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Study on the Influence of Physical Activity Intensity and Maturation on Sports Injuries in Children and Adolescents

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Abstract: Intensive training combined with a growing body can predispose children to sports injuries. Our aim was to identify the importance of physical activity (PA) intensity and maturity as predictors of injury in youth. Information about injuries was collected using a questionnaire (LESADO), the PA intensity was assessed via accelerometry, and maturity was assessed using the Tanner–Whitehouse III bone age method and maturity offset. A total of 121 participants aged between 10 and 18 years were selected from four different schools. Regression analyses were used to determine the significant predictors of the injury profile. Only the injury type presented significant results. The time spent on moderate PA ($\chi^2(2) = 6.701, p = 0.035$) and bone age ($\chi^2(2) = 7.196, p = 0.027$) were the final predictors. The odds of having a strain or a fracture relative to a sprain increased 1.04 times for each minute of time spent on moderate PA. Likewise, the odds of having a strain or a fracture relative to a sprain decreased by 1.7 times per year of bone age. The PA intensity and bone age proved to be injury predictors in the growing athletes, with more predictive power in injury type. No meaningful associations were found for the injury occurrence, injury rate and body area injury location.

Keywords: accelerometry; maturation; physical activity intensity; sports injuries



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1. Introduction

Despite an increase in the participation of younger generations in sports and physical activities (PAs), a lack of knowledge regarding sports injuries is still an issue [1], and although several influencing factors are already described in the literature [2–19], as presented in Table 1, there are still many limitations and inconsistent data concerning variables such as maturation and physical activity intensity [5,6,17,19,20].

Increased sports involvement from an early age through the years of growth raises serious concerns [1,17,19–23]. Currently, there is a general trend towards specialization, intensive training and competition in early to middle childhood. These factors, combined with a growing body, can predispose young children to sports injuries that may result in long-term dysfunction [1,5,6,17–20,22,24–26]. Intensity in youth sports not only sacrifices fun but also produces injuries, burnout, social isolation and dropouts and may lead to reduced motor skill development [1,14,21,24]. If the cycle of sports specialization occurs too early in youth, motor skills and neuromuscular development are impaired, which, in turn, increases the risk of injury and potentially reduces opportunities for the child to achieve optimal sport performance [10,13,22,27]. Clear guidelines set by multiple health

organizations, designed to reduce injury rates, state that intensive training in children has no physiological or educational justification and claim that diversity of movement and all-around physical conditioning should take priority over specialization. They also advise that specialization in a single sport before adolescence should be discouraged. Moreover, age-appropriate levels of competition should be respected [10,24]. Likewise, several studies have found an association between injuries and a higher intensity and volume of training, a higher competition level, long training sessions that require repetitive movements, over-scheduling and overtraining [7,10,14,21,24,28]. Recent studies have pointed out an increase in sports participation, load and/or intensity prior to injury [7,29].

Table 1. Sports injury influence factors in children and adolescents.

Intrinsic Influence Factors		Extrinsic Influence Factors	
Non-Modifiable	Modifiable	Non-Modifiable	Modifiable
Previous injuries; age; sex; anthropometric characteristics; maturation	Neuromuscular control; strength; flexibility; stability; general physical fitness; biomechanical factors; psychosocial factors	Type of sport (team/individual, contact/non contact); competition level; technical gestures; sports season period	Exposure (volume, intensity, frequency); practice environmental context; footwear and protective equipment; respect for rules and sports ethics

