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Perceptual and Motor Skills
2021, Vol. 128(2) 746–765

DOI: 10.1177/0031512520987359
journals.sagepub.com/home/pms
SAGE

# Motor Competence in Children With and Without Ambliopia

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**Abstract**

The purpose of this study was to assess the motor competence of children with and without amblyopia. Study participants were 165 primary school children, aged 6–9 years, divided into three groups based on their visual acuity with the Snellen chart: (a) non-amblyopia, (b) corrected amblyopia, and (c) non-corrected amblyopia. We assessed the children's motor competence with the Motor Competence Assessment battery (MCA) and their physical activity with the Physical Activity Questionnaire for Older Children (PAQ-C). The non-amblyopia group presented significantly better motor competence on the MCA than either the corrected amblyopia group or the non-corrected amblyopia group; there were no statistically significant motor differences between the two amblyopia subgroups. Amblyopia versus non-amblyopia differences on the MCA were mainly in stability and locomotor components, involving dynamic balance and the change of spatial position and direction of movement, but not in the manipulative component (ball throwing velocity and ball kicking velocity). Predictably, from within an integrated visual motor perspective of child development, our findings suggest that intact vision played an important role in children's motor

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competence. The development of fundamental motor skills, especially of stability and locomotor skills, may be affected by poor visual processing in that participants with uncorrected amblyopia showed poor movement accuracy, uncoordinated movement, and impaired balance.

**Keywords**
amblyopia, child, child development, motor skills, postural balance, visual acuity

## Introduction

Amblyopia refers to the impairment of uni- or bilateral temporal space vision during the first five years of life (Barrett et al., 2003; Levi, 2006; Sireteanu et al., 2007; Miller & Lessin, 2012; Siretenau et al., 2007), and amblyopia can be caused by any condition that interferes with ocular focus at this age (American Academy of Ophthalmology, 2007; American Academy of Pediatrics Section on Ophthalmology & Committee on Practice and Ambulatory Medicine, 2012; Jefferis et al., 2015). Clinically, amblyopia is defined as reduced visual acuity accompanied by one or more known factors, such as strabismus, anisometropia and refractive error (Birch, 2013). Amblyopia is considered the second most common cause of visual impairment in children and adolescents, second only to uncorrected refractive error (Webber, 2018).

Failing to identify and treat amblyopia early can cause permanent visual impairment and adversely effects school performance, development of gross and fine motor skills, social interaction and self-image (Birch et al, 2019; Engel-Yeger, 2008; O'Connor et al., 2010; Webber, 2018; Webber et al., 2008).When amblyopia is treated, even if the underlying cause is corrected, visual focus is not restored immediately, as there remains a need for brain adaptation in order to achieve accurate visual processing (Birch, 2013;, Levi et al., 2015; Mills, 2003).

When visual impairment is a primary problem, as in amblyopia, it is important to determine not only the level of children's visual impairment, but also the impact of visual impairment on children's motor, cognitive and behavioral development (Atkinson, 2017; Atkinson et al., 2002; Birch et al., 2019; Largo et al., 2001). Vision is essential for mapping the environment and for understanding visual perspectives and visual relationships between people and objects that are necessary for developing movement in three-dimensional space (Borel et al., 2001; Gentaz, 1991). In the course of normal infant and child development, visual-motor capabilities are well integrated, and threats to either the visual or motor system can be expected to adversely affect the development of the allied unaffected system (Atkinson, 2017; Braddick & Atkinson, 2013). In the case of children with non-verbal learning disability (non-verbal LD), characterized by specific visuospatial impairments, there are reports of problems learning or encoding through pictures, processing gestures, and orienting in space and fine motor skills (Drummond et al., 2005). The findings of impaired motor coordination (manual dexterity, ball skills, static and dynamic balance) (Mammarella, 2020; Poletti, 2019; Rourke et al.,2002) are observed in some non-verbal learning disability populations, which may have altered visual capability as the primary cause of non-verbal LD. Hence, the development of fundamental motor skills (FMS) may be affected by poor movement accuracy, uncoordinated movement, and impaired balance associated with visual limitations (Engel-Yeger, 2008; Zipori et al., 2018).

