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Cognition and Sport: How Does Sport Participation Affect Cognitive Function?

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Abstract

Cognitive-executive functions are essential processes for daily activities, academic, occupational and sporting success, health and quality of life. One way to improve them is through regular participation in physical activities. The aim of the study is to assess the effect of sports training on cognitive-executive functions. A total of 328 boys (220 young soccer players and 108 boys without participation in sport training) aged 12.0–14.9 years performed tests to assess their cognitive-executive functions (Deary-Liewald task, Corsii block test, Trail Making test). Two Way ANOVA was used to evaluate the significance of differences in cognitive functions in terms of two factors - sport (sporting vs. non-sporting boys) and age (12, 13 and 14-year old boys) and their interaction (group*age). ANOVA showed a significant effect of sport (in favour of soccer players) and age (increasing performance due to age in the soccer players group, ambiguous results in the non-sporting group) in the Deary-Liewald task assessing simple and choice reaction time. There were no significant effects of the observed factors in the Trail Making test and Corsii block test tasks. No interaction effect was demonstrated in any of the cognitive-executive tasks. The results indicate the influence of age and training process, especially in sports games, on reaction abilities. Short-term memory and visual control, perception, working memory, and cognitive flexibility are not significantly affected by participation in sport.

Keywords: *soccer players, non-sporting boys, simple reaction time, choice reaction time, visuospatial working memory, speed of visual search*

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Introduction

Physical activity is essential not only for physical but also mental health (García-Hermoso et al., 2021). Positive neurophysiological consequences of PA have been described by Cirrik & Hacioglu (2018), who referred to the increased level of hippocampal neuroplasticity due to exercising.

A direct positive correlation between PA and neurophysiological characteristics, including cognition, has been indicated by several studies. Specifically, PA can positively influence attention (Moratal et al. 2020), executive functions (Hillman et al., 2009), as well as academic achievements (Vaquerizo, 2022). It is also important to distinguish between acute PA and long-term (chronic) PA. Festa et al. (2023) describe that acute PA induces a transient response, whereas long-term and regularly performed PA produces a long-lasting effect.

In the context of long-term and regular PA, different ef-

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fects can be observed in relation to the nature of the activities. Closed-skill sports (gymnastics, running, etc.) are more predictable and stable, are less affected by environmental influences, and are performed according to predetermined movement patterns that are likely to require lower cognitive demands (Gu et al., 2019). In contrast, sports games (i.e. soccer, badminton, etc.) and sports with a direct contact with an opponent (martial arts) involve open motor skills and thus the response to external situational demands and active decision-making are crucial (Gu et al., 2019), which may lead to increased demands on the level of cognitive function. In this sense, Möhring et al. (2022) reported that children practicing sports containing open-skill activities had higher cognitive engagement and the ability to respond flexibly to changing situations than children practicing sports with predominantly closed-skill activities. Therefore, intentional practice of team-based, strategic sports may also represent a transfer to enhanced performance on non-sport-related cognitive tasks (Rahimi et al., 2022). Differences in the level of cognitive and especially cognitive-motor skills were also identified with respect to performance. Positive relationships have been found between measures of executive functions (Vestberg et al., 2017), attention test (Verburgh et al., 2014) and sports performance in youth soccer players. Differences between elite and sub-elite players were particularly evident at the highest age groups (Ehmann et al., 2022). Based on these findings, the difference in cognitive functions may be even more significant when comparing the sporting and general populations. Verburgh et al. (2016) compared youth soccer players with non-athletic children and found out that elite players outperformed sub-elite players and non-athletes in terms of inhibition, short-term memory, and working memory, while non-athletes were outperformed by sub-elite soccer players, as well. Children's participation in organized sports activities increases their fitness, and children with higher levels of fitness and coordination have been shown to have higher levels of attention and memory performance.