These injuries may also be linked to the unique and vulnerable phase of musculoskeletal, motor and cognitive development in youth. High training intensities overlapping with growth spurts increase the risk of sports injuries [12,30]. The immature musculoskeletal system undergoes several structural and tissue changes and may become less able to cope with traumatic situations and repetitive biomechanical stress [5,17–20,26,31–33]. These changes include the asynchronous development of bone and soft tissue [34]: longitudinal growth leaves the bone temporarily more porous and therefore fragile [33], while soft tissues do not undergo this rapid growth and become progressively tighter [31], increasing the tensile forces over growth plates, cartilage, apophyses, muscle–tendon units and joints [24,31,33–35]. Likewise, muscles do not reach their full size until 6 to 12 months after the peak height velocity (PHV), implying a decrease in strength during this stage. In addition, an imbalance between strength and flexibility can occur, as can abnormal movement mechanics [30]. Furthermore, during adolescence, motor control can be affected by changes in balance and coordination, which may have an impact on injury risk [25,31]. Equally, cognitive maturation at this stage is an important factor to consider. Children and adolescents with poorer concentration may not yet be capable of participating in very demanding activities [35].

Despite a heightened awareness of sports injuries, their risk factors and their complex interactions, the available evidence is still limited and inconclusive, particularly with respect to reliable data about predictors such as biological age and PA intensity [24,36]. Thus, our aim was to identify the influence of PA intensity and maturity as predictors of injury occurrence, injury rate, body area injury location and injury type in Portuguese children and adolescents.

2. Materials and Methods

Experimental design and subjects

A cross-sectional study was conducted. A total of 121 participants, 57 boys and 64 girls, aged between 10 and 18 years (mean, 13.8 ± 1.9 years), from four Portuguese public schools and who were involved in different types of sports participation, joined the present study. All the participants filled out the sports injury questionnaires and were instructed to wear an ActiGraph GT3X activity monitor for 5 days. The other variables, related to maturity evaluation (according to Mirwald and TW3-bone age), were obtained at the same time

as described below. Before inclusion in the study, all the participants' guardians gave their written informed consent. The research protocol was in accordance with the Helsinki Declaration and was approved by the Ethics Committee of the Faculty of Human Kinetics, University of Lisbon.

Testing methods

To assess the injury profile, the LESADO questionnaire was used. LESADO is a self-reported questionnaire that gathers information about the injury profile. Valid and reliable information about injury on children aged 10+ years [37] can be obtained through self-report surveys [38]. However, children under the age of 12 years may require assistance to complete it [38]. To prevent bias and interpretation difficulties, all the participants were guided by the investigator when completing the questionnaires. The time frame used was 6 months, as recommended in retrospective studies [39]. A clear definition of injury based on current epidemiological research was also provided [40,41]. LESADO comes from an extensive literature review on the topic and was adapted and based on epidemiological questionnaires used in Portuguese sports samples [15,16,42,43].

Daily physical activity was measured using an ActiGraph GT3X activity monitor (Actigraph LLC, Fort Walton Beach, FL, USA) worn around the waist, for five consecutive days (three weekdays and two weekend days). This device is a small ($3.8 \times 3.7 \times 1.8$ cm), lightweight (27 g) accelerometer that uses a piezoelectric acceleration sensor to collect motion data in three axes: vertical (Y), horizontal right-left (X) and horizontal front-back (Z). These data are filtered into signals of frequency in hertz, for an interval of time or epoch [44,45]. The epochs were established as 1 s of time wear and then converted into 5 s counts of activity, which were linearly related to the intensity of PA during those periods of time [46]. A valid day was defined as a day with more than 600 min of device wear, and non-wear periods were determined as those with more than 60 continuous zero-activity counts [47]. Participants were only included in the study if they had at least three valid wear days. All the participants were instructed to wear the accelerometer while awake and to take it off for any water-based activity (e.g., showering or swimming), any activity that could compromise the physical performance or integrity of the device (e.g., gymnastics or sports fights) and activity that involved cycling or rolling. The participants were instructed to record the abovementioned instances when they took off the accelerometer in a diary [47]. The information registered in those diaries was coded by the time engaged in those activities multiplied by the estimated MET (metabolic equivalent task) values according to the compendium energy expenditure [48]. Those activities were included in the daily PA on the corresponding day, replacing the hours in which it was assumed that the device was unworn, and then added for the valid days [49]. The PA intensity level was recorded according to moderate, vigorous or very vigorous intensity PA, as proposed by Freedson [50]. The time encompassed by moderate and vigorous PA (MVPA) was determined [50]. The mean times per day at the different intensities were determined by summing all the minutes spent in the count criteria and dividing them by the valid days. The defined cut-points proposed by the Freedson equation [50] were 500–3999 counts for moderate intensity, 4000–7599 counts for vigorous intensity and 7600 or more counts for very vigorous intensity.