It is essential to assess motor skills in children with amblyopia, due to children's dependency on visual-perceptual processing for controlling movement and balance skills (Hirabayashi & Iwasaki, 1995; Sá et al., 2018; Tseng & Chow, 2000; Zipori et al., 2018) and since visual motor impairment may compromise children's decisions to engage or not engage in physical or sports activities (Engel-Yeger, 2008; Zipori et al., 2018). Studies have shown that children with amblyopia have deficits in spatial (e.g., location, fixation, attention, perception of movement) and temporal processing that impede their abilities to move in space and manipulate objects (Asper et al., 2000; Engel-Yeger, 2008; Hess et al., 1997).

Zipori et al. (2018) used the balance subtests of the Bruininks-Oseretsky Test of Motor Proficiency 2 (BOT2) to investigate whether children with amblyopia have reduced balance compared to both children with strabismus without amblyopia and children without visual problems. This widely accepted test can assess both static and dynamic balance functions. These researchers found that normal vision played an important role in the development and maintenance of balance control. When normal binocular vision was disrupted in childhood due to strabismus and/or amblyopia, both vision and balance were compromised.

Other studies with children with amblyopia mostly investigated fine motor skills (Birch et al., 2019; Fronius et al., 2004; Grant & Moseley, 2011; Niechwiej-Szwedo et al., 2011; Webber et al., 2008). To our knowledge, only a few studies of this kind have investigated the development of gross motor skills (Engel-Yeger, 2008; Zipori et al., 2018), despite their importance to a physically active lifestyle (Robinson et al., 2015; Tomkinson et al., 2018). Since children with amblyopia may present deficits or delays in visuomotor development and motor action planning (Atkinson, 2017), there is reason to suspect they may also experience interference in the development of fundamental motor repertoires (motor competence).

Based on past studies, children with amblyopia have difficulties performing real world tasks such as catching and throwing objects, walking, running, driving, and reading. Their impairment in motor control, specifically in the speed and precision of movement, seems to be more related to loss of stereoacuity (binocular perception of depth that allows quick and easy access to spatial awareness information) (Hrisos et al., 2006) than to the severity of amblyopia (Birch, 2013; Webber et al., 2008).

Motor competence (MC) can be defined as a person's ability to be proficient in a broad range of locomotor, stability and manipulative skills (Fransen et al., 2014; Luz et al., 2016), as proposed by the theoretical framework developed by Gallahue et al. (2013). MC has been found to be important for developing an active and healthy lifestyle (Holfelder & Schott, 2014; Lubans et al., 2010). Evaluating all the constructs of MC enables a diagnosis of motor development delays among children with amblyopia. Accordingly, in this study, we aimed to assess the MC of children with and without amblyopia. Our hypothesis was that children with amblyopia would show lower levels of MC than their peers without amblyopia, particularly with regard to MC components of stability and object manipulation.

## Method

### *Participants*

Participants in this study were 165 primary school children in Lisbon, Portugal, aged between 6–9 years (77 boys; 88 girls). The children had no motor, cognitive or health impairments other than visual amblyopia that could affect their performance on the motor tests. They were divided into three groups: (a) non-amblyopia ($n = 97$; 51 boys and 46 girls), (b) corrected amblyopia ($n = 37$; 15 boys and 22 girls), and (c) non-corrected amblyopia (i.e., underdiagnosed amblyopia; $n = 31$; 11 boys and 20 girls) based on their visual acuity on the Snellen chart (see Table 1). Of the 37 children with a confirmed diagnosis of amblyopia (corrected amblyopia), five were diagnosed with myopia, 19 with astigmatism, six with strabismus and myopia, six with hyperopia, and one with another diagnosis. According to parental report, the time for correcting amblyopia (i.e., wearing corrective lenses) varied from 1–72 months: (a) 1–6 months = five children; (b) 7–12 months = five children; (c) 16–18 months = three children; (d) 24 months = 3 children; (e) 36 months = six children; (f) 48 months = three children; (g) 54 months = one child; (h) 60 months = two children; (i) 66 months = one child; (j) 72 months = two children; and (k) parents of six children did not report the correction time.

