Part B

Neurocognitive functioning in talented soccer players

Chapter 4

Visuomotor coordination in youth elite soccer players, amateur soccer players and non-players

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ABSTRACT

Purpose Research has shown that elite athletes outperform lower-level athletes and non-athletes on several essential aspects of performance such as visual reaction time, visual search behavior and executive functions, but studies on visuomotor coordination are inconsistent. Aim of the present study was to investigate visuomotor coordination in youth elite soccer players in a dynamic environment, by increasing difficulty levels and providing predictable and unpredictable conditions in which participants have to adapt their motor behavior.

Methods Youth elite soccer players (n=36), youth amateur soccer players (n=48) and non-players (n=40), aged 7 to 12 years, were compared on visuomotor coordination abilities using a task that measured visuomotor coordination in both structured (predictable) and unstructured (unpredictable) conditions at varying difficulty (speed) levels. Group differences were tested using repeated analyses of variance.

Results No group differences were found on the predictable condition. However, it was found that at the highest speed levels, youth elite soccer players exhibited lower variability in unpredictable situations as compared to amateur soccer players and non-players.

Conclusions These results may provide preliminary evidence for high adaptability of the visuomotor system of highly talented athletes.

INTRODUCTION

Clearly, visual skills are essential for high performance in elite athletes. Superior visual acuity, stereoscopic vision, and visual reaction time are examples of skills that characterize elite athletes (e.g., Christenson & Winkelstein, 1988; Sillero, Refoyo, Lorenzo, & Sampedro, 2007; Mann, Williams, Ward, & Janelle, 2007). In addition, for open sports such as soccer, tennis and basketball, the more complex visuomotor coordination may be even more important for performance. In open sports, athletes have to react on changing behavior from opponents and other situations in the field such as ball positions (Di Russo et al., 2010). Visuomotor coordination is defined as continuous adjustment of movements throughout movement execution, based on the combination of visual and motor information (Rilk, Soekadar, Sauseng, & Plewnia, 2011). It might be argued that excellent visuomotor coordination is essential for elite athletes because many sports require the ability to quickly process visual and motor information during movements and to adjust motor actions accordingly (Helsen & Starkes, 1999). Knowledge about visuomotor coordination in young talented athletes may be useful, because next to physical and anthropometrical characteristics (Huijgen, Elferink-Gemser, Lemmink, & Visscher, 2014), visuomotor coordination could be an important determinant for successful performance in open sports.

In a study by Kioumourtzoglou and colleagues (1997), it was found that a simple eye-hand coordination task was not able to discriminate between youth elite rhythmic gymnasts and non-elite rhythmic gymnasts. Likewise, a study on adult boxers found no differences between highly successful boxers and less successful boxers on a visuomotor coordination test (Obimiński, Mroczkowska, Kownacka, & Stabno, 2011). In contrast, a recent study by Faber, Oosterveld, & Nijhuis-Van der Sanden (2014) showed that on an eye-hand coordination task, national level youth table tennis players outperformed regional level youth tennis players. In addition, one study found that youth soccer players outperformed non-players on eye-hand and eye-foot coordination tasks (Montés-Micó , Bueno, Candel, & Pons, 2000), but another study by Vänttinen, Blomqvist, Luhtanen, & Häkkinen (2010) found no differences between youth elite soccer players, amateurs soccer players and non-players on an eye-hand-foot coordination task. However, these studies did not address visuomotor coordination or motor adaptation, which are important in changing situations. Contrasting results have thus been found on visuomotor coordination in athletes, and it remains unclear whether talented athletes show superior visuomotor coordination as compared to lower level athletes or non-athletes, and if so, if this is solely expressed during execution of the sport, or whether underlying capacities to excel in visuomotor coordination in talented and young athletes are present and measurable at any time.

In the present study, youth elite soccer players are compared to youth amateur soccer players and non-players on a visuomotor coordination task. In addition, the relationship between participation in physical activity (i.e., sports, active transport, physical education and outdoor play) and visuomotor coordination will be explored as previous findings on the relationship between physical activity and visuomotor coordination are contrasting (e.g., Okely, Booth, & Patterson, 2001; Reed, Metzker, & Philips, 2004). In contrast to other studies addressing visuomotor coordination in athletes, our task is able to assess visuomotor coordination in a dynamic environment by increasing difficulty levels and providing structured (predictable) and unstructured (unpredictable) conditions in which participants have to adapt their motor behavior (de Kieviet et al., 2013). This allows comparisons between visuomotor coordination in a predictable environment where participants can prepare their movements based on visual information, and visuomotor coordination in an unpredictable environment where constant updating of movement execution is required. Given the requirements for performance in soccer at the highest level, it is hypothesized that youth elite soccer players outperform both other groups on accuracy and variability in the unpredictable conditions.