The maturity measures consisted of determining the maturity offset during adolescence and the time before or after the PHV according to Mirwald [51], and of calculating the bone age using radiographs of the left hand and wrist according to the Tanner-Whitehouse III (TW3) method [52]. X-rays were performed in a single session, and the ossification of thirteen bones was evaluated. Maturity was rated by one trained examiner without knowledge of the chronological ages of the participants. The maturity evaluation was independently replicated two weeks later by the same observer, and the intra-observer technical error of measurement (TEM) was determined. An expert observer evaluated a random subsample of 37 radiographies, and the inter-observer TEM was determined. The intra-observer TEM was 0.03 (± 0.004) years, and the inter-observer TEM was 0.03 (± 0.99) years. Three bone maturity groups were considered for descriptive data: late

maturers, in which the bone age was lower than the decimal age by more than one year; normal maturers, in which the difference between the bone and decimal ages was no more than one year; and early maturers, in which the bone age was more than one year higher than the decimal age (0 = “late”; 1 = “on time”; 2 = “early”) [53,54]. The maturity offset was predicted using a specific equation for each sex (the standard error of the estimates was 0.592 for boys and 0.569 for girls) based on Canadian and Belgian samples [51]. This equation can be used to classify adolescents as pre- or post-PHV and can also be used to group the individuals according to years before or after PHV. The chronological age minus the maturity offset provides an estimate of the age of PHV. The method appears to be useful during the period of growth acceleration [55]. Three maturity offset groups were also defined: pre-PHV (0 = “<−0.5 years of PHV”), on PHV (1 = “[−0.5, 0.5] years of PHV”) and post-PHV (2 = “>0.5 years of PHV”).

Chronological age was defined as a whole year at the midpoint of a range (e.g., the “12-year-old” CA group of youth had chronological ages between 11.50 and 12.49). In order to perform descriptive analysis, four age groups were defined. The age groups had an interval of two years (0 = “9.5–11.49 years”, 1 = “11.5–13.49 years”, 2 = “13.50–15.49 years”, and 3 = “≥15.50 years”).

Data analysis

The statistical analysis was conducted using SPSS 22.0 software (SPSS Inc., Chicago, IL, USA), and a significance level of 5% was considered. Descriptive statistics were used to determine the sample characteristics. The variable selection started with a bivariate analysis of the dependent variables and each predictor. The dependent variables were injury occurrence (0 = “no”; 1 = “yes”), injury rate (number of sports injuries per 1000 h of exposure), injury type (0 = “strain”; 1 = “sprain”; 2 = “fracture”) and body area injury location (0 = “lower limbs”; 1 = “upper limbs”). The evaluated predictors were sex, PA intensity (in minutes and classified according to the different levels of intensity proposed by Freedson [50]), decimal and bone age (years) and maturity offset (years). The set of candidate predictors for multiple regressions consisted of all the variables that presented $p < 0.25$ in the bivariate analysis, and a backward stepwise method using the likelihood ratio statistic was applied to select the model variables. Only injury type presented statistically significant results. Multinomial logistic regression was used to identify the significant predictors of injury type.

3. Results

A total of 121 participants aged between 10 and 18 years, involved in different types of sports participation, were evaluated. Of this sample, 51 participants (42.1%) reported a sports injury during the previous 6 months (see Figure 1).