The research protocol for this study received ethical approval from the investigators' Research Ethics Committee. School directors approved the study, and parents, or legal guardians of all underage children gave their informed consent for each child's participation. Additionally, all children gave their verbal assent prior to data collection. All procedures were in accordance with the 1964 Helsinki declaration and its later amendments. Researchers were trained in

**Table 1.** Means (Standard Deviations) of Participant Characteristics Across Three Visual Acuity Groups.

| | Groups | | |
|---|---|---|---|
| | Non amblyopia (n = 97) | Corrected amblyopia (n = 37) | Non corrected amblyopia (n = 31) |
| Age (years) | 7.6 (1.2) | 7.6 (1.3) | 6.9 (1.0) |
| Weight (kg) | 28.4 (6.7) | 29.4 (8.1) | 26.5 (6.7) |
| Height (meters) | 1.29 (0.0) | 1.28 (0.1) | 1.24 (0.0) |
| BMI (kg/m$^2$) | 16.8 (2.6) | 17.7 (3.1) | 17.0 (2.8) |
| PAQ-C | 2.5 (0.3) | 2.5 (0.3) | 2.4 (0.3) |

BMI – Body Mass Index; PAQ-C – Physical Activity Questionnaire for Older Children.

the specifications of the assessment's protocols. Evaluations of motor competence were conducted in the school gymnasium.

## *Procedures*

We assessed the children's visual acuity with the Snellen chart (Kronbauer et al., 2008), their motor competence with the Motor Competence Assessment (MCA) battery (Luz et al., 2016; Rodrigues et al., 2019), and physical activity with the Physical Activity Questionnaire for older children (PAQ-C; Crocker et al., 1997; Kowalski et al., 1997), as described next.

*Visual Acuity Assessment.* Visual acuity was assessed using the Snellen chart (Kronbauer et al., 2008). The Snellen chart is the universally accepted method for measuring visual acuity, a screening tool for detecting poor vision. The test consists of reading images aloud (i.e., letters, and numbers arranged in eight horizontal lines); visual acuity is considered to be the lowest line on the chart on which the individual is able to "read" all images correctly (Zapparoli et al., 2009). Corrective lenses are allowed in the non-specific clinic. We positioned the Snellen Optotype Chart six meters away from the child and fixed it one meter from the floor. The evaluation was performed by non-compressive occlusion of one eye at a time, starting with the occlusion of the left eye, and visual acuity values were recorded on a logarithmic scale in the individual questionnaire. Children who used optical correction underwent the test with glasses only. Low visual acuity corresponds to font values that are $\leq$0.7 in the Snellen table and, according to the criteria of the World Health Organization (WHO), visual acuity greater than 0.7 is considered normal.

The Snellen test results were used to divide the children into three groups: non-amblyopia, corrected amblyopia and non-corrected amblyopia (underdiagnosed amblyope, i.e, without optical correction). To classify a child as an underdiagnosed amblyope, the following conditions had to be met: (a) visual acuity values $< 0.7$ on the Snellen scale in one or both eyes (although the WHO considers values less than or equal to 0.7); (b) difference in vision between the eyes greater than two lines on that scale, and (c) signs and symptoms of ophthalmic changes, such as forward body tilt, furrowed brow, tearing, continuous blinking of the eyes and strabismus. All tests with low visual acuity results $< 0.7$ were repeated, and, if the test results were confirmed, the child was included in the underdiagnosed amblyopic group and referred to the ophthalmologist for diagnosis.

Parents and/or guardians answered a questionnaire (prepared by the main investigator) that queried parents with regard to their child's ophthalmic dysfunction, specifically as to whether the child's vision was characterized by decreased uni or bilateral visual acuity (medical diagnosis), the type and time of treatment performed, and the time needed to correct the child's visual focus with glasses or contact lenses.