These theories suggest that children's long-term physical and sports activity may contribute to improving the quality of children's cognitive function; therefore, we hypothesize that children participating in organized sports training in soccer at the age of 12-14 years will perform better on tests of cognitive-motor functions (i. executive function; ii. visuospatial working memory; iii. speed of visual search and executive function) compared to the population without participation in organized sport activities.

Methods

Participants and design

The research was conducted as a two-group two-factor nonrandomized cross-sectional study. A total of 328 boys aged 11.8-14.9 years were divided according to their participation in organized physical activities into sporting and non-sporting group. Healthy adolescents who did not exhibit impaired mental functioning or medically identified cognitive decline were included in the research. In terms of decimal age, participants were divided into three age groups of 12-, 13- and 14-year olds with respect to the factor of sports activity, applying decimal age grouping (example 12.0 - 12.99 y.). Detailed demographic data for the groups of participants divided in terms of sport activity factor and age are presented in Table 1. The sporting group consisted of young talented soccer players (n = 220) and testing was carried out during the competitive season. They participated in an organized training process 3-4 times per week and played one match during the weekend, with a total load of 6-8 hours during the week. The training age of the players ranged from 4.0 - 7.5 years. The non-sporting group consisted of 108 boys who indicated in the demographic surveys that they did not participate in sports, did not engage in organized physical activity, or were included in it for less than half a year, as well as participants who practiced sports activities that did not include an element of systematic training (e.g. firefighting, skateboarding, riding a scooter, etc.).

Table 1. Demographic characteristics of research sample (mean ± SEM [95 % CI])

sport_group	Age_group	n	Age (y)	BW (kg)	BH (cm)	BMI (kg.m-2)
Sporting	12 y.	87	12.6±0.03 [12.5-12.6]	47.2±1.02 [45.2-49.3]	157.3±0.83 [155,6-158,9]	19.0±0.31 [18.4-19-6]
	13 y.	51	13.4±0.04 [13.3-13.4]	50.2±1.37 [47.4-52.9]	162.9±1.26 [160.4-165.5]	18.8±0.35 [18.1-19.5]
	14 y.	82	14.6±0.03 [14.5-14.6]	60.8±1.15 [58.5-63.1]	173.1±0.80 [171.4-174,8]	20.2±0,29 [19.7-20.8]
Non-sporting	12 y.	59	12.3±0.06 [12.1-12.4]	45.4±0.90 [43.6-47.2]	156.8±1.02 [154.7-158.8]	18.4±0.27 [17.9-18.9]
	13 y.	29	13.5±0.06 [13.3-13.6]	51.6±1.95 [47.6-55.6]	161.0±1.82 [157.3-164.7]	19.8±0.53 [18.7-20.9]
	14 y.	20	14.3±0.06 [14.2-14.4]	60.8±3.29 [53.9-67.7]	174.3±1.42 [171,4-177.3]	19.9±0.93 [18.0-21.9]

Note. BW - body weight; BH - body height; BMI - Quetelet's index

Variables

The study variables included somatic parameters (body height, body weight, BMI) as a part of description of the groups of participants and variables describing cognitive function (decision-making level, visuospatial working memory, visual screening ability and executive speed) divided to data subgroups in context of sport activity participation (sporting/non-sporting group) and age (12, 13, 14 y. old).

Diagnostic procedures were performed by individual participants on the same day always in the morning between 8:00 AM and 1:00 PM, maintaining the chronological order of the tests as listed below. Between each test item assessing cognitive function, a rest interval of 3-5 min was maintained corresponding to the time required to record the test result and prepare the next test item. Prior to the examination of cognitive ability level, demographic data were tested, namely body height with the accuracy of 0.1 cm using a Seca 217 stadiometer (SECA, Ham-

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burg, Germany) and body weight with the accuracy of 0.1 kg using an InBody 230 bioimpedance body composition analyser (Biospace Co., Ltd.; Seoul, Korea). BMI was calculated using a standard formula of body weight (in kg) divided by the square of body height (in m). Decision-making levels were assessed from the results of the Deary-Liewald task (Deary et al., 2010), including the measurement of simple (SRT) and choice (CRT) reaction time. To assess the visuospatial working memory, Corsi Block-Tapping test (Kessels et al., 2000). Speed of visual screening ability and executive functions were evaluated using Trail Making Test TMT-A a TMT-B (Tombaugh, 2004). All tests were performed by the test subjects alone in a quiet room with a trained examiner present, minimizing outside distractions.