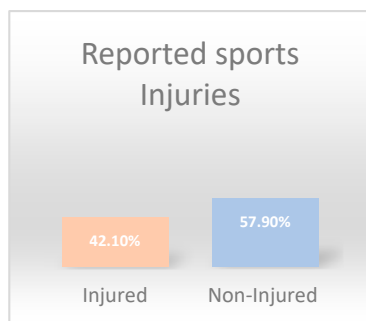


Figure 1. Reported sports injuries.

Considering the analysis by sex, 22 of 57 boys reported injury (38.6%) and 29 of 64 girls reported injury (45.3%). The mean decimal age of the participants was 13.8 years ($SD = 1.9$), quite similar to the mean bone age ($M = 13.8$; $SD = 2.2$). The maturity offset presented a mean value of 0.7 years ($SD = 1.7$) after PHV. Considering the sample that reported a sports injury, the average injury rate was 11.2 ($SD = 6.2$) per 1000 h of PA exposure. The most

injured body areas were the lower limbs (62.0%), followed by the upper limbs (24.0%), and the types of injuries found were strains (34.1%), sprains (38.6%), and fractures (27.3%), as shown in Figures 2 and 3. Tables 2 and 3 present the time spent on PA (minutes) by the level of intensity considering the total sample, sex, age and maturity categorical variables and injury profile variables.

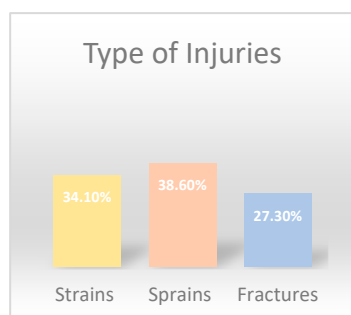


Figure 2. Types of injuries.

Table 2. Mean (M) and standard deviation (SD) of time spent (minutes) on PA at each intensity level—moderate, vigorous, very vigorous and total MVPA (moderate to very vigorous)—for the total sample and by sex, age and maturity profile.

	PA Intensity (Minutes)			
	Moderate ⁽⁵⁾ M (SD)	Vigorous ⁽⁶⁾ M (SD)	Very Vigorous ⁽⁷⁾ M (SD)	Total MVPA ⁽⁸⁾ M (SD)
Total Sample (N = 121)	109.59 (35.21)	18.55 (14.79)	5.49 (13.20)	134.57 (52.90)
Sex ⁽¹⁾				
Male (N = 57)	119.12 (39.63)	25.43 (16.93)	8.82 (17.82)	156.07 (62.01)
Female (N = 64)	101.09 (28.45)	12.42 (8.99)	2.52 (5.54)	115.41 (33.48)
	<i>p</i>			
	0.005 **	<0.001 **	0.013 *	<0.001 **
Age Group ⁽²⁾				
9.5–11.5 (N = 20)	132.50 (39.27)	17.97 (9.31)	3.74 (3.77)	154.22 (45.97)
11.5–13.5 (N = 30)	124.98 (31.55)	19.55 (13.34)	8.71 (22.41)	158.36 (66.78)
13.5–15.5 (N = 47)	97.40 (30.86)	16.52 (18.05)	4.59 (9.63)	117.67 (45.57)
≥15.5 (N = 24)	95.11 (27.33)	21.76 (13.15)	4.68 (7.76)	121.55 (35.24)
	<i>p</i>			
	<0.001 **	0.540	0.116	0.001 **
Maturity Offset ⁽³⁾				
PHV < −0.5 (N = 36)	132.34 (40.48)	20.55 (11.97)	8.65 (20.46)	165.81 (67.83)
−0.5 ≤ PHV ≤ 0.5 (N = 18)	121.20 (23.31)	24.70 (22.81)	2.87 (2.67)	148.76 (36.57)
PHV > 0.5 (N = 67)	94.24 (26.21)	15.83 (12.95)	4.50 (9.20)	113.97 (35.84)
	<i>p</i>			
	<0.001 **	0.017 *	0.143	<0.001 **
Bone Maturity ⁽⁴⁾				
Late (N = 23)	121.35 (39.41)	22.20 (18.27)	6.11 (12.48)	149.67 (49.09)
On time (N = 80)	105.98 (31.60)	17.64 (14.06)	4.79 (13.31)	130.33 (54.85)
Early (N = 18)	110.60 (43.02)	17.91 (13.10)	7.81 (14.04)	134.10 (47.53)
	<i>p</i>			
	0.191	0.471	0.212	0.108

