rooms. Including medical center rooms with a maximum of 60 dBA, offices with a maximum of 65 dBA, galleys with a maximum of 75 dBA, and engine rooms with a maximum of 110 dBA [34].

Multiple studies have shown seafarers suffer various health problems, including hearing impairments [37]. Hearing problems include tinnitus, noise induced hearing loss (NIHL), and conductive sensorineural hearing loss [18]. In addition, noise exposure has been associated with increased accident risk [34]. In the NRAR, noise levels above 80 dBA are considered high: above 85 dBA, the use of hearing protection devices (HPD) is required, and above 115 dBA, a 10 min maximum inspection period is permitted. The NRAR does not include additional noise exposure guidelines for individuals [33].

5.3 Noise Control Recommendation

Noise control can initially be accomplished through elimination. In most situations, it is preferable to eliminate the noise source [20]. However, this is impossible due to the noise being generated by the ship's primary component, the propulsion engine. Without the machine, the vessel cannot move on its own. As shown in Table 2, there were no articles that discussed eliminating noise on ships as a means of mitigation. When elimination is impractical, replacing loud equipment with quieter material may be the most effective way to protect workers from hazardous noise [8, 27, 37]. It is possible to replace the engine that is causing the noise with a new machine that is less noisy. Several factors must be considered, including cost and efficiency. Purchasing a new machine will incur additional fees and possibly expensive maintenance costs [27]. In addition, adjustments are necessary because the new device may require special care, particularly during maintenance. However, replacing the engine with

one that produces less noise is one effective method, even make an investment by buying a new, better ship [25].

Implementing engineering controls to prevent worker exposure to 8 h TWA excessive noise levels of 85 dB or higher is the next step. Engineering controls involve alterations to the physical work environment, such as the modification of equipment to remove noise sources and the installation of noise-blocking barriers [20]. Typically, the Noise Hazard is controlled by isolating workers from the hazard and erecting a noise-blocking barrier [18, 27, 37]. Installation of an additional reflective type of muffler on the power system of the ferryboat [19], installation of soundproofing materials in the engine room [8, 25, 29, 30, 37], and periodic machine maintenance are all possible engineering tasks [13].

The subsequent step is administrative control. Administrative is a control that can be implemented through non-technical means, such as conducting medical examinations and periodically evaluate hearing loss at work by measuring the ears [2, 8, 19]. Involving ship workers in various pieces of training about workplace hazards, particularly noise hazards [9], limiting working time in the engine room, and rotating workers' jobs could be done [13, 27, 30].

Using ear protection is the final precaution that can be taken (ear plugs or muffs). The use of PPE has been described in nearly all articles the author has reviewed. Interestingly, ear protection is used both to reduce exposure to noise entering the ear canal and as a means of communication between workers [19]. This is a recommendation for implementation. If this is accomplished, it will be possible to resolve the issues that have arisen for workers who find it difficult to communicate with their coworkers and who rely solely on sign language.

6 Conclusions

This study concludes that the author-reviewed article measures noise on ships, including fishing vessels, ferryboats, navy vessels, container ships, and floating storage and offloading vessels (FSO). In addition, shipyards where ships are constructed, repaired, and recycled are evaluated to supplement the data. The engine room is the location on board each vessel where the highest noise levels are measured. A Sound Level Meter (to measure noise around workers) and a Dosimeter (to measure noise exposure received by workers) are the two primary noise measurement tools. The available noise measurement techniques are based on task based measurement (TBM), full-day measurement (FDM), and the job-based method (JBM). The simplified IMO (sIMO) method recommended by ISO 9612 can also be utilized to measure noise levels on larger commercial vessels.

It provides recommendations for noise control efforts based on the National Institute for Occupational Safety and Health (NIOSH) and International Maritime Organization (IMO) regulations, including elimination, substitution, engineering, administration, and ear protection. The implementation of noise control innovations begins with an engineering control. In addition to noise detection, installing a

sensor connected to the machine is necessary to make it easier/automated to determine if the engine has been damaged without manually inspecting it. Administrative controls are implemented by producing occupational safety and health videos, applications for reporting workplace hazards, and simulations for new employees. Hearing Protection Devices (HPDs) are a tool for minimizing noise and improving worker communication.

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Visual Fatigue from Occupational Environment: A Review Study



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Abstract Visual fatigue occurs from different causes, and this problem is also related to personal, environmental, task, and device factors. Therefore, this research aimed to review the literature on visual fatigue in work environments with an emphasis on ergonomics, safety, and occupational health. The methodology consisted of searching for scientific articles in the Scopus, Science Direct, Web of Science, and PubMed databases using six combinations of keywords. Inclusion criteria considered complete articles from scientific journals in English, Spanish, and Portuguese published between 2011 and 2021. A total of 1385 references were found, of which 10 were chosen as suitable for inclusion in the research according to the selection criteria. The results indicate that chemical factors, the use of electronic devices, and staying in environments with poor lighting and ventilation are causes of visual fatigue. It is concluded that environmental, personal, task, and equipment factors influence visual fatigue, with the most identified in the studies being those related to the excess or overload of visual demand, the lack or low frequency of breaks during the workday, and the lack of measures application in occupational environments that reduce the occurrence of visual fatigue.

Keywords Asthenopia · Electronic devices · Occupational health · Work environment · Ergonomics

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1 Introduction

Visual fatigue, also known as asthenopia and eyestrain, is a condition consisting of symptoms that usually occur after excessive vision performance that cause exhaustion of the ciliary muscles of the eye by exposure of the cornea in the action of focusing, also decreasing the rate of eye blinking due to mental concentration, which can cause dry eyes [20]. It can be manifested in different ways, such as: feeling tired, sensitivity to light, irritation/burning in the eyes, redness, excessive tearing, blurred vision, double vision, and especially headaches [1, 16]. This condition often has its causes and can be manifested in the occupational environment for several reasons, including excessive use of screens, workers' contact with physical-chemical materials, environmental factors such as poor lighting or even excessive and disqualified use of vision in addition to possible personal factors. Eyestrain has been increasingly in occupational context and in our lives as the progress and access of computers and smartphones is growing up [9].

The effects of visual fatigue can include various harms in the professional activity, such as visual complications, stress, reduced quality, slowness in carrying out work activities and loss of productivity [8]. This problem can cause incidents or accidents in occupational environments, harming the safety and health of workers, being important to identify the causes of visual fatigue to adopt measures to prevent its as much as possible [6].

To justify and contextualize this research, was started from the fact that ergonomics allows us to identify work situations that potentially generate occupational problems due to improper accommodations, and by the conditions analysis, allow to elaborate practices and techniques that result in the improved adaptation of people to occupational environments and work. Thus, in view of the ergonomics approach to vision, it is possible to act with the aim of adapting the occupational environment and the work design to comfort and well-being of people, in the same way as developing actions that reduce the risks of pathologies and problems arising from tasks that require visual effort.