In the Deary-Liewald SRT task, a single white square is presented in the center of the screen against the blue background. Whenever a black "X" appears within the square, a subject must respond as quickly as possible by pressing a spacebar key on a standard keyboard with the index finger of their dominant hand. The computer randomly generates 20 stimuli and the average reaction time is summarized in the results. In the CRT task, there were four stimuli and participants had to press the button that corresponded to the correct response. Four white squares ordered in a row are presented in the center of the screen. A black "X" appears in one of the squares per trial, and participants must indicate the correct answer by pressing one of the four keys, each corresponding to one of the spatial positions of the squares on the screen. From the leftmost to the rightmost square position, the following keys had to be pressed, respectively: the "z" key with the left middle finger, the "x" key with the left index finger, the "," key with the right index finger, and the "." key with the right middle finger (Peskar et al., 2023). A total of 40 temporally and positionally randomized stimuli were generated. Both SRT and CRT tasks were preceded by training trials consisting of 9 stimuli.

In the CORSI Block-Tapping task, nine pink squares are randomly positioned on the screen and (some of them) flash yellow in a certain order (different each run). A participant is instructed to repeat the observed sequence by clicking on the squares in the same order as presented before. With each iteration, the sequence is becoming longer, starting with 2 and increasing by one each time. If a mistake is made, a second trial with the same sequence-length but different square distribution is offered. The task is finished after two consecutive fails or when the longest sequence of 9 items is successfully demonstrated. The score reflects the longest correctly reproduced sequence and ranges from 2-9 (Peskar et al., 2023).

Trail Making Test Part A (TMT-A) is based on time needed to connect an array of 25 numbers in ascending order randomly distributed on a sheet of paper, by drawing a continuous line between them as quickly and accurately as possible. In the TMT-B, participants are required to connect an array of both numbers and letters in alternating ascending order (1, A, 2, B, 3, C, …) with the same emphasis on speed and accuracy (Hagenaars et al., 2018). In both versions, the result is a score in the form of the time taken to complete the prescribed task.

Two-way analysis of Variance (ANOVA 2x3) was used to assess the effect of group factor (sporting/non-sporting group) and age (12-, 13-, and 14-years old group) and their interaction on the level of selected cognitive abilities. To check the condition of normal distribution of research data for the use of Two-way ANOVA, rank transformation of raw values of the observed characteristics was used and the Shapiro – Wilk test showed violation of normality (nonpublished data). Levene's test was used to assess the equality of variances of the dependent variable between groups. The effect size of the observed factors was evaluated using Eta squared (η^2). Multiple comparisons of means were performed using a LSD post hoc analysis. Statistical significance was assessed with a 5% probability of incorrectly rejecting the null hypothesis ($\alpha = 0.05$). Statistical analyses were performed using IBM SPSS Statistics software, version 20 (IBM SPSS Inc., Chicago, IL).

Results

Table 2 shows the results of the ANOVA in the context of the observed factors of sports activity and age of adolescent boys. Table 3 presents the values of the descriptive statistical analysis of the observed variables of cognitive functions for each subset of participants.