* $p < 0.05$; ** $p < 0.01$. ⁽¹⁾ Sex differences were evaluated using Welch’s independent-samples *t*-tests. ⁽²⁾ Age group differences were evaluated using ANOVA tests and Tukey’s HSD post hoc tests, except for very vigorous PA intensity, for which the Kruskal–Wallis test and Dunn–Bonferroni post hoc tests were used. ⁽³⁾ The maturity offset group differences were evaluated using Welch’s ANOVA tests and Games–Howell post hoc tests, except for vigorous PA intensity, for which the Kruskal–Wallis test and Dunn–Bonferroni post hoc tests were used. ⁽⁴⁾ The bone maturity group differences were evaluated using the Kruskal–Wallis test and Dunn–Bonferroni post hoc tests. ⁽⁵⁾ For moderate PA intensity, there were significant differences between the following: males and females; the age group 9.5–11.5 and the two oldest age groups; the age group 11.5–13.5 and the two oldest age groups; the group with PHV > 0.5 and the other two groups of maturity offset. ⁽⁶⁾ For vigorous PA intensity, there were significant differences between the following: males and females; the groups of PHV > 0.5 and PHV > 0.5. ⁽⁷⁾ For very vigorous PA intensity, there were significant differences only between the male and female groups. ⁽⁸⁾ For total moderate to vigorous PA intensity, there were significant differences between the following: the male and female groups; the age group 9.5–11.5 and the age group 13.5–15.5; the age group 11.5–13.5 and the two oldest age groups; the group with PHV > 0.5 and the other two groups of maturity offset.

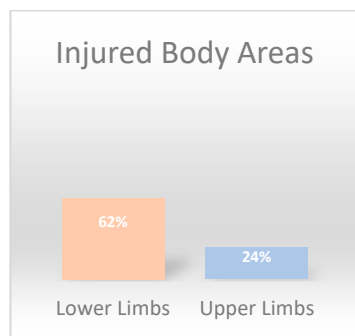


Figure 3. Injured body areas.

Table 3. Mean (M) and standard deviation (SD) of time spent (minutes) on PA at each intensity level—moderate, vigorous, very vigorous and total MVPA (moderate to very vigorous)—by injury occurrence, body area injury location, injury type and injury rate.

	PA Intensity (Minutes)			
	Moderate ⁽⁴⁾ M (SD)	Vigorous M (SD)	Very Vigorous M (SD)	Total MVPA ⁽⁵⁾ M (SD)
Injury Occurrence ⁽¹⁾				
No (N = 70)	110.47 (38.63)	17.97 (13.97)	4.47 (13.53)	135.1 (6.67)
Yes (N = 51)	108.37 (30.23)	19.35 (15.95)	6.9 (12.75)	133.84 (38.3)
<i>p</i>	0.747	0.612	0.319	0.897
Body Area Injury Location ⁽²⁾				
Lower limbs (N = 31)	110.98 (31.52)	21.75 (18.25)	7.28 (13.71)	140.01 (37.95)
Upper limbs (N = 12)	98.46 (22.51)	13.81 (9.73)	5.06 (11.18)	114.0 (31.12)
<i>p</i>	0.217	0.162	0.534	0.041 *
Injury Type ⁽³⁾				
Strains (N = 17)	118.02 (29.91)	25.11 (21.55)	5.22 (9.24)	148.36 (40.24)
Sprains (N = 15)	88.98 (18.21)	19.47 (15.1)	12.3 (19.18)	118.38 (34.04)
Fractures (N = 12)	117.38 (32.92)	15.30 (8.82)	4.25 (4.44)	136.93 (37.91)
<i>p</i>	0.005 **	0.508	0.578	0.084
Injury Rate	108.37 (30.23)	19.35 (15.95)	6.9 (12.75)	133.84 (38.3)