Currently, many activities are carried out on electronic devices, increasing the time spent in front of screens, which has recently been intensified by the COVID19 pandemic [2]. In some more recent studies, visual fatigue is identified as induced effects of the use of virtual reality [5, 18], effects of the use of digital work environments [7], influenced by software interface design [22], as well as a phenomenon in visual communication design integrated with artificial intelligence [19], among others. Despite these trends pointed out in the literature, this research focused on visual fatigue in the occupational field.

To carry out this review, the research was based on the following question: "what does the scientific literature present about visual fatigue in the occupational context?" to raise an overview with the main factors that allow a better understanding of this problem.

Thus, the review was limited to the theme of visual fatigue in work environments, but references about the activity of reading were also included because they are

more frequent nowadays in the work activities of professionals such as teachers, researchers, journalists, office workers, among others. In addition, were included references about visual fatigue in unacceptable work contexts, such as child labour, for example, due to the relevance of the results presented in the studies, although this does not mean support for this form of work. On the other hand, it is known that any form of child labour must be curbed, and that child labour is considered unacceptable by the United Nations in the 2030 Agenda for Sustainable Development, in the target 8.7 which proposes the eradication of all forms of child labour [12].

Therefore, the objective of this research was to make an overview of the literature on visual fatigue from work environments with emphasis on ergonomic aspects and occupational safety and health, with the aim of discussing the subject, highlighting the main causes, consequences and indicating corrective measures that can mitigate the visual fatigue.

2 Methodology

To carry out this research, the literature review technique was used, inspired in the extension for scope reviews of the PRISMA statement adapted by the authors because it is an initial study focused on visual fatigue in occupational environments.

The methodology consisted of searching for scientific articles in the following databases: Scopus, Science Direct, Web of Science, and PubMed. Six combinations of keywords were used to the identification of references: “fatigue AND vision”; “vision AND workload”; “fatigue AND workload”; “eyestrain AND work”; “eyestrain”; “vision AND occupational”.

In the identification stage of the references in the databases, the keywords were placed in combination and filters were used for the selection of works according to the selected screening requirements, namely: the selection of references only in full articles of indexed scientific journals; published in Portuguese, English and Spanish; in the period between the years 2011 and 2021. The research was carried out in 2021 and it was chosen a period of ten years due to the increase in the use of information technologies and the expansion of home office and telework modes that was intensified in the climax of the COVID-19 pandemic.

The search results were recorded in electronic spreadsheets, highlighting their respective titles, authors, journals, year, and country of the publication researchers’ institutions. In the electronic spreadsheets, the titles of the references were arranged in alphabetical order to facilitate the next step, which was the exclusion of duplicate references. As several works were found in more than one database, they were classified as repeated, and duplicity was excluded.

The next step was the analysis of references by their titles and abstracts to exclude those that were outside the research topic. Then, the complete articles from scientific journals that met all other criteria were analysed and studied.

The snowball search process was not carried out, but this option is considered for the continuation of this research.

3 Results and Discussion

As a result of the search, 1,385 references were found, of which ten were chosen as suitable for inclusion in the research according to the selection criteria. The research steps and the numerical registration of identification, screening, exclusion, and inclusion, highlighting the methodological aspects and main contributions to this review, are represented in the flow diagram in Fig. 1.

Information about the articles included in the review are presented on Table 1.

It is observed that there was no relevant pattern of predominance about the years, journals, and countries of publication of the articles included. Regarding the year of publication, three articles were published in 2019 and one article in each of the following years 2011, 2013, 2014, 2017, 2018, 2020 and 2021. About the country of association of the article's authors, three articles are from the United States of America, two from South Korea, two India, one Saudi Arabia, one from Australia, and one from Sweden.

All articles were found in English-language databases. Eligible articles were research about asthenopia in work environments, conducting studies on real situations and works; and articles about eyestrain causes and consequences that imply and interfere with human well-being and performance in occupational environments. One of the articles included is a review article.