Table 2. Results of assessment of the influence of sports activity and age on the level of cognitive abilities of adolescents (ANOVA 2x3)

Test	Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
	group	64483.7	1	64483.67	7.822	0.005	0.024
SRT	age	80263.6	2	40131.78	4.868	0.008	0.029
	group*age	28784.1	2	14392.04	1.746	0.176	0.011
	group	45532.1	1	45532.14	5.369	0.021	0.016
CRT	age	108933.4	2	54466.69	6.423	0.002	0.038
	group*age	4780.8	2	2390.38	0.282	0.755	0.002
	group	16185.5	1	16185.54	1.998	0.158	0.006
CBT	age	22152.1	2	11076.05	1.368	0.256	0.008
	group*age	27460.8	2	13730.39	1.695	0.185	0.010
	group	333.8	1	333.80	0.038	0.845	0.000
TMT-A	age	52607.6	2	26303.78	3.004	0.051	0.018
	group*age	21297.6	2	10648.81	1.216	0.298	0.007
	group	3385.2	1	3385.15	0.383	0.536	0.001
TMT-B	age	41563.2	2	20781.61	2.354	0.097	0.014
	group*age	11992.6	2	5996.29	0.679	0.508	0.004

Note. df – degree of freedom; F – value of ANOVA testing criterion; Sig – p value; SRT – simple reaction time; CRT – choice reaction time; CBT – Corsi block tapping test; TMT-A – trail making test version A; TMT-B – trail making test version B

For none of the cognitive ability tests, two-way ANOVA (2x3) showed a significant effect of the interaction of the observed factors group*age (p>0.05). Partial Eta squared achieved values interpreting a small effect size of the studied factors of age and sports activity on the level of cognitive abilities (Table 2). The age factor proved to be statistically significant in the decision-making levels in the simple and choice reaction time tests (p<0.05). However, there were no statistical differences between age groups in the level of visuospatial working memory (CBT) and speed of visual search and executive function (TMT-A and TMT-B), regardless of the sports activity performed.

Similarly, the participation in organized sports training was shown to be a significant factor only in the comparison of executive functions in SRT and CRT tests (p<0.05), when soccer players performed better in all age groups (Table 3).

Table 3. Results of aggregated descriptive characteristics of cognitive abilities of adolescents assigned to groups according to sport activity and age (presented as mean±SEM [95% CI])

Group	Age	SRT (ms)	CRT (ms)	CBT (no)	TMT-A (s)	TMT-B (s)
sport	12 y. old	291.5±2.8 [286.0-297.0]	485,6±7.7 [470.5-500.7]	5.29±0.12 [5.06-5.52]	31.1±0.88 [29.4-32.9]	68.6±2.8 [63.0-74.1]
	13 y. old	282.5±3.6 [275.7-290.0]	467,4±10.0 [447.0-487.1]	5.78±0.15 [5.48-6.08]	28.5±1.15 [26.2-30.8]	68.9±3.7 [61.7-76.1]
	14 y. old	274.7±2.9 [269.1-280.4]	463,0±7.9 [447.4-478.5]	5.77±0.12 [5.53-6.00]	27.4±0.91 [25.6-29.2]	59.7±2.9 [54.0-65.4]
non-sport	12 y. old	295.1±3.4 [288.5-301.8]	520,2±9.3 [501.8-538.5]	5.42±0.14 [5.14-5.70]	29.0±1.07 [26.9-31.1]	69.3±3.4 [62.6-76.0]
	13 y. old	289.7±4.8 [280.2-299.2]	475,2±13.3 [449.1-501.4]	5.45±0.20 [5.05-5.85]	29.3±1.53 [26.3-31.5]	64.7±4.9 [55.1-74.3]
	14 y. old	289.3±5.8 [277.8-300.7]	479,4±16,0 [447.8-510.9]	5.40±0.24 [4.92-5.88]	27.9±1.84 [24.2-31.5]	62.0±5.9 [50.4-73.5]

Note. SEM – standard error of mean; 95% CI – 95% confidence interval; SRT – simple reaction time; CRT – choice reaction time; CBT – Corsi block tapping test; TMT-A – trail making test version A; TMT-B – trail making test version B