METHODS

PARTICIPANTS

A total of 124 children between 7 and 12 years of age (all boys) participated in the study: One group of 36 elite soccer players (mean age=10.1 ± 1.4); one group of 40 amateur soccer players (mean age=10.5 ± 1.3), and a third group of 48 children not involved in organized sports (non-players, mean age=10.4 ± 1.4). All participants lived in or around Amsterdam. The elite soccer players were recruited from the youth academy of a Dutch professional soccer club and were following the talent development program of the youth academy (for more information, see Verburgh, Scherder, van Lange, & Oosterlaan, 2014). The amateur soccer players were recruited from an amateur soccer club and non-players were not involved in any organized sports activities (i.e., were neither member of a sports club, nor participating in an extracurricular sports program at school) and were recruited at elementary schools. Participants were free of known behavioral, learning and medical conditions that might impact neurocognitive functioning and were excluded when they had an IQ<70 as measured by a short version of the Wechsler Intelligence Scale for Children III (described later, Wechsler, 2002). Demographics are displayed in table 1.

VISUOMOTOR COORDINATION TASK

Visuomotor coordination was examined using a newly developed computerized task as described by de Kieviet et al. (2013). Participants were instructed to follow the trail of a moving caterpillar with the index finger of their dominant hand on a touch screen. There were two conditions in this task. First, a structured condition was administered in which the caterpillar followed a structured path (a counterclockwise circle with a diameter of 19.5 cm). In the second condition, the caterpillar followed a randomly (unstructured) generated path (that was identical for all participants). In both conditions, there was one practice trial with the caterpillar moving at a speed of 40 pixels/s. Following the practice trial, speed of the caterpillar increased in four consecutive trials (80, 120, 160 and 200 pixels/s). Each trial lasted 30s. The position of the index finger on the touch screen in terms of x and y coordinates was stored every 16.6 ms, and compared with x and y coordinates of the position of the (nose of the) caterpillar to determine accuracy of visuomotor performance. To minimize the possibility that poor visuomotor performance reflected distraction from the task, the 5% most deviating data of a trial were removed for each child. Absolute differences in the x and y directions between the position of the caterpillar and the position of the index finger on the touch screen were averaged across each trial as a measure of accuracy of performance. Variability in accuracy of performance was the sum of squared means of the variances in xy directions. Accordingly, dependent measures were accuracy (mean distance in ms) and variability (standard deviation in ms) of performance in the structured and the unstructured condition, at four different speed levels. Accuracy and variability served as measures of precision and stability of visuomotor coordination, respectively.

FULL-SCALE IQ ESTIMATION

IQ was measured using a short-form of the Wechsler Intelligence Scale for Children (3rd edition; WISC-III), using the subtests Vocabulary and Block Design. Both subtests correlate strongly (r>0.90) with Full-scale IQ (Groth-Marnat, 2001).

PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOR

Physical activity was assessed using a self-report questionnaire (TNO, 2007). Dependent measures were active transport to school (i.e., cycling or walking), playing outdoor and physical education during a typical week 13 questions about physical activities (e.g., “How many days a week are you going to school walking or cycling?”). In addition, frequency and duration of soccer training and matches (if applicable) were assessed.

The second part of the questionnaire comprised questions on sedentary behavior. Participants were required to indicate how many days per week and how many minutes per day they participated in each of the activities listed (e.g., gaming on a personal computer, tablet or game console). Dependent measures were TV watching, computer time and active gaming (e.g., Wii Sports®). Adequate reliability and validity have been reported for the questionnaire (TNO, 2007).

PROCEDURE

Measures were administered in the same order for each participant by trained assessors using standardized instructions. Data were collected during the competitive soccer season at the training centers of the professional soccer and amateur soccer club, respectively. Data of the non-players were collected at elementary schools, during or immediately after school time. All participants and parents and/or legal guardians were informed about the procedures of the study before giving their informed consent prior to participation. The study was approved by the local ethical committee of the VU University.