* $p < 0.05$; ** $p < 0.01$. ⁽¹⁾ The injury occurrence differences were evaluated using independent-samples *t*-tests. ⁽²⁾ The body area injury location differences were evaluated using independent-samples *t*-tests, except for very vigorous PA intensity, for which the Mann–Whitney test was used. ⁽³⁾ The injury type differences were evaluated using ANOVA tests and Tukey’s HSD post hoc tests, except for vigorous and very vigorous PA intensities, for which the Kruskal–Wallis test and Dunn–Bonferroni post hoc tests were used. ⁽⁴⁾ For moderate PA intensity, there were significant differences between strains and the other two types of injury. ⁽⁵⁾ For total moderate to vigorous PA intensity, there were significant differences between lower limbs and upper limbs.

3.1. Injury Occurrence, Injury Rate and Body Area Injury Location—Predictors

No statistically significant results were found for these variables.

3.2. Injury Type—Predictors

The multinomial logistic regression results show that the addition of the predictors time spent on PA of moderate intensity (likelihood ratio chi-square test: $\chi^2(2) = 6.701$, $p = 0.035$) and bone age (likelihood ratio chi-square test: $\chi^2(2) = 7.196$, $p = 0.027$) to a model that contained only the intercept significantly improved the fit between the model and data (likelihood ratio chi-square test: $\chi^2(4) = 19.377$, $p = 0.001$). Pearson’s ($\chi^2(82) = 81.956$, $p = 0.481$) and deviance ($\chi^2(82) = 76.424$, $p = 0.653$) chi-square goodness of fit tests indicated that the model fitted the data. The model pseudo R-squares (Cox and Snell R-square = 0.356; Nagelkerke R-square = 0.402; McFadden R-square = 0.202) showed that the model has reasonable predictive power. The predictors bone age and moderate PA intensity were significant in distinguishing both strains and fractures from sprains. The odds of having a strain or a fracture compared to having a sprain increased 1.04 times per unit increment

(minute) in the time spent on moderate PA. Likewise, the odds of having a strain or a fracture compared to having a sprain decreased by 1.7 times per unit increment (year) in bone age (strain: $1/0.577 = 1.733$; fracture: $1/0.574 = 1.742$). The results can be seen in Table 4. The variable time spent on MVPA, decimal age and maturity offset, which were significant predictors in the preliminary analysis, lost significance in the final multinomial logistic regression model.

Table 4. Multinomial logistic regression model for injury type.

Injury Type ¹	Predictor	B(SE)	<i>p</i>	Odds Ratio	95% CI Odds Ratio
Strain	Constant	3.794 (4.180)	0.364		
	Time spent on moderate PA	0.040 (0.019)	0.035	1.041	(1.003, 1.080)
	Bone age	−0.549 (0.246)	0.025	0.577	(0.357, 0.935)
Fracture	Constant	3.744 (4.313)	0.385		
	Time spent on moderate PA	0.039 (0.019)	0.044	1.040	(1.001, 1.080)
	Bone age	−0.555 (0.254)	0.029	0.574	(0.349, 0.944)

¹ The reference category is sprain.

4. Discussion

Youth sports participation has evolved from being child-driven recreational free play to adult-driven. It has become an extremely structured activity practiced at high intensity levels and devoted to the development of specific sports skills. Sports injuries usually result from the combination of several risk factors interacting at a given time [23]. Biological development in adolescence and PA intensity levels can be part of this complex equation. The purpose of this investigation was to identify the influence of PA intensity and maturity as predictors of injury profile in Portuguese children and adolescents. To date, no studies have accurately quantified maturation and PA intensity levels, making this study new in its approach. The obtained results show that the risk of a fracture or strain increased with an increase in the time spent on moderate PA and a decrease in bone age. Despite this pattern of injury occurrence, the injury rate and body area injury location did not present significant results, which may indicate that the actual effect of the PA intensity on injury is far from simple.