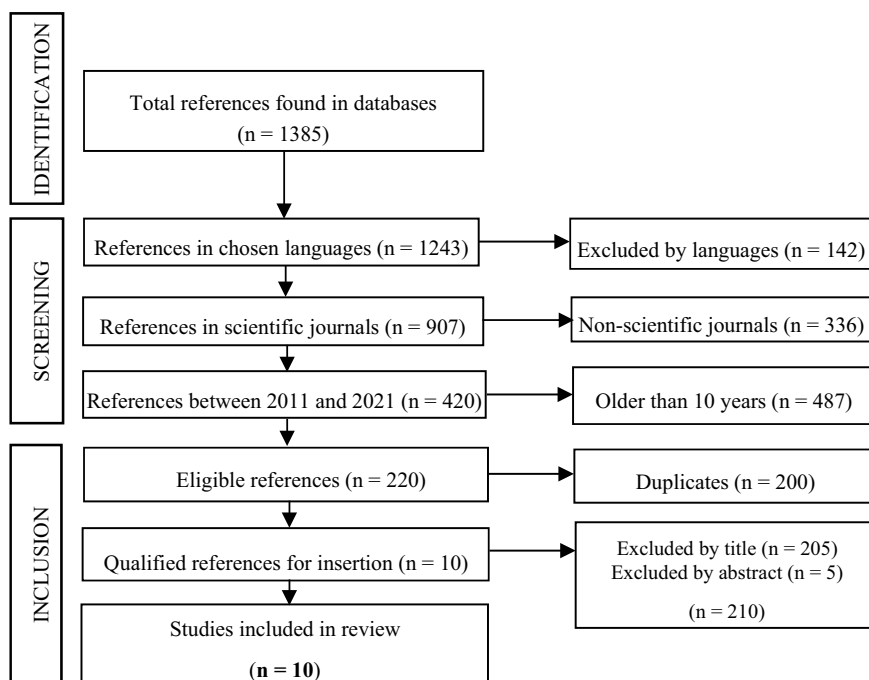


Fig. 1 Flow diagram from the stages of the review

Table 1 Characterization of articles and main contribution to this research

Authors	Kind of work/ task	Sample	Data treatment	Main contribution to this review
[16]	Employed, students, homemaker, retired	97 respondents (88 Male; 9 Female) Age ≥ 18 y	Multivariable logistic regression analysis	The COVID-19 pandemic-increased eyestrain symptoms
[1]	Radiologists	198 (111 men and 87 women). Age: (30y > years old ≥ 60 y)	Chi-square tests and logistic regression analysis	Female radiologist and lack of frequent breaks were associated with higher rates of eyestrain
[6]	Construction workers	1.945 (Male: 1.856, and Female: 89) Ages: (39y > years old > 60y)	Chi-square test, multivariable logistic regression analysis	Associated to exposition of vibration, smoke, mist, dust, others fume, and organic solvents
[13]	Reading	24 subjects (7 males, 17 females). Ages (22y –27y), mean $= 24.3y \pm 1.01y$)	Analysis of variance testing (using the Tukey test.)	They concluded there was little evidence at that time to support the use of Blue Blocking filters to minimize asthenopia
[14]	Reading	50 college students. Mean age $\pm$ SD = 22.3 ± 1.6	Analysis of variance, Tukey's test, Pearson correlation. Regression analysis	Visual fatigue may be described as function of reading speed, visual discomfort, blinking duration, and frequency
[11]	Nurse	24 references cited	Not applicable	Interventions can reduce eyestrain
[10]	Reading	18 (age: 21.5 ± 3.3 years, range 18–29 years, Male and 6 Female)	Wilcoxon test, and Friedman test, and Spearman correlation	Viewing distance is associated with eyestrain and is aggravated by smartphone using
[4]	Postmen	18 participants: 17 Male and 1 Female. $26y < \text{age} < 62y$, mean = 47	Non-parametric Wilcoxon matched pairs signed-ranks test	Eyestrain may be associated with musculoskeletal discomfort
[20]	Footwear industry	139 exposed and 160 comparison group subjects	Uniand multivariate analysis; descriptive analysis. Chi-square test	Eyestrain was associated with exposition to chemical substance, workplace, personal factors
[21]	Gem-polishing industries	Exposed group: 432 worker children (<18y); compared group: 569 nonworker children	Uniand multivariate analysis; descriptive analysis. Chi-square test	Eyestrain was associated with age and female sex, expositions to chemical substances, environmental and personal factors

Three of the studies performed experiments aiming to compare groups of people under different conditions. Five works were carried out using self-reported questionnaires of symptoms of visual fatigue, among them two articles used point scales to assess the occurrences of asthenopia. Another article was a literature review about the computational syndrome and the respective implications for the occupational health of nurses and the last article was already done applying interventions within the work environment and describing the differences perceived by the workers.

The self-report used as a research method in 5 articles [4, 10, 13, 20, 21] may provide results with some limitations, as these symptoms have not been identified by specialists or by robust statistical methods, and which may consider effects of other conditions, for example habits practiced outside the work environment and/or pre-existing personal problems.

The chi-square test and regression analysis methodologies were the most used to assess the occurrence of the probability that visual fatigue happens randomly and to compare variables of possible homogeneity [1, 6, 20, 21]. Non-parametric tests [4, 10], correlation tests [10, 14], multivariate logistic regression analysis [1, 6, 16], analysis of variance and test of means [13, 14], were also used.

The occupations and activities studied in the researches were diverse, such as: construction workers, industries (shoes and stone polishing), health workers (nurses and radiologists), self-employed professionals, students, housewives, retirees, postmen and readers.

3.1 Leading Causes of Visual Fatigue

The research results showed that the main causes of asthenopia in the occupational environment are excessive exposure to electronic devices, contact with physical-chemical substances and work environments with poor lighting and ventilation. About the physical-chemical factors the authors highlighted that workers who have contact with chemical substances may experience visual fatigue due to exposure to vapors of organic solvents that emanate from adhesive solutions and when in contact with the eyes they may result in irritation, tearing, itching and other symptoms. As [20] points out in his study about children workers at an India shoes manufacturing: after carrying out an analysis survey, comparing them with children who had never worked, those who were studied had a higher percentage of self-reports of asthenopia symptoms, which indicates the possibility of a relationship between contact with substances from that work activity and visual fatigue, which may evolve and extend into adulthood, anticipating other ocular problems.

Jung et al. [6] presented that the construction workers more exposed to chemical agents, noise and vibrations in closed areas reported more complaints of symptoms of eye fatigue. These authors also highlight other factors such as active and passive smoking, which is very common in civil construction work environments, which can have a significant influence on the research results, together with exposure to physical-chemical factors of eyestrain.

Continuous exposure to electronic devices is also one of the main causes of visual fatigue and tends to increase, because with the development of technology, most workplaces make use of these tools that cause a great difference in human life, but which can also have negative effects on health, especially on vision. Continuous visual focus slows down the worker's blink rate, leaving the eyes increasingly dry from concentrating on the task. This was increased during the period of the COVID19 pandemic to many occupations that used devices less frequently and began to use them more, increasing the incidence of visual fatigue in an occupational context [7].

During the COVID-19 pandemic, there was a significant increase in telemedicine for several professionals, including radiologists, increasing the use of electronic devices and the screen time of these workers. As stated by [16] the pandemic was a fact that negatively impacted the visual function of several people, especially those who already suffered from the dry eye condition, which causes the worsening of symptoms already related to eye fatigue.

Long et al. [10] aimed to analyse visual fatigue, observed the behavior of some readers after going through a period of reading for 60 min on an electronic device, concluding that the scores indicated a significant increase in tired eyes and vision blurring, which it may also be linked to poor accommodation, the size of the font type, and the distance between the eyes and the device.

Park et al. [14] in their study examined the effects of screen curvature and task duration on computers to assess the negative effects from an ergonomic point of view. For this, they used scales from 0 to 7 to consider visual fatigue of readers. Considering as variable the reading speed and the blinking frequency, it was noticed that visual discomfort increased as users were exposed to screens longer.

The computer vision syndrome is a phenomenon that causes the worsening of the visual health of individuals, impacting concentration, which may have consequences on other aspects such as productivity, efficiency, and safety of workers. This syndrome tends to increase in frequency due to contemporary technological advances and trends in new work configurations [3] that will facilitate the activities of some professionals mainly or exclusively through remote work, which will contribute to the increase in professionals' screen time. In addition to the injury caused by the reduction in blinking when using computers and smartphones, the problem is also linked to the heat generated by such electronics by non-ionizing radiation and the increased exposure to short-wavelength light [17].

In addition to excessive use of computers, laptops, tablets and smartphones, there are factors external to the individual, such as: poor lighting, ventilation and improper accommodation adopted by workers that may be linked to or even increase the reported symptoms.

In addition, Lurati [11] presents in his study that there are postural demands, including the static demand of the muscles that contribute to increased eye fatigue, which may be directly related to the manifestation of asthenopia symptoms in workers.

In general, all articles included in this review highlight manifestations related to visual fatigue in the work environment, environmental factors that influence visual fatigue, and present suggestions for reducing impacts on workers' health. Based

on the studies, it is possible to state that generally the factors are associated with work overload, lack of breaks, lack of frequent and periodic rest during the working day and lack of measures within the occupational environments that reduce the condition of visual fatigue. The results show that asthenopia often is more manifested in older people, usually those who have worked longer with exposure to unfavorable environments and conditions. In addition, the results indicate that visual fatigue appears more frequently in female workers, but no study was found that proves the prevalence of symptoms related to gender.

3.2 Consequences and Health Issues of Visual Fatigue

Tiwari et al. [21] observed that children who worked in gem polishing industries, compared with children who did not work, were at greater risk of developing eye fatigue.

In the two case studies children worked for long hours in closed places with poor lighting and poor ventilation, which worsens the situation [20, 21]. Complaints of symptoms were manifested in older children and in those who had been working for a longer time, because with the cumulative condition, the phenomenon was intensified. Such prolonged exposure can harm children for life, affecting both their personal and professional dimensions, reflecting on the productivity of this future professional in their adult phase. Therefore, it is important to highlight that these articles show evidence of a relationship between the contact of chemical substances and asthenopia.