*Motor Competence Assessment (MCA).* The MCA is composed of two tests for each component of MC (i.e., stability, locomotor, and manipulative) (Luz et al., 2016; Rodrigues et al., 2019). All motor tests are scored quantitatively (product-oriented), without a marked developmental (age) ceiling effect, and based on the child's feasible execution of motor tasks. In this study, testing conditions were arranged prior to beginning assessments, and children performed all tests in small groups (usually about five children per task). All participants completed a 10-minute general and standardized warm-up before beginning the tests. Examiners were previously trained in administering all tests, and the following requirements were standardized: (a) a proficient demonstration of each test technique was provided along with a verbal explanation; (b) every participant experimented with each task before the actual test administration; (c) the instructions emphasized that children should try to perform the task at their maximum capacity (e.g., "as fast as possible" for the stability tests and $4 \times 10$ shuttle run; "as far as possible" for the standing long jump; and "as hard as possible" for the manipulative tests); and (d) motivational, but no verbal feedback was provided.

*Shifting platforms:* The test began with the participant standing with both feet on one of the two wooden platforms (25 cm $\times$ 25 cm $\times$ 2 cm with four small 3.7 cm feet at the corners) with the second wooden platform on the floor at his side (right or left as convenient). At the starting commands (Ready and Go) the participant reached for one platform, moved it to the opposite side and stepped onto it as quickly as possible. This process was repeated for 20 seconds, and each successful transfer from one platform to the other was scored with two points (one point for moving the platform to the other side; and one point for moving the body to the platform). Participants were given two of these 20-

second trials, with a 2-minute interval between trials, and only the child's best score was used in subsequent analyses.

*Jumping Sideways:* Standing on one side of a rectangular surface (100 cm length × 60 cm width) divided by a small wooden beam (60 cm length × cm high 2 cm width) in the middle, the participant jumped sideways with two feet together (simultaneously) as fast as possible for 15 seconds. The test began with voice commands (Ready and Go), and each correct jump (two feet together, without touching outside the rectangle, and without stepping in the wooden beam) was scored with 1 point. We considered only the child's best of two trials in further analyses.

*Shuttle Run:* From the start line (100 cm × 5 cm), and at the voice command (Ready and Go), the participant ran at maximal speed to a second line (100 cm × 5 cm) placed 10 meters apart where two rounded blocks (10 cm high, 5 cm in diameter) were placed immediately after the line and 25 cm apart from each other. The participant picked up one of the blocks, ran back to the starting line, and placed it on the ground after the line (no matter what position), and then ran back to retrieve the second block. The test was finished when the participant passed the start/finish line carrying the second block. Two trials were allowed with a 2-minute interval between them, and we used only the best score of the two trials for further analyses.

*Standing Long Jump*: The participant jumped as far as possible, using both feet simultaneously on the take-off and landing. The distance (in cm) was measured between the starting line and the place where the back of the heel closest to the starting line landed. The final score was the child's best score out of three correctly conducted trials.

*Ball Throwing Velocity:* Using an overarm action, the participant threw a ball at a maximum speed against a wall. The participant could choose to have a preparatory balance (one or two steps) before throwing the ball. For children between 3–10 years old a tennis ball was used (diameter: 6.5 cm; weight: 57 g). The ball's peak velocity was measured in meters/second with a velocity radar gun (e.g. Pro II Stalker radar gun) placed at the side of the participant's dominant hand at about his/her shoulder level and facing the target wall. The final score was the best of three correct trials.

*Ball Kicking Velocity:* The participant kicked a soccer ball at a maximum speed against a wall. The participant could choose to assume a preparatory balance (1–2 steps) before kicking the ball. For children between 3–8 years old, we used a number three soccer ball (circumference: 62 cm, weight: 350 g). For children 9–10 years of age, we used a number four soccer ball (circumference: 64 cm, weight: 360 g). The ball's peak velocity was measured in meters/second with a velocity radar gun (e.g. Pro II Stalker radar gun) placed at the side of the participant's dominant foot, close to the line on the floor at one meter from the ground and facing the target wall. Every participant performed three trials, with the final score being the child's best trial.

### Physical Activity Assessment

All children completed the physical activity questionnaire for older children (PAQ-C) to assess the physical activity they had performed over the last seven days. The PAQ-C consists of nine structured questions aimed at characterizing different aspects of physical activity. Responses are coded on a 5-point Likert scale, with higher scores indicating higher levels of physical activity. Scores $< 3$ indicated that children were sedentary (Crocker et al., 1997; Kowalski et al., 1997). The information from the PAQ-C, obtained through assisted interviews based on the European Portuguese version of the PAQ-C (Sabino et al., 2018) was used to classify the children's physical acitivity.