STATISTICAL ANALYSES

SPSS version 22.0 (SPSS Inc., Chicago, IL, USA), and bootstrapping with the statistical software R 2.15.2 were used for the statistical analyses (R Development Core Team; http://www.R-project.org). Technical difficulties with the visuomotor coordination task resulted in 1.0% missing data (n=5 measures in the elite soccer players, n=5 in the amateur players, and n=3 in the non-players), which were replaced by expectation maximalization (Tabachnick & Fidell, 2001). Group differences in age, IQ, physical activities and computer time were tested using univariate analyses of variance (ANOVA) and Pearson correlations were performed to determine the possible relationship between those variables and dependent variables of the visuomotor coordination task. If necessary, variables were entered as a covariate in subsequent analyses.

Dependent variables from the visuomotor coordination task were derived using MATLAB and resulted in 2 x 4 (condition x speed) variables for accuracy and 2 x 4 variables for variability. Given the skewed nature of the accuracy and variability data, the non-parametric bootstrap-F approach for repeated measures designs was used (10,000 bias-corrected replications) to derive all dependent variables. First, to investigate whether there are differences in the (structured) condition between groups, the bootstrapped data for accuracy and variability of the structured condition were subjected to separate one-way repeated-measures ANOVAs with speed (four levels: 80, 120, 160, 200 pixels/s) as within-participant factor and group (three levels: elite soccer players, amateur soccer players and non-players) as the between-participant factor. Second, to study group differences on visuomotor coordination in the unstructured (unpredictable) condition, difference scores were calculated between the unstructured and the structured condition for each speed level, which resulted in four dependent measures for accuracy and four dependent measures for variability. In this way we were able to investigate group differences visuomotor control under unstructured conditions, controlling for performance under structured conditions. These measures were subjected to the same analytic strategy as used for the structured condition. Separate one-way repeated-measures ANOVAs with speed (four levels: 80, 120, 160, 200 pixels/s) as within-participant factors and group (three levels: elite soccer players, amateur soccer players and non-players) as the between-participant factor. To model the effects of speed, polynomial contrast analyses were used to examine linear, quadratic, or cubic trends. If a significant effect of group emerged, post hoc contrast analyses controlling overall alpha level (p<.05) were conducted to further study group differences.

RESULTS

Group differences in age, IQ, physical activities and sedentary behavior are displayed in table 1. The amateur soccer players were slightly older than the elite soccer players (p=.046). Pearson correlations between age and the dependent measures of the visuomotor task showed that higher age was associated with better performance on all dependent measures derived from the visuomotor task (.27>rs<.41, .002<ps>.001), therefore, age was included as covariate in all subsequent analyses. Furthermore, IQ of the elite soccer player group was lower as compared to the other two groups, but because Pearson correlations between IQ and the dependent variables of the visuomotor coordination task were not significant (-.01>rs<-.18, .93<ps>.06), IQ was not included as covariate in subsequent analyses. Partial correlations (controlling for age) testing the association between active transport, physical education, outdoor play, sports, TV watching, computer time, active gaming and the dependent measures derived from the visuomotor task were all not significant and below the threshold for a small effect (.12>rs<-.16, .90<ps>.08). Therefore, the variables derived from the physical activity and sedentary behavior questionnaire were not included as covariate in subsequent analyses.

ACCURACY OF VISUOMOTOR COORDINATION PERFORMANCE

The one-way repeated measures ANOVA for accuracy on the structured condition revealed a linear main effect of speed (F(3,112)=3.4, p<.05, partial eta^2=.09), indicating decreasing performance at higher speed levels. Furthermore, no main effect of group was found (F(2,114)=.93, p=.40), and the interactions between group and speed was not significant (F(3,112)=3.4, p=.70). Group contrasts were also not significant: elite versus amateur soccer players p=.53, 95% confidence interval (CI)=-.71–2.5, amateur players versus non-players p=.99, 95% CI= -1.9–.71, and elite players versus non players p=.99, 95% CI=-1.0–1.9. A main effect of age was found (F(1,114)=10.2, p<.01, partial eta^2 =.08), indicating that accuracy increased with age. Interaction terms with age were not significant (Fs<1, ps>.65).