In the study of [6] when performing a survey comparing outdoor construction workers and in indoor construction workers in the same sector, it was found that those more exposed to chemical agents, noise and vibrations in closed areas reported more complaints of symptoms of eye fatigue. In this case, employees have contact with substances such as cement dust that can irritate the eyes, they are also exposed to vibrations and noise that cause disturbances in the nervous system and that, in combination, cause physiological changes, such as headaches. It is also important to highlight that those workers exposed for periods longer than the normal working journey were the ones who most complained about the symptoms.

According to Al Dandan et al. [1] exposition to electronic devices is also present in the lives of radiologists, since spend long hours on digital devices performing clinical readings. In a survey carried out among radiologists in Saudi Arabia, complaints of symptoms such as tired eyes, headaches, itching, and/or blurred vision were more found in those workers who did not take breaks during the work period and who spent more time in front of the screens.

Furthermore, in occupational environments within inadequate lighting, there is a greater interference in the professional's performance due to the decrease in the pace of work, less perception of details, an increase in the rate of errors and accidents and a greater effort of the individual's vision, which can lead to negative effects. over time [15].

Therefore, to reduce, control or eliminate the consequences of visual fatigue in occupational environments, it is necessary to adopt preventive or corrective measures, seeking the best visual comfort among workers.

3.3 Preventive and Corrective Measures of Visual Fatigue

As a result of the review it is observed that some authors present preventive and corrective measures to reduce the effects of visual fatigue in workers, such as the study carried out by [16] that claim that the use of blue filters reduces brightness and improves the quality of images on computers, which can reduce the negative effects of devices on vision and, consequently, can generate better visual comfort. On the other hand, the results of [13] indicate that these filters promote the blocking of wavelengths, but the difference is not significant in relation to the minimization of asthenopia symptoms.

Hemphälä et al. [4] observed in their investigation with postmen that, through intervention in the ambient lighting, leaving it uniform with greater illuminance and less glare, there was a reduction in eye fatigue and a decrease in musculoskeletal discomfort, improving the productivity of professionals.

This indicates the importance of interventions considering people, devices, tasks, and environments to reduce visual fatigue.

Thus, it is important to apply ergonomic knowledge to adapt workstations, tasks, and devices to the psychophysiological characteristics of the workers, considering that the factors that generate visual fatigue can be manageable, both by management and by workers.

For those who suffer from asthenopia due to physical-chemical factors, Tiwari [20] proposes some measures such as the use of protective glasses to minimize eye exposure to these agents, providing workers with free access to spaces with natural ventilation, in addition to offer workers frequent rest cycles to relax the ciliary muscles.

For workers who are exposed to screens, some measures include taking frequent breaks to rest their eyes, adjusting electronic devices correctly by controlling screen brightness to comfortable levels and maintaining an adequate distance between eyes and screens, to use lubricating eye drops that help relieve dry eyes and pay attention to the frequency of blinking when performing tasks that require concentration, as such action helps keep the eyes moist and reduce the symptoms of visual fatigue.

It is also important to adapt work environments with good lighting and ventilation that provide greater visual comfort, which may include the use of uniform lighting, natural light, and ventilation or even the use of air humidifiers.

With the adoption of adequate measures, relief of the symptoms of visual fatigue is expected, which can influence the productivity of workers who feel the difficulties that this condition provides, as well as improving attention, reducing possible errors, increasing levels of satisfaction and motivation in task performance. Whether after

adopting mitigating practices, workers continue to have symptoms of visual fatigue, it is recommended to have a consultation with a specialist to assess the problem.

4 Conclusions

The aim of this research was to review the literature on visual fatigue in work environments with an emphasis on ergonomics, safety, and occupational health, pointing out the main causes, consequences and mitigating actions suggested by the authors of articles published in journals indexed in the researched databases. After the selection, 10 articles that met the proposed criteria were included. Based on the works consulted, physical-chemical factors and electronic devices are the main causes of asthenopia, which can be aggravated by personal factors and environmental factors, such as the level of lighting and ventilation in work environments.

The data collection methods of the analysed studies were questionnaires, self-report, point scales, review study, application of interventions and comparative experiments between groups of people submitted to conditions of visual fatigue and groups not submitted to such conditions. Although the studies did not present specific conclusions about the main causes of visual fatigue, some factors related to asthenopia were identified, such as: relationship with age, exposure to unfavourable conditions in the work environment for longer periods of time during the working day, lack of frequent breaks and lack of measures within occupational environments that reduce the condition of visual fatigue.

Therefore, the recommendations proposed in the studied articles include adjusting the environments lighting and ventilation, offer rest periods for workers, also requiring actions to raise awareness among workers and managers. Furthermore, these practices need to be applied even if there are no complaints of visual fatigue problems among workers to prevent them from developing visual health problems, but also to prevent pre-existing ophthalmological problems from getting worse.

Based on the results of the review, it was possible to identify environmental, personal, task and device factors related to visual fatigue. It was also possible to identify actions that can be used by companies to improve the well-being of their workers, reflecting on their performance and productivity. It is expected this work serves to other research on visual fatigue in occupational situations and contribute to highlight the importance of interventions in work design considering aspects of safety and health in work environments. In addition, it is observed that there are still research gaps for the deepening of the theme in view of the perspectives of new configurations of the work, considering the interdisciplinarity of the theme and the importance of the perspective of other specialists and their expertise.

Some review limitations can be presented, such as the number of databases consulted, number of key terms used, the publication period chosen, and others. To solve some limitations and improve the study, some possibilities for future work can be presented, such as: expanding the databases consulted and the key terms adopted; expand the period of publications consulted to have a larger sample and to analyse

older relevant research; perform the snowball reference sampling search; performing meta-analysis; to develop research with more specific objectives according to the results of this review, such as the influence of break periods, specific aspects of the relationship between sex and age with visual fatigue, size of devices and screens used, the influence of the type of screen and glasses lenses used by the workers; deepen studies on the relationship between different levels of illuminance and ventilation, as well as explore the relationship between different levels of temperature, humidity, vibration and non-ionizing radiation in work environments with visual fatigue.

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Qualities of the Alternative Approach of the Functional Resonance Analysis Method and the Analytic Hierarchy Process. Review



José Marcelo Tierra-Arévalo , María del Carmen Pardo-Ferreira , Virginia Herrera-Pérez , and Juan Carlos Rubio-Romero 

Abstract The Resilience Engineering (RE) aims to provide the necessary means for an adequate management of safety in these Complex Sociotechnical Systems (CSS), which considers variability as a determining factor for an adequate management. Some tools used in studies related to the RE, such as FRAM and AHP, allow the variability of these CSS, such as the construction sector, to be analysed in a more realistic way. Therefore, the aim of this article is to identify the main qualities of the alternative approach using FRAM and AHP in the construction sector. This review was conducted under the PRISMA guidelines. The electronic databases used were: Web Of Science (WoS), Scopus, ScienceDirect and PubMed. The main search string was performed using “Title/Abs/Key”. Five studies are presented that mark the alternative approach using FRAM and AHP in the construction sector. The compatibility of FRAM for analysing variability in conjunction with other tools and approaches could be confirmed, allowing specific problems to be analysed while maintaining a global perspective of the CSS. However, the combination of FRAM and AHP could be complicated if the staff analysing it does not have an adequate level of expertise and knowledge.