*Statistical Analysis.* We performed an *a priori* power analysis to estimate the needed participant sample size for this study. We used Gpower 3.3 and set alpha at $p < 0.05$, a statistical power estimate R 0.80, a predicted effect size of 0.25, and an error value of 0.05. This calculation yielded a required sample size of 90, or a sub-sample size of 30 participants for each group. We calculated descriptive statistics (means and standard deviations) to characterize participants' age, weight, height, BMI, physical activity level (PAQ-C) and motor competence (MC), with data aggregated by each amblyopia group. We transformed the raw scores for each task into Portuguese normative values (percentiles), according to age and gender, based on data from Rodrigues et al. (2019). We computed stability, locomotor and manipulative category scores as the sum of the two tasks' percentiles. We calculated total MC as the mean of the percentiles for all tests.

We verified the normality of the data distributions with the Shapiro-Wilk test and used Levene's test to assess the homogeneity of the variables. The omnibus statistical significance of the difference in MC between the three groups (non-amblyopia, corrected amblyopia and non-corrected amblyopia) was determined by using one-way analysis of variance (ANOVAs) for each MCA task (shifting platforms, jumping sideways, shuttle run, standing long jump, ball throwing velocity, ball kicking velocity), and for the individual MC components (stability, locomotor and manipulative), following up with post-hoc Least Significant Difference (LSD) tests when necessary. We set the statistical significance level at $p <$ less 0.05 for all statistical tests. All statistical analyses were conducted in SPSS Version 23.0 (IBM Corporation and other(s) 1989, 2013, Armonk, North Castle, New York, United States).

## Results

Table 1 presents the participants' descriptive statistics for age, weight, height, body mass index (BMI) and physical activity level (PAQ-C), according to the three amblyopia conditions. An examination of the children's physical activity levels (from the PAQ-C) revealed that, on average, children in all groups were classified as sedentary, as they averaged scores $<3$. Only 12.4% of non-amblyopia children were classified as active, with scores between 3 and 5; 10.8% of corrected amblyopia children were active and 9.7% of non-corrected amblyopia were active.

## MCA Tasks

Overall, the ANOVA results on the MCA showed that the non-amblyopia children presented the best MC results, followed by the corrected amblyopia group and then the non-corrected amblyopia group.

On the shifting platforms task, the ANOVA showed a significant group effect ($F_{2,162} = 5.947$, $p < 0.003$) (see Table 2) with post hoc tests indicating that the non-amblyopia children performed significantly better than either their non-corrected amblyopia peers ($p = 0.010$) or their corrected amblyopia ($p = 0.005$) peers. No significant differences were found between the corrected amblyopia and non-corrected amblyopia groups ($p = 0.742$) on the shifting platforms task.

Regarding the jumping laterally task, the ANOVA again showed significant differences between groups ($F_{2,162} = 4.035$, $p < 0.019$), with post hoc tests indicating that children in the non-amblyopia group performed significantly better than their peers in the non-corrected amblyopia group ($p = 0.008$).

In the standing long jump task, there was a tendency toward better performance by the non-amblyope children, but this analysis failed to reach a significant group effect ($F_{2,162} = 2.800$, $p = 0.064$) (see Table 2).

**Table 2.** Means (Standard Deviations) of the Percentiles and Significant Group Difference Findings of MCA Tasks, MCA Components and of MCA Total Score by Amblyopia Group.