4.1. Biological and Injury Profile Characteristics

The descriptive data for the injury prevalence, injury rate and injury profile were quite similar to the results of previous studies [8,15,16]. The injury prevalence and injury rate in Portuguese school-age children presented meaningful results. Lower and upper limbs were the most affected areas, and strains, sprains and fractures were the major injuries registered. This sample did not present significant differences between the decimal age and bone age. Nonetheless, the maturity offset mean and standard deviation showed that the majority of the study participants were in or near the PHV stage.

The recorded PA intensities for both sexes were mainly moderate. The daily times spent on vigorous and very vigorous PA were low. Portuguese children and adolescents do not undertake sufficient PA as recommended by international health guidelines [56,57]. PA of vigorous intensity accounts for the lowest proportion of the overall PA among young people and may decline more rapidly than PA of any other intensity during this period [58]. The age group results also showed that, as age increases, the time spent on MVPA decreases. Although it is widely accepted that the PA intensity rises with age, studies have consistently shown that PA declines throughout adolescence [59,60], especially vigorous PA [58]. The time available for PA is reduced in this transition from childhood to adolescence. Despite the steady increase in organized sport participation during the last few years, the evidence shows that active play during leisure as well as non-organized sport activities seems to

be decreasing due to increasing access to technology and other activities [56]. Also, other responsibilities can arise such as part-time jobs or more hours devoted to studies [60]. Moreover, influences from the school environment and peer groups can strongly affect PA behaviors [60,61].

The maturity offset and bone maturity category group results presented a similar pattern. The participants before PHV and late maturers spent more time on MVPA than the other maturity groups. This supports the fact that maturation is a significant variable concerning PA participation. The hormonal fluctuations involved in puberty tend to create marked changes in body composition. Adolescents become taller and heavier, and there is an increase in adipose tissue, especially in girls [62]. A lower proficiency in motor skills may also become present [30,31]. All of these factors can discourage adolescents from regular PA.

As expected, there were also differences between the sexes in the time spent on PA at different intensity levels. The boys consistently spent more time on moderate, vigorous and very vigorous PA. Boys are less sedentary and more active than girls at all ages [57,58,60,61], and girls tend to have lower involvement in PA, especially those who mature earlier [16,62]. Boys are usually more active and have more freedom to explore outdoors [61,63]. Moreover, they seem to receive more encouragement from parents to practice PA compared to girls [60].

Considering injury location, descriptive data revealed that the participants with lower limb injuries spent more time on PA at all intensity levels than the participants with upper limb injuries. Lower limb injuries are often associated with overuse mechanisms [1], which, in turn, are associated with more time spent participating in sports [8,15,30,35].

Regarding injury types, the participants who had strains or fractures spent more time on PA of moderate intensity than the participants with sprains, but participants who had sprains spent more time on very vigorous PA [64]. Sprains are closely related to traumatic mechanisms [11] due to joint stiffness and abnormal movement mechanics during growth [30,64,65]. The risk of sprains may increase when participants exercise at a very vigorous intensity [35].