Keywords Resilience engineering · Tools · FRAM · AHP · Construction

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1 Introduction

1.1 Background

Resilience has been considered as a multidisciplinary area of study, which has been researched in various fields and from various perspectives for some years now, applied to various types of systems [2]. Resilience related to safety management could be referred to as the activities undertaken to understand, assess and manage the safety of a system, an organisation or even a society based on both conceptual and pragmatic knowledge. Safety is a system characteristic that prevents damage to human health, property or the environment, therefore, organisational processes would be safe when they are harmless or even risk-free. Resilience Engineering (RE) which focuses on the sociotechnical complexity of the system and analyses how this complexity affects the behaviour and performance of this system [14, 16].

RE is therefore about the characteristics of resilient performance, how it can be recognised, how it can be assessed or measured and then how it can be improved. The RE aims to provide the necessary means for an adequate management of safety in these Complex Sociotechnical Systems (CSS), which considers variability as a determining factor for an adequate management [10]. CSS present some difficulty in understanding their behaviour over time, as they work well most of the time but can fail unexpectedly, so it has become a factor of interest that RE could study [8].

The RE considers the same origin or source for things that go right and things that go wrong, therefore, this is a paradigm shift in safety management to address the complexity of CSS [11]. Some tools used in RE-related studies proposed by [9] are as follows: Functional Resonance Analysis Method (FRAM) and Resilience Assessment Grid (RAG) have been widely used to date and other applied tools such as the Analytic Hierarchy Process (AHP) [4], are favourably received by CSS research, including the AHP has served as a support that complements the tools mentioned.

The FRAM has been applied in various sectors detailed in order from the largest number of investigations to the smallest in each area mentioned as follows: aviation, healthcare, industrial operations, maritime, railway, construction, Oil & Gas, information technology, nuclear, power plants, critical infrastructure, defense, emergency management, road safety, urban planning, mining and others [18]. Specifically in the construction sector, which is characterised by high levels of occupational accidents [15, 21, 24].

The highest accident rate has been recorded, considered to be more than double the average for the rest of the industry [6]. Therefore, the proposal has been to emphasise a resilient safety culture based on the principles of CSS [22], with the tools necessary to understand the CSS [3]. Therefore, given the importance of this sector and the limited research presented, the following research questions are posed that could guide the study.

Are there any studies presenting the alternative approach using FRAM and AHP in the construction sector?

What are the main qualities of the alternative approach using FRAM and AHP in the construction sector?

The aim of this article is to identify the main qualities of the alternative approach using FRAM and AHP in the construction sector.

The following sections are presented in this article, Sect. 1 begins with an introduction to RE. Section 2 presents the methodology applied in this study. The third part presents the results and discussion. And finally, the conclusions of the study are presented.

1.2 FRAM

FRAM based on resonance, it allows us to analyse how the variability of a function can affect subsequent functions to a greater or lesser degree. The four main principles are set out below [9]:

1. Principle of equivalence of failures and successes.
2. Principle of approximate adjustments.
3. Principle of emergence.
4. Principle of functional resonance [17].

The development for the implementation of FRAM requires the following 4 main steps to be followed [9, 14]:

Step 1: Identification and description of system functions

When considering that a function could represent the activities necessary for a given outcome, FRAM analyses the functions that help the day-to-day work to be carried out successfully. These functions contain 6 different aspects as can be seen in Fig. 1, detailed as follows: Input, Output, Precondition, Resources, Control and Time [9, 17].

Fig. 1 Graphical representation of a FRAM function realised in FRAM model visualiser. *Source* Authors

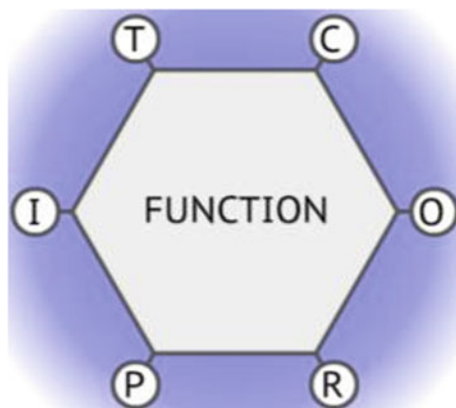




Fig. 2 Example of functions and their couplings realised in FRAM model visualiser. *Source* Authors

Step 2: Identification of performance variability

The aim is to characterise the potential and actual variability of performance.

Step 3: Aggregation of variability

The potential variability of each function may lead to unexpected results due to functional resonance, which is related to upstream–downstream functional couplings, and will depend on the number of functions in the system, Fig. 2 shows an example of couplings in a simple system.

Step 4: Managing variability

Variability of performance can lead to positive or negative results; therefore, it is recommended that actions should aim to amplify the positive effects and dampen the negative effects in order to achieve the desired results [9, 14].

1.3 AHP

Analytic Hierarchy Process (AHP) proposed by the mathematician Saaty focuses on solving problems with several complex criteria or where the decision is based on several parameters, in a hierarchy of problems that are easier to solve and easier to achieve the desired goal. AHP is a widely accepted technique that seeks solutions to complex problems such as conflict resolution where several criteria for unique alternatives are found [13].

Therefore, the AHP tool that deals with complex problems in decision making provides decision makers with the best alternative based on multiple criteria and sub-criteria that reduces complications and allows capturing the subjective and objective perspective of the associated problems by linking them in a single pathway. As an input, it can also measure the consistency of the decisions obtained and thus reduce the biases about this decision, all this can be achieved in 3 fundamental steps, which are as follows [12]:

1. The first phase of the AHP focuses on transforming the multi-criteria decision making problem into a hierarchical model formed firstly by the objective.
2. The second phase of the AHP consists of identifying the level of importance of one criterion over another criterion. At this stage it is very important to use Saaty's Table 1.
3. In the last phase of the AHP, some calculations must be made to evaluate the vector of priorities or weightings and the coherence of the judgements determined [12].

The different phases applied in the AHP can be seen in Fig. 3.