To investigate group differences visuomotor coordination under unstructured conditions, difference scores were calculated between the unstructured and the structured condition to control for performance under structured conditions. Results again showed a linear main effect of speed (F(1,114)=16.2, p<.001, partial eta^2=.13), indicating that difference scores became larger with increasing speed levels. Furthermore, there was no main effect of group (F(1,114)=.86, p=.43, but a significant interaction between the linear effect of speed and group was found (F(2,114)=3.1, p=.045, partial eta^2=.06). Post hoc contrast analyses between groups showed a significant interaction between the elite and the amateur soccer players (p=.047, partial eta^2=.06), between amateur soccer players and non-players (p=.018, partial eta^2=.07), but not between elite soccer players and non-players (p=.93). As is shown in figure 1, this indicates that the elite soccer players and the non-players showed a smaller difference in accuracy between the structured and unstructured condition as compared to the amateur soccer players at higher speed levels.

VARIABILITY OF VISUOMOTOR COORDINATION PERFORMANCE

For variability, ANOVA on data of the structured condition showed a linear main effect of speed (F(3,112)=2.9, p<.05, partial eta^2=.07), indicating decreasing performance at higher speed levels. Furthermore, no main effect of group was found (F(2,114)=1.4 p=.27) and the interaction between group and speed was not significant (F(6,226)=1.5, p=.19). Group contrasts were also not significant: elite versus amateur soccer players p=.37, 95% CI=-.38–1.7, amateur soccer players versus non-players p=.60, 95% CI=-1.5–.46, elite soccer players versus non-players p=1, 95% CI=-1.1–.80. Furthermore, a main effect of age was found (F(2,114)=1.3, p<.05), indicating that variability decreased with age. Interaction terms with age were not significant (Fs<1, ps>.40).

To investigate performance in the unstructured condition, difference scores were calculated between variability of the unstructured and the structured condition to control for performance under structured conditions. Results showed a linear trend for speed (F(3,112)=2.3, p=.078, partial eta^2=.06), indicating somewhat increased difference scores at higher speed levels. Furthermore, a trend was found for group (F(2,114)=2.3, p=.09, partial eta^2=.04) as well as a significant interaction between speed and group (F(2,114)=4.4, p=.015, partial eta^2=.08). Post hoc group contrasts showed significant interactions between group and speed between elite and amateur soccer players (p<.01, partial eta^2=.12), elite players and non-players (p<.05, partial eta^2=.05), but not between amateur soccer players and non-players (p=.17). As illustrated in figure 1, at the highest speed level, the elite soccer player group showed less difference in variability between the structured and unstructured condition as compared to the other groups.

DISCUSSION

The present study compared three groups of preadolescent children on a computerized measure of visuomotor coordination: Elite soccer players, amateur soccer players, and children who are not involved in any organized sports. Aim of the study was to extend existing literature on visuomotor coordination in youth elite soccer players using a non-sport specific task with difficulty manipulations in structured (predictable) and unstructured (unpredictable) conditions, in order to examine whether highly talented soccer players have higher underlying capacities in the visuomotor system as compared to lower level soccer players and non-players.

It was found that the structured (predictable) condition did not differentiate between groups. This finding is in line with studies showing that elite athletes do not outperform amateur athletes or non-athletes on simple neurocognitive tasks such as two-choice reaction time tasks (Kida, Oda, & Matsumura, 2005; Di Russo et al., 2006; Endo, Kato, Kizuka, & Takeda, 2006; Nakamoto & Mori, 2008).
On the difference scores between the unstructured (unpredictable) and structured (predictable) condition, a significant interaction was found between difficulty level (speed) and group on accuracy, where the amateur soccer players exhibited a larger difference between the conditions at higher speed levels than the two other groups. Overall, the elite players showed the best accuracy, although the comparison with the sedentary children did not reach significance.

In other words, the elite players may exhibit a greater ability to adapt to highly unpredictable situations, which was particularly expressed in a smaller performance decrement at the more difficult unstructured trials as compared to performance at the high speed structured trials both in terms of variability. It may be possible, that the many hours of training in high-level and fast soccer explain the better adaptability of the elite soccer players. However, such an explanation seems unlikely because in that case differences would have emerged between the amateur soccer players and non-players in our study, which were not observed.