| MCA tasks | 1 Non-amblyopia | 2 Corrected amblyopia | 3 Non-corrected amblyopia | Significant group differences |
|---|---|---|---|---|
| Shifting platforms | 82.18 (22.33) | 69.32 ± 31.94 | 67.29 ± 25.63 | 1>2; 1>3 |
| Jumping laterally | 50.31 (24.96) | 42.70 ± 24.75 | 36.13 ± 27.68 | 1>3 |
| Standing long jump (cm) | 68.46 (23.13) | 57.92 ± 27.61 | 61.97 ± 23.57 | – |
| Shuttle run (s) | 50.54 (24.21) | 39.59 ± 27.29 | 31.26 ± 23.31 | 1>2; 1>3 |
| Ball throwing velocity (km/h) | 64.73 (26.77) | 56.51 ± 30.02 | 50.71 ± 28.90 | 1>3 |
| Ball kicking velocity (km/h) | 51.94 (29.67) | 51.19 (26.91) | 46.26 (31.64) | – |
| MC components | | | | |
| Stability | 66.24 (19.36) | 56.01 (23.5) | 51.71 (23.20) | 1>2; 1>3 |
| Locomotor | 59.50 (20.18) | 48.75 (24.40) | 46.61 (20.01) | 1>2; 1>3 |
| Manipulative | 58.33 (22.47) | 53.85 (21.40) | 48.48 (25.19) | – |
| MCA total | 66.24 (19.36) | 56.01 (23.57) | 51.71 (23.20) | 1>2; 1>3 |

For the shuttle run, the ANOVA showed a significant difference between groups ($F_{2,162} = 8.034$, $p < 0.001$) (see Table 2), with post hoc testing showing that the non-amblyopia children performed significantly better than both the non corrected amblyopia group ($p = 0.024$) and the corrected amblyopia group ($p < 0.001$). No significant differences were found between the corrected amblyopia and non-corrected amblyopia groups ($p = 0.169$).

For ball throwing velocity, the ANOVA showed a significant group effect ($F_{2,162} = 3.389$, $p = 0.036$) (see Table 2). Although the non-amblyopia group presented better results than the other groups, post hoc analyses revealed only one statistically significant difference between the non-amblyopia group and the non-corrected amblyopia group ($p = 0.016$).

Regarding kicking ball velocity, the ANOVA did not reveal a significant group effect ($F_{2,162} = 0.443$, $p = 0.643$) (see Table 2). The performance of the three groups was very similar on this task.

### *MC Components*

Considering the MC components, there were main group effects for the components of stability ($F_{2,162} = 7.035$, $p = 0.001$) and locomotor ($F_{2,162} = 6.210$, $p = 0.003$) (see Table 2). Post hoc tests showed that the non-amblyopia children performed significantly better than both their non-corrected amblyopia peers (stability: $p = 0.001$; locomotor: $p = 0.004$) and their corrected amblyopia peers (stability: $p = 0.013$; locomotor: $p = 0.009$), but there were no significant differences between the corrected amblyopia and non-corrected amblyopia groups (stability: $p = 0.403$; locomotor: $p = 0.678$) (Table 2). For the manipulative component, the ANOVA did not reveal statistically significant differences ($F_{2,162} = 2.311$, $p = 0.102$) (see Table 2).

Regarding the MC total score, the ANOVA revealed a statistically significant difference between groups ($F_{2,162} = 7.703$, $p = 0.001$) with post hoc testing revealing that the non-amblyopia children performed significantly better than both the non-corrected amblyopia group ($p = 0.001$) and the corrected amblyopia children ($p = 0.011$), but no significant differences were found between the corrected amblyopia and non-corrected amblyopia groups ($p = 0.345$) (see Table 2).

## Discussion

In this study, we assessed the motor competence of children with and without amblyopia. Amblyopia is related to the presence of strabismus, refractive errors, astigmatism, and anisometropia. Determination of visual acuity is generally the first clinical step to identify the presence of amblyopia (Asper et al., 2000; Webber, 2018), and we used the Snellen chart to evaluate visual acuity of children in this study, referring all children with uncorrected amblyopia to a specialist to confirm the diagnosis of amblyopia.

Overall, our results showed that children without amblyopia presented better MC results on the MCA battery than children with corrected amblyopia and non-corrected amblyopia. These results confirmed our hypothesis that children with amblyopia would show lower levels of motor competence. These group differences were mainly in terms of the stability and locomotor components of the MCA, implying that dynamic balance and the change of spatial position and direction of movement (Gallahue et al., 2013), rather than the manipulative MCA component (ball throwing velocity and ball kicking velocity), were the bases for these group findings.