4.2. Predictors of Injury Profile

The injury type presented two predictors: the time spent on moderate PA and bone age. The odds of having a strain or a fracture compared to having a sprain increased by 1.04 times per unit increment (minute) in the time spent on moderate PA. The nature of organized youth sports participation with longer periods of extensive training and participation in large numbers of competitive events may contribute to the increase in sports injuries [1,14,16]. Moreover, specialized athletes, in order to achieve their goals, may push themselves harder and play despite pain [10,21,24], often not respecting the adequate resting periods for a developing child [16,24]. Likewise, repetitive movements expose the neuromuscular system and musculoskeletal tissues to repeated loads [30]. If sport specialization has already occurred, only one set of motor patterns will be trained, increasing the chance of injury [30]. Recent studies have emphasized that recreational free play is important precisely because regular and diversified PA allows the development of motor skills that are effective in preventing injuries [10,13,14,21,24,66]. However, a transition in PA behavior in adolescence has been observed [57]. A shift from unstructured free PA towards sedentary activities during leisure time makes sports club participation the more important contributor to the daily time spent on MVPA [57], which can, as explained above, create favorable conditions for the occurrence of specific injuries. Also, as already seen in a larger sample [8], strains and fractures are more likely to occur near the PHV. Descriptive data showed that the majority of the study participants were near or in the PHV stage. The combination of more time spent on PA of moderate intensity and PHV may create conditions allowing strains and fractures to occur. Fractures are common during pubertal maturation due to deficits in bone mass [8,20,67], and at this stage, there are more accidental and traumatic injuries during sports practice [8,26,40,67]. On the other

hand, strains are more likely to occur in participants who have recently passed PHV. This condition makes them more vulnerable to excessive loads [8,23,68]. Although, after PHV, tissue and structural dynamic equilibrium begins to be reached, some degree of fragility still persists, especially in soft tissues [8,20,25]. Participants who have not developed certain skills such as strength, endurance and motor control may be at increased risk of injury as they begin to spend more time on moderate PA [14,19].

Similar results were obtained for bone age. The odds of having a strain or fracture compared to having a sprain decreased by 1.7 times per unit increment (years) in the bone age. It is observed that the participants of a lower biological age are normally more engaged in sports practice, which clearly increases the exposure to risk. Also, the growth process and biological development start at these ages, and an unbalanced phase of motor control and tissue adaptations occurs [16,24,69]. As mentioned above, strains and fractures are common in this stage [8,13,30,70]. Increased vulnerability to traumatic and overuse injuries has been reported [2,5,30]. In addition to these factors, in PA, maturing children and adolescents are not grouped according to their biological age [14,66]. Participants are normally grouped by chronological age. Children of the same chronological age may vary considerably in their biological maturity status, leading to apparent individual differences [22,33,36]. Athletes with higher biological ages perform better, being structurally and functionally stronger than those with lower biological ages [22,30]. The direct confrontation between these two groups may represent a risk for injury [71]. Furthermore, younger children may not be cognitively prepared to participate in highly structured PA. Children who are easily distracted and have a lower capacity for understanding may present a higher injury risk [35].

No meaningful statistical associations between injury occurrence and injury rate and the evaluated predictors were found. Several studies have already discussed the association between injuries and higher intensity PA [7,29]. However, considering the present results and those of previous studies by Costa e Silva [8,15,16], the PA volume and level of sports participation seem to influence these variables more significantly. However, the sample used in this study had limited dimensions, so the generalizability of the results must be carefully considered. Also, the PA intensities recorded were mainly moderate, which may not have been sufficiently discriminatory for evaluating whether the time spent in vigorous and very vigorous PA increases the risk and occurrence of injury. The recall bias was minimized by the used definitions and recall period (6 months). Difficulties in interpretation were prevented by rigorous monitoring during the completion of the survey.

5. Conclusions

It is essential to clarify the actual benefits and disadvantages of sports participation at these ages discussed here in order to determine the best ways to prevent injury. The injury profile in youth has different presentations considering the maturation and PA intensity. Children who reported more time spent on MPA and had lower bone ages presented higher risks of strains and fractures. However, no significant predictors were found when considering the injury occurrence, injury rate and body area injury location. Intense PA combined with a maturing body may create conditions under which sports injuries become an issue, but the risks associated with these variables still need to be clarified with larger samples and more discriminating PA intensities. These conditions must be studied in future work.

Final Recommendations

- Intensity levels in subjects with lower biological ages should be approached with caution.
- During adolescence, it is clinically sensible to control and adjust the training load (frequency, intensity or duration) and promote rest and recovery. The goal should be to optimize performance while minimizing injuries.

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