Table 1. Group characteristics

	Elite Soccer Players (EP, N=36) Mean (SD)	Amateur Soccer Players (AP, N=40) Mean (SD)	Non-players (SC, N=48) Mean (SD)	Test Statistic	p-value	Posthoc Tukey (p<.05)
Age	10.0 (1.1)	10.7 (1.3)	10.3(1.2)	F(2,121)=2.9	.054	EP<AP
Handedness (% right)	89.6	83.7	84.1	χ2=1.1	.59	
IQ	94 (10.9)	107.3 (13)	101.7 (14.9)	F(2,121)=12.1	<.001	EP<AP=SC
BMI Underweight (%) Healthy (%) Overweight (%)	17.5 (.38) 100% 	16.9 (1.8) 12.2 77.6 10.2	17.9 (3.1) 4.5 75 20.5	F(2,121)=3.9	.43	
Total physical activity (min/week)	1223 (400.7)	1177.9 (717.2)	741.7 (354.1)	F(2,121)=13.6	<.001	AP=EP>SC
Transport (minutes/week)[a]	154.9 (92.6)	133.5 (87)	98.2 (68.1)	F(2, 121)=4.8	.01	EP>SC
Physical Education (minutes/week)	96.4 (48.9)	91.8 (52.1)	95.9 (30.1)	F(2,121)=.13	.88	
Outdoor Play (minutes/week)	585.7 (320.3)	681.3 (425.5)	547.5 (327.7)	F(2,121)=1.5	.22	
Sports (minutes/week)	386 (60.9)	271.3 (101.8)	n/a	F(1,74)=33.4	<.001	EP>AP
Total sedentary behavior (min/week)	476.6(348.2)	674(495)	883.2 (641.8)	F(2,121)=6.2	<.01	EP<SC
TV Watching (minutes/week)	308.8 (223.2)	445 (327.1)	581.2 (380.9)	F(2,121)=7.3	.001	EP<SC
Computer/Internet/Gaming (min/week)[b]	167.8 (177.9)	229 (234.7)	302 (371.1)	F(2,121)=2.4	.09	
Active Gamingb (minutes/week)[c]	61.4 (78.5)	75.8 (129.2)	59.0 (107.2)	F(2,121)=.29	.75	

Note: SC=sedentary children; AP=amateur soccer players; EP= elite soccer players; IQ=intelligent quotient; BMI=body mass index. [a]Actively walking or cycling to school. [c]Using computer, internet, playing games or at game console (e.g. Playstation®, Nintendo®). [b]Playing active games on the computer or game console (e.g. Wii Sports®).

Age was related to both accuracy and variability, with better performance on both measures with increasing age. This is in line with other studies in school-aged children (e.g., Piper, 2011; Stirling, Lipsitz, Qureshi, Kelty-Stephen, Goldberger, & Costa, 2013), and suggest that visuomotor coordination continues to develop during childhood. However, because no interactions were found between age and group, findings of the present study do not provide evidence for the suggestion that differences on visuomotor coordination between soccer players and non-players increase with age (Väntinnen et al., 2010).

With regard to the relationship between visuomotor coordination and participation in physical activity, we found no significant associations between involvement in soccer, active transport, outdoor play, physical education, and visuomotor coordination, which is in contrast to other findings (e.g., Fisher et al., 2005; Okely et al., 2001; Reed et al., 2004), although in these studies mainly gross motor skills were examined and weak correlations were found. To examine this relationship in more detail, it is recommended to include more objective measures of physical activity in future research, for instance by using heart rate monitors or accelerometers (see for a review, Rowlands et al., 2014).

Furthermore, no significant association was found between time spent on the computer, and (active) gaming, on the one hand, and visuomotor coordination, on the other hand. These findings are in contrast with other studies addressing this relationship (e.g., Rosenthal et al., 2011; Barnett, Hinkley, Okely, Hesketh, & Salmon, 2012). However, a limitation of our study is that no clear distinction was made between interactive games such as Nintendo Wii Sports® and non-interactive games such as playing FIFA soccer at the Playstation®, which may explain differences between the findings of Barnett and colleagues (2012) and ours. It is important to make this distinction in type of games since it is shown that active games involve gross motor skills and light-to-moderate physical activity (Biddiss & Irwin, 2010).

Another limitation of the current study is that only one aspect of visuomotor coordination was included, which clearly mostly appealed to eye-hand coordination. In future research, the task used in the present study may be modified to assess for instance eye-hand-foot coordination, which is more complex and is important in many open sports such as field hockey, rugby and basketball. Furthermore, as visuomotor coordination in unpredictable situations may be crucial for performance in open sports, it should be investigated whether this skill could be trained. Such an approach may be valuable, since several studies show that visual training in athletes help in decision making and accuracy in performance in open sports (Oudejans, Heubers, Ruitenbeek, & Janssen, 2012; Vine, Moore, & Wilson, 2012).