Vision played an important role in affecting stability motor skills by influencing these children's posture and balance (static and dynamic), which are fundamental for the performance of tasks involving stability. This is consistent with a generally accepted integration of visual and motor skills in child development and with a presumption that impairments in either visual or motor systems would be expected to be associated with impairment in the accompanying system (Atkinson, 2017). Prior research has established that, with age, there is a decreased dependence on the visual system for motor skills. There is a progressive mastery of the somatosensory and vestibular systems in the control of postural balance (Sá et al., 2018; Steindl et al., 2006). This process continues until all of the systems are fully calibrated to adult levels of performance, at which point the vestibular system seems to dominate (Bucci et al., 2009; Hirabayashi & Iwasaki, 1995; Sá et al., 2018; Steindl et al., 2006). It is worth mentioning that, in the MCA battery, the stability tasks and one task of the locomotor component (shuttle run), involve interaction with objects, requiring other components of visual functioning, such as acuity, binocular vision (stereopsis) and eye movements, all of which may be compromised in children with different degrees of amblyopia (Fox, 1990; Gaertner et al., 2013a, 2013b; Paulus et al., 1984). The results in our study for the jumping sideways, shifting platforms and the shuttle run tasks indicate that children with amblyopia were not making good use of compensatory postural mechanisms and/or of other sensory systems (proprioception and vestibular) to adapt to challenging tasks that involved interaction with objects. These findings support the hypothesis of a broad "dorsal stream vulnerability" in neurodevelopmental disorders with different etiologies, such as amblyopia (Atkinson, 2017; Braddick & Atkinson, 2013). Visual processing is divided into dorsal and ventral streams, with the ventral stream (occipito - temporal pathway) processing color and form, allowing object recognition, and the dorsal stream (occipito-parietal pathway) processing motion and spatial information, controlling action. Hence, dorsal and ventral visual streams interact in complex object-oriented movements (Milner, 2017; Poletti, 2019), such as jumping sideways, shifting platforms and shuttle run tasks.Our results indicate that vision components affected postural control among children with mild visual disorders, both in the non-corrected amblyopia group (as expected) and in the corrected amblyopia group. Thus, amblyopia correction did not lead to an immediate improvement in motor skill performance, probably because improvement from this correction requires further time for brain processing adaptations in the visual processing system associated with the execution of motor tasks. These findings are in line with the results of studies involving children with strabismus (Dickmann et al., 2016; Gaertner et al., 2013b; Legrand et al., 2011; Lions et al., 2013; Odenrick et al., 1984) and with a study by Zipori et al. (2018) that found a reduction in balance control among children with amblyopia and strabismus without amblyopia, compared to control children with normal vision.

Another point regarding children with corrected amblyopia is their need to adapt to wearing eye glasses. This adaptation is often not easy, when glasses are used only in certain situations, such as when reading or during activities that take place in the classroom, but not during physical education classes or class breaks. Yet, throughout these occasions there is time for directed or free play situations, in which children experience activities that involve motor skills; and the use of corrective lenses in these circumstances would assist in their adjustment to altered visual information needed for movement. The time that these children with amblyopia remain undiagnosed can further influence their motor skill development, especially because early stages of development are characterized by an integrated visual-motor dependence (Brandt, 2003; Gibbs et al., 2007; Losse et al., 1991; Woollacott & Shumway-Cook, 1990). For childern with amblyopia, this integrated visual-motor functioning is altered by impaired binocularity that affects postural control and balance needed for stability, locomotor and manipulative MC. We expected that children with amblyopia would depend more on vestibular and somatosensory system inputs for postural control, compared to children without amblyopia. However, it seems that these children could not fully substitute for missing visual input with compensatory postural mechanisms from other sensory systems in order to keep up with peers regarding balance and other fundamental aspects of MC.

Regarding the manipulative tasks, namely ball throwing velocity and ball kicking velocity, contrary to our hypothesis, we found no significant amblyopia group differences. Ball throwing velocity was poorer among children with uncorrected amblyopia in relation to children without amblyopia, perhaps indicating that visual input assisted but did not determine performance in the same way as it did for fine motor tasks, such as directing the hand at a target in space to grasp it (Brandt, 2003).