Table 1 The fundamental scale by Saaty. Adapted to the original from [12]

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgement strongly favor one activity over another
5	Essential or strong importance	Experience and judgement strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practise
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2/4/6/8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	Activities	If activity "i" has one of the above numbers assigned to it when compared with activity "j", then "j" has the reciprocal value when compared with "i"
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining "n" numerical values to span the matrix

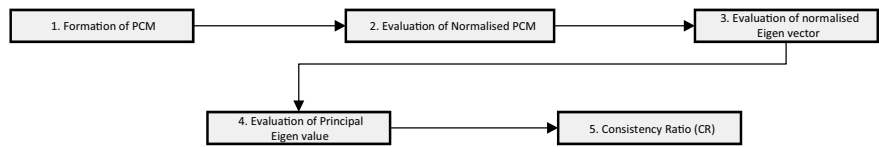


Fig. 3 Phases applied in the AHP. Adapted from [12]

2 Methodology

This review was conducted under the guidelines of the PRISMA [25]. The electronic bases used were the following: Web of Science (WoS), Scopus, ScienceDirect and PubMed. The main search string used by “Title/Abs/Key” included the following search terms: “Functional Resonance Analysis Method” OR “Functional Resonance Analysis Model” OR “FRAM” OR “F.R.A.M” AND “Construction”.

A number of papers referenced in the documents found were examined using the snowball technique [23]. The Mendeley software identified 121 articles as follows: 46 articles from WoS, 60 articles from Scopus, another 8 articles from ScienceDirect and finally 7 articles from PubMed. Figure 1 shows the process to obtain the 5 articles of the study. With no date limit, the following inclusion criteria were defined:

- The identified studies could be considered as: Articles, Conference Paper, Conference Review, Book Chapter, Review, Book, Article in Press, which could be open access or subscription.
- Articles derived from sources such as: Conference Proceeding, Book, Book Series, Trade Journal.

The following exclusion criteria were defined (Fig. 4):

- Articles that are not in the English language.
- Articles that did not contain both tools.
- Articles not related to the construction sector.

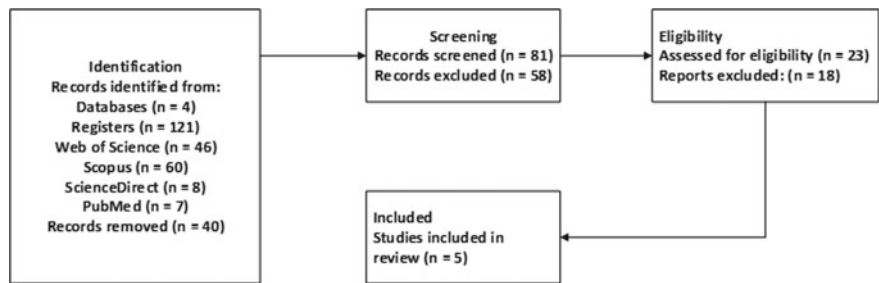


Fig. 4 Phases of the review according to PRISMA guidelines

Table 2 Main characteristics of the investigations Source: Authors

Author	Year	Country	Introduction of tools	Construction	FRAM applied	Original AHP Scale
Haddad and Rosa [7]	2015	Brazil	Yes	Green buildings	Yes	Yes
Rosa et al. [19]	2015	Brazil	Yes	Green buildings	Yes	Yes
Rosa et al. [20]	2017	Brazil	Yes	Green buildings	Yes	Yes
Alboghobeish and Shirali [1]	2022	Iran	Yes	Water reservoir construction	Yes	Yes
França et al. [5]	2020	Brazil	Yes	Offshore oil well drilling	Yes	Yes—but not exposed

3 Results and Discussion

According to the first research question: Are there any studies presenting the alternative approach using FRAM and AHP in the construction sector?

Five case studies are presented that mark the alternative approach using FRAM and AHP in the construction sector. The main characteristics are set out in Table 2.

The determined studies have been presented from 2015 to 2022, whose country of origin of the authors is Brazil with the highest number of contributions, where each study prior to the application of the approach makes an introduction to the applied tools. Most of the studies focus on “Green buildings” and also on the “Water reservoir construction” and “Offshore oil well drilling” sectors.

According to the second research question: What are the main qualities of the alternative approach using FRAM and AHP in the construction sector?

A summary of the main qualities of the alternative approach using FRAM and AHP in the construction sector is presented in Table 3.

In all cases FRAM is the central research method and the AHP supports the data provided with respect to variability and therefore even aims to quantify it with proposed indicators that could be used for safety management.

4 Conclusions

According to the main qualities and analysis of the alternative approach, it can be concluded that FRAM is originally considered a qualitative method that has been able to interpret the CSS accurately, but according to some researchers it could be insufficient in large systems with couplings and interactions that are difficult to visualise. Some proposals suggest the possibility of combining these qualitative characteristics with a quantitative approach based on variability, in order to subsequently propose indicators that allow for monitoring and control of the CSS.

Table 3 Summary of the main qualities and analysis of the alternative approach Source: Authors

Author	Case study applied to	Qualities of the study	Analysis of the approach
Haddad and Rosa [7]	A large construction company	Positive: FRAM proved to be the most appropriate methodology for this CSS despite the series of purely qualitative assessments because it reflects reality Negative: Managers use procedures, schemas, experience, and common sense to monitor and understand what is happening now in order to make future decisions	The combination of FRAM and AHP allows the exploration of a new perspective on the method that promotes stakeholder involvement in addressing complex issues of FRAM and AHP to describe and assess the sustainability of construction was able to determine how the couplings can be combined so that variability in performance generates unexpected results; and not necessarily failure
Rosa et al. [19]	Construction industry occurred in partnership with a large construction company	Positive: FRAM could be considered as a solid basis for proposing indicators and, therefore, monitoring. Positive: The AHP offers itself as a welcoming proposal to perform functional characterisation of variability	The combination of FRAM and AHP allows for the exploration of a new perspective on the method that promotes stakeholder participation in dealing with complex issues
Rosa et al. [20]	Modernisation work on the Maracana stadium in Rio de Janeiro	Positive: The combination of FRAM and AHP could recognise uncontrolled situations, thus allowing to propose indicators and/or a relevant monitoring system	The combination of FRAM with AHP has allowed exploring new perspectives for risk assessment, firmly introducing stakeholder participation and quantifying some results

(continued)

Table 3 (continued)

Author	Case study applied to	Qualities of the study	Analysis of the approach
Alboghobeish and Shirali [1]	The construction process of a water reservoir	Negative: The combination of FRAM and AHP involves knowledge with a certain degree of complexity and therefore its application requires specialisation and precision to obtain an adequate analysis of the task Negative: For some analysts the qualitative results may not have much impact despite being obtained from interviews with experts in the field	The combination of FRAM with AHP could successfully identify emerging risks based on the work performed rather than the work described in procedures and/or guidelines. FRAM has been able to identify a large variability in certain functions which is then prioritised by AHP
França et al. [5]	Offshore oil well drilling and construction	Positive: The combination of FRAM and AHP successfully identified WAD in the drilling and construction of an offshore oil well Positive: When analysing each function, the difference between WAI and WAD is evident. Positive: Because of its qualities FRAM provides opportunities to work in combination with other tools and approaches, therefore, it would allow the analysis of specific problems while maintaining a global perspective of the CSS	FRAM could be considered as a suitable methodology to address complexities between factors, identifies the day-to-day variability of activities, and would reveal the critical elements in order to manage the CSS to deliver a safe and productive work environment. The contribution of AHP could ratify the results

The qualities note that AHP contemplates the subjective and objective components of management decision making that reduces the complexity of the choice to a process of pairwise comparisons until a single, simple and global decision is obtained. Therefore, AHP could be considered as a very suitable support tool for resource allocation, selection of the best alternatives, planning and system management. Based on the hierarchical structuring of a problem, alternatives can be presented, with an analysis of the relationship between objective, criteria and alternatives.