In conclusion, our study adds to the existing literature on eye-hand coordination in young athletes by showing that, at the highest speed levels, youth elite soccer players exhibit better variability in visuomotor coordination in unpredictable situations as compared to amateur soccer players and non-players. This was examined with a task assessing visuomotor coordination in dynamic situations, providing preliminary findings for high adaptability of the visuomotor system of highly talented athletes.

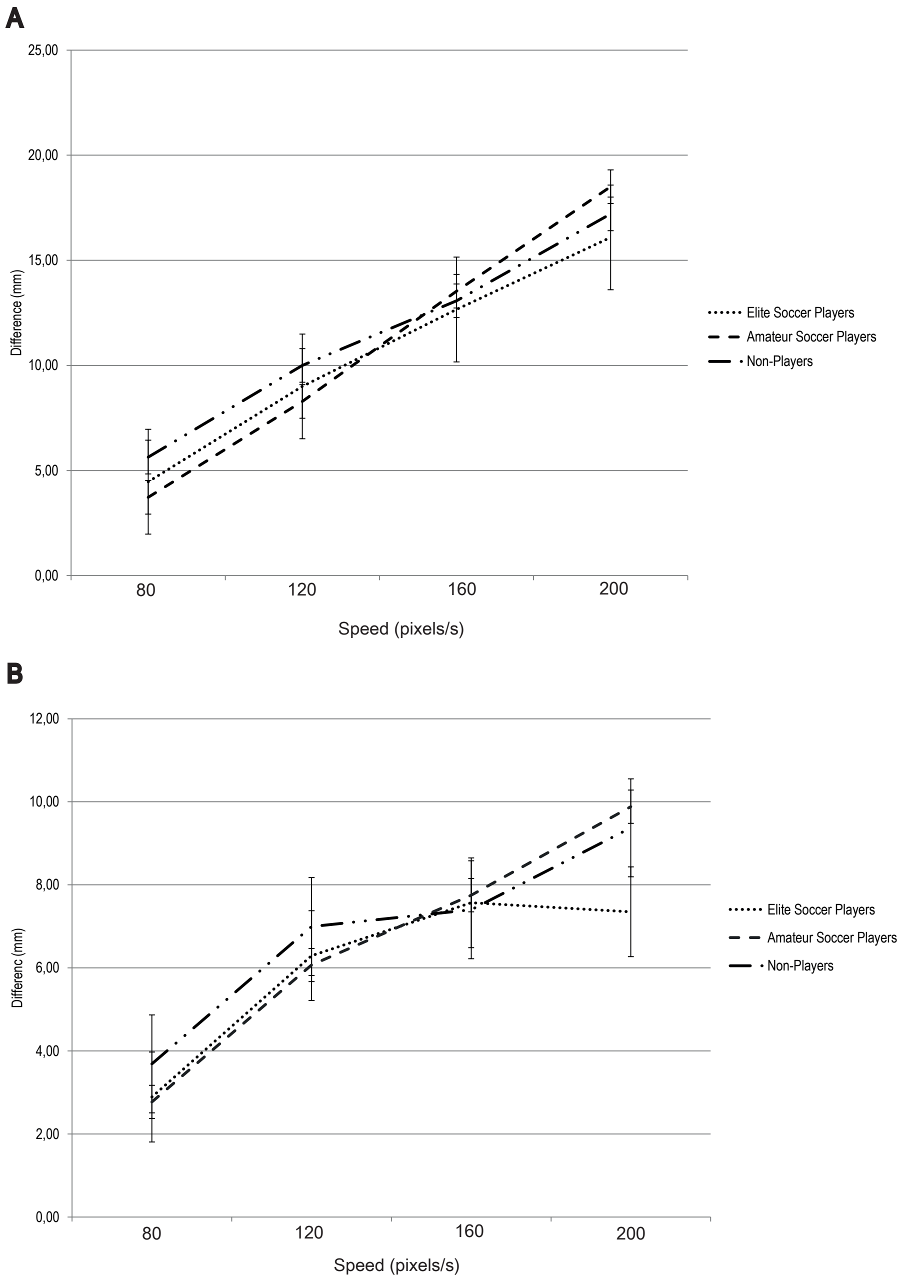

Figure 1. Results of the difference scores between the structured and unstructured condition for accuracy (A) and variability (B) for elite soccer players, amateur soccer players, and non-players.

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