The development of manipulative skills involves muscle coordination and the ability to organize visual information, and this development varies from child to child. The ball throwing task depends on such factors as the size and age of the child and the size of the ball (Gabbard, 2008). When throwing a ball, the child predominantly uses the proximal joints of the upper limb that must be coordinated with the transfer of weight in the lower limbs and with trunk rotation movement (Goodway et al., 2019). Visual information has an important role in this process, not only to assist postural control, as previously mentioned, but also because other components of visual functioning, such as acuity, binocular vision (stereopsis) and eye movements, are necessary for a successful action. These components are more or less affected in children with amblyopia (Fox, 1990; Gaertner et al., 2013a, 2013b; Paulus et al., 1984).

Kicking a ball is influenced by the same aspects mentioned above for the throwing task, but in kicking it is the foot and not the hand that is used to project the ball into space (Goodway et al., 2019). Despite the similarities between these tasks, there were no differences between any of the amblyopia groups for the kicking task, and having amblyopia or not had no influence on ball kicking. It should be noted that many children fail to master this task even during the normal course of development, perhaps helping to explain why we found no significant differences between ambyopia groups on this task.

School-age children with deficits in fundamental motor skills, such as those associated with amblyopia, may also have impaired school performance, delayed social development and weaker self-esteem (Gabbard, 2008). Thus, it is important to assess the fundamental motor skills (motor competence) of children with amblyopia to avoid long-term consequences of undiagnosed and uncorrected vision problems (Legrand et al., 2011; Lions et al., 2013). This circumstance highlights the need for child professionals to have access to and use reliable developmentally normed assessment instruments (Bucci et al., 2016). The MCA battery we administered revealed the greatest MC difference between non-amblyopia and amblyopia children. The advantage of the MCA is that it can be administered without putting children at any physical risks due to their amblyopia. Additionally, it is easy to perform, even by children with vision problems, and it isolates the three components of MC for a more refined analysis. Large scale screening programs enable health conditions to be identified so that effective interventions can be offered. The assessment of visual acuity is also essential in child screening programs. In our sample, we identified 31 children with visual acuity disorders who might have remained undiagnosed and vulnerable to delays in their motor development and larger developmental implications as noted.

## *Limitations and Directions for Further Study*

Among this study's limitations, the children with corrected amblyopia showed widely varied lengths of time wearing corrective lenses with small numbers of children in each category of specific corrective time periods. Thus, we were unable to further analyze the effect of amblyopia correction time on the development of motor competence. In cases where visual impairment is a primary problem, such as with amblyopia, it is essential to determine not only the level of visual impairment, but also its impact on children's motor, cognitive and behavioral development, including the impact of varied correction time periods. In addition, it would have been interesting to include a hand-eye coordination task as a supplement to the MCA test battery. Tasks that involve eye-hand coordination skills for reaching and accurately grasping and manipulating real-world objects involve a series of actions that are critically influenced by visual information about the three dimensional properties of the target and of the near-space environment in which the target resides (Grant & Moseley, 2011). Future studies might address this motor component among children with amblyopia and better analyze the effect of variations in amblyopia correction times. Finally, in light of our sample size, we did not separately analyze the relationship between amblyopia and motor competence in boys and girls, and this analysis may also be a target of investigation for future researchers.

## Conclusion

Our findings suggest that vision plays an important role in the development of children's motor competence, with specific implications for children with amblyopia, not just for fine motor but also for gross motor skills and, in some instances, even when amblyopia has been corrected. We found that children without amblyopia presented better results than children with corrected and especially uncorrected amblyopia, particularly in stability and locomotion components of motor competence. The development of fundamental motor skills, especially of stability and locomotor skills, may be affected by visual limitations, as poor visual processing leads to poor movement accuracy, uncoordinated movements, and impaired balance. The identification of children at risk of not developing adequate levels of motor competence, due to visual impairment or other reasons is important because reduced motor competence can have lifelong effects on physical activity, sports participation, fitness level, and overall health.

### Ethical Approval

The study approved by the Research Ethics Committee of the Scientific Council of the Lisbon School of Health Technology (CE-ESTeSL-N°47.-2019).

### Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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