Among the positive qualities of the combination of FRAM and AHP, it can be mentioned that it has allowed to successfully identify the Work-as-Done (WAD) of several CSS, as the analysis of each function allows to differentiate the Work-as-Imagined (WAI) from the WAD. The compatibility of FRAM to analyse variability in conjunction with other tools and approaches could be confirmed, thus allowing the analysis of specific problems while maintaining a global perspective of the CSS. However, the combination of FRAM and AHP could be complicated and even deliver undesirable results if the staff analysing it does not have an adequate degree of specialisation and knowledge.

Acknowledgements Special thanks to the “Ministerio de Ciencia e Innovación del Gobierno de España” and the “Programa Estatal de Generación de Conocimiento y Retos de la Sociedad” for funding the project: PID2020-114502GB-I00; entitled: “Complejidad y resiliencia: Un enfoque sistémico para la monitorización y mejora de la gestión de la seguridad en la construcción”

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The Emergent Perspective of Applied Observability in Occupational Health and Safety. The Exploratory Scoping Review for the Future Framework



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Abstract Applied Observability is an emergent approach within the competitive companies' Data-Driven strategies characterized by potential of being used in different areas of management. The Occupational Health and Safety (OHS) is one of strategic and operational areas that can increase substantially in the efficacy and precision if Applied Observability implemented. Applied Observability can be a powerful tool for improving the OHS by helping organizations identify and address potential hazards and risks, and by providing a way to continuously monitor and improve safety practices. To be able to carry on the present scoping review on such an emergent topic, the wide variety of scientific and sectorial records were screened. Most of these shows that the Applied Observability can take the OHS from reactive approach into predictive one if correct performance framework adapted. The preliminary areas of Applied Observability impacts are outlined as a partial result of this work. In addition, the analysis shows Applied Observability can nurture predictive models of human-machine, human-human or machine-machine-with-impact-on-humans interactions within Industry 4.0 systems.

Keywords Occupational safety and health · Applied observability · Data-driven strategy · Predictive safety management

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1 Introduction

In today's fast-paced business environment, managers and decision-makers face a multitude of challenges in making informed decisions. With increasing competition, rapidly changing markets, and evolving customer needs, it is critical for organizations to adopt data-driven strategies to stay ahead of the curve. Data-driven strategies involve the collection, analysis, and interpretation of data to inform business decisions [24]. The use of data enables organizations to make informed decisions based on real-world insights, rather than intuition or guesswork. By leveraging data, managers can identify patterns, trends, and opportunities that may not be immediately apparent through qualitative analysis alone [2].

Data-driven strategies are essential for effective management for several reasons. First, data enables managers to identify opportunities for growth, reduce costs, and improve efficiency. By analyzing data, managers can identify areas of the business that are performing well and areas that need improvement, leading to better decision-making [3, 29]. Second, data-driven strategies allow for more accurate forecasting and predictive modeling [30]. By using data to forecast trends and demand, managers can make pro-active decisions that prevent problems before they occur, rather than reacting to them after the fact. Third, data-driven strategies help managers to make decisions based on evidence rather than assumptions. This approach reduces the risk of making poor decisions based on incomplete or biased information and can lead to better outcomes [9, 10, 26].

Overall, the use of data-driven strategies in management is crucial for businesses to stay competitive and relevant in today's market. By leveraging data, managers can make more informed decisions that lead to better outcomes, improved efficiency, and increased profitability. The OHS is one of mentioned company's areas on continuous path to the improvement and optimization [5, 6].

Data-driven strategies can be implemented in occupational health and safety by using data to identify and address potential hazards and improve safety practices. Here are a few ways this can be done, including the most implemented ones as the collecting and analyzing data on safety incidents, followed by more predictive and prospective features. By collecting data on safety incidents, such as injuries, nearmisses, and accidents, organizations can identify patterns and trends that can help them prevent future incidents. This can be done through incident reporting systems or other methods of data collection [13].

However, the most interesting fields of application of data-driven strategies in the OHS are those related to the more predictive scopes. Many authors [8, 14, 16, 21] arise data-driven strategies as a future booster of data-driven modeling related to OHS:

- Use data to identify risk factors: By analyzing data on safety incidents, organizations can identify risk factors that contribute to accidents and injuries. This can include factors such as specific tasks, equipment, or processes that have a higher risk of accidents.

- Implement safety interventions based on data: Once risk factors have been identified, organizations can implement interventions to address those risks. For example, if a specific task has a high risk of accidents, the organization could implement additional training or safety protocols to reduce that risk.
- Monitor the effectiveness of safety interventions: By collecting and analyzing data on the effectiveness of safety interventions, organizations can determine whether those interventions are successful in reducing accidents and injuries. This can help organizations refine their safety practices over time.

Overall, a data-driven strategy for the OHS can help organizations identify and address potential hazards, improve safety practices, and reduce the risk of accidents and injuries. In this paper, alongside the scoping exploratory review, the authors draw potential areas of application of one of emergent Data-Driven strategies within the Safety Management and OHS in general. This area of Data-Driven strategy, considered by many practitioners [7] as one of most impact on predictive strategies and operations, is Applied Observability.

2 Theoretical Background

The real time response of any firm system is becoming major changemaking feature in highly competitive industries. In general, the observability is the ability to infer the internal state of a system based on its external outputs [20]. Applied Observability refers to the systematic approach of instrumenting and collecting data from a system to enable this inference. In the context of modern software systems, observability is increasingly critical to ensuring that these systems are performing as expected, identifying and resolving issues quickly, and continuously improving them [17, 25].

Applied Observability provides the ability to monitor, troubleshoot, and optimize complex systems. Competitive companies that rely on software systems, such as those in e-commerce, finance, and healthcare, can benefit significantly from applied observability (Fig. 1).

As data-driven strategy in the OHS can be implemented by collecting and analysing data related to workplace hazards, incidents, and accidents, it can be used in larger scope to predictive modelling of Safety Management [1, 5]. This can, on one hand, help identify trends and patterns that can be used to develop targeted interventions to prevent future incidents; and on the other hand it can nurture more predictive models of human-machine, human-human or machine-machine-with-impact-on-humans interactions [4, 8].

According to mainstream approach in Safety Management [11, 27] to implement a data-driven strategy, it may be necessary to establish systems for collecting and storing data related to OHS mainframe of the company. This could include installing sensors or other monitoring devices to track the performance of equipment and systems, as well as implementing processes for collecting data on accidents and incidents. Once data has been collected, it can be analyzed to identify trends and

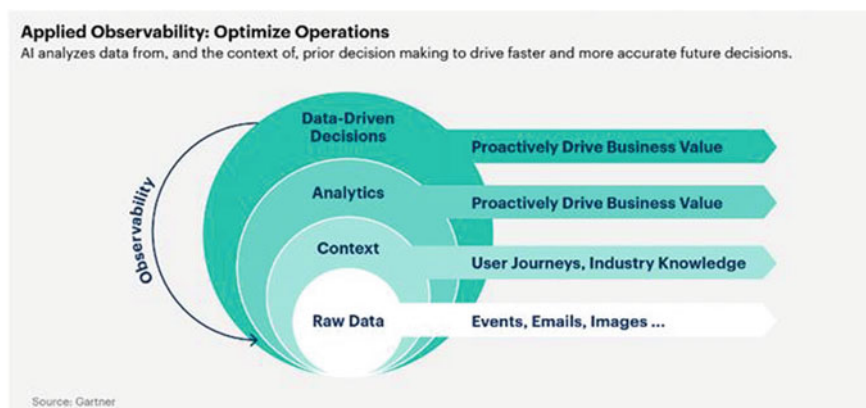


Fig. 1 Applied observability: optimize operations. *Source* Gartner

patterns. For example, data on accidents and incidents can be used to identify the most common causes of accidents and the specific types of hazards that are most likely to lead to incidents. This information can then be used to develop targeted interventions, such as training programs or equipment upgrades, to reduce the risk of future incidents. It is important to note that a data-driven approach to OHS requires a strong commitment to data integrity and privacy, as well as careful consideration of ethical and legal issues. Applied Observability is a systematic and integrated approach that applies observable data across various business functions, applications, and infrastructure and operations teams [17]. This approach aims to minimize the time between stakeholder actions and organizational responses, facilitating proactive planning of business decisions.

Applied Observability is also an approach to monitoring and understanding the behaviour of complex systems that involves collecting and analysing data from various sources in order to gain insights into the system's performance and behaviour [5]. In the context of OHS, Applied Observability can be used to monitor the conditions and activities in a workplace in order to identify potential hazards and risks to the health and safety of workers [8].

By collecting data on factors such as temperature, humidity, air quality, noise levels, and other environmental conditions, as well as data on the work processes and activities being performed, applied observability can help organizations identify potential hazards and take corrective action to mitigate those risks. For example, if data collected through Applied Observability shows that noise levels in a particular area of a facility are consistently above recommended levels, the organization could take steps to reduce the noise levels by implementing engineering controls or providing hearing protection to workers.

In addition to identifying potential hazards, Applied Observability can also be used to monitor the effectiveness of safety measures and procedures, and to identify areas where additional safety measures may be needed [25]. By continuously monitoring and analysing data, organizations can stay up-to-date on the status of their safety programs and make changes as needed to ensure the health and safety of their workers [12, 15]. Overall, Applied Observability can be a powerful tool for improving OHS by helping organizations identify and address potential hazards and risks, and by providing a way to continuously monitor and improve safety practices.

3 Methods

This work is a preliminary study focused on the elaboration of Applied Observability implementation model in different industries, in particular, those with advanced Industry 4.0 systems and active cyber-human environments. Those industries require increasing effectiveness of risk and safety systems' responses; real-time monitoring and predictive early-response scouting based on Applied Observability. The scoping review carried on in this study [18], has aimed to establish the initial Applied Observability nexus with the OHS, as well as to determine the future experimental scope of OHS Applied Observability in Agrifood Industry. As well as it aimed to develop hypotheses based on the results of the PRISMA scoping review [18] and use them to inform future research or decision-making processes.

Scoping reviews [18, 19] within the preliminary exploratory studies are used to gain insight and develop an initial understanding of a phenomenon, with the aim of generating hypotheses or informing further research [22, 23]. Overall, an exploratory study is a flexible and iterative process that involves constant reevaluation and revision of the research question and methods in response to the findings. A multi-stage content refinement process was used for this scoping review driven by the four development stages: Identification-Screening-Eligible-Included. The search areas consisted of a combination of search terms related to: (a) Occupational Health and Safety, Safety Management, Workplace Safety, (b) data-driven strategies, including data-driven decision making and prediction modelling in general and (c) topics relating to "observability" and "Applied Observability". The scope development instrument applied was the Knowledge Development Process-Constructivist (ProKnow-C) [28].

4 Results

The exploratory initial literature and knowledge field analysis confirm the incoming change in the OHS Management through the real-time measuring and data processing. Emergent in-company (as well as in some cases industry or city) systems and applications focused on monitoring are already evolving into Machine-Learning

schemes capable to extract patterns and predict some risk situations. Applied Observability implementation as a pillar of strategic, more than operative, framework of data-driven approach to the OHS within the complex, industrial, connected and automated environments, is the boosting trend that should be considered both by science experts and companies. By leveraging this approach, these companies will be able to (Table 1).

Table 1 Potential positive impact of applied observability on OHS performance

Improvements based on applied observability	
Improve system reliability and performance	Applied observability enables companies to identify and address issues in real time, minimizing downtime and improving system performance. This can help ensure that their customers have the best possible experience. This can help prevent system failures and downtime, which can reduce the risk of accidents and injuries caused by malfunctioning equipment
Gain deeper insights into user behavior and needs	By collecting data on user interactions with their systems, companies can gain better understanding of their needs and preferences. This can help them develop more targeted products and services, improving customer satisfaction and retention
Enhance security	Applied Observability can help identify security threats, allowing companies to respond quickly and minimize the impact of any security breaches. This can help protect their customers and their reputation. Applied Observability can also be used to provide real-time feedback and training to employees, helping them understand how to operate equipment safely and efficiently. This can reduce the risk of accidents and injuries caused by incorrect or unsafe practices
Early warning system	Applied Observability can provide early warning signs of potential issues or problems, allowing organizations to take proactive measures to prevent accidents or injuries from occurring. For example, if a machine is showing signs of wear and tear, maintenance can be scheduled before it breaks down and cause an accident
Enhanced communication	Applied observability can improve communication between different teams and departments within an organization by providing a central platform for sharing data and insights. This can help identify and resolve potential issues more quickly, reducing the risk of accidents and injuries
Increase innovation and agility	By continuously monitoring and improving their systems, companies can quickly identify opportunities to innovate and respond to changing market conditions. This can help them stay ahead of the competition and increase their market share

5 Conclusions

Applied Observability can have a positive impact on the OHS by providing visibility into the operation of systems and processes, which can help identify potential hazards and prevent accidents. Observability can also be used to track the performance of safety systems, such as fire suppression or emergency shutdown systems, to ensure that they are functioning properly.

The robust Applied Observability in the OHS framework is required to better understand the potential of the approach. As well as to be able to establish the “*hot points*”—exact interaction within the industrial, manufacturing process in which risk prediction is more exigent or depends on changing external variables. In conclusion, Applied Observability is a critical tool for modern software systems, and competitive companies can benefit significantly from its adoption. By leveraging this approach, companies can improve system reliability, gain deeper insights into user behaviour and needs, enhance security, and increase innovation and agility.

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