Discussion

The results of the study indicate higher levels of executive function in the form of simple and choice reaction (Deary-Liewald task) in individuals performing organized physical activity across the observed age groups. On the other hand, there were no differences in visuospatial working memory (Corsi block test) as well as in visual screening ability and executive speed (TMT-A and TMT-B). The influence of the age factor was manifested in the group of sporting individuals (in the group of football players), where the level of the observed cognitive functions gradually increased, with the exception of the comparison of groups 13- and 14-years old in visuospatial working memory, where stagnation of performance was recorded. On the contrary, in the group of non-sporting individuals, the results are heterogeneous without the possibility of determining trends of development due to the influence of age."Simple and choice reaction time (Deary-Liewald task)

Reaction time is conditioned by the speed of perception, the conduction of impulses to the controlling organs along afferent pathways and then to the executive organs in the periphery along efferent pathways; in summary, the speed of task execution is conditioned by the level of mental processes, especially thinking. Reaction time is also an important factor influencing athletic performance in team sports, and by performing sporting activities, cognitive stimulation can be achieved in relation to reaction time (Vidal et al., 2015). Consistent with the above premise, in terms of mean SRT values, better performances were observed in all defined age groups of soccer players (Table 3). The differences in simple reaction time between the sporting and non-sporting population have been also confirmed in studies by Vestberg (2017) or Badau et al. (2024).

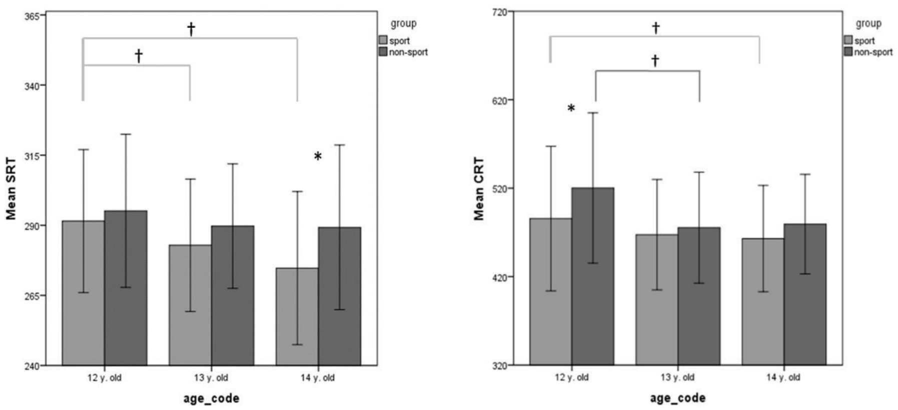

Figure 1. Graphical comparison of performance in simple reaction time (SRT) and choice reaction time (CRT) tasks in relation to sports activity and age with identified significant differences based on LSD post hoc analysis († significant differences between age groups; * significant differences between soccer and non-sporting group)

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Significant differences in SRT were only demonstrated in the group of 14-year olds. The reasoning can be found in the structure of the required activity in the test. As the test used was nonspecific in the context of the physical activity performed, the daily routine activities seem to generate a sufficient number of stimuli to ensure a relative equality of performances between sporting and non-sporting individuals at the beginning of the adolescent period. This assumption has been confirmed by observing the differences in terms of age. In the group of soccer players, the difference in the level of simple response between age groups was significant (group 12 vs. 13 y. old, similarly for 12 vs. 14 y. old), in contrast to the group of non-athletes (Figure 1). These results may support the theory of a positive effect of long-term physical activity with a predominance of open skills on simple reaction time.

The choice or cognitive reaction time involves the selection or combination of some tasks in the shortest possible time in relation to the nature, complexity, and intensity of the stimulus (Quoilin et al., 2019). The recorded changes indicated the same trend as in the SRT evaluation. Better performance of soccer players in the CRT was captured across the whole spectrum of age groups tested. However, in contrast to the SRT, the sports activity factor proved significant in this test only for the youngest group of 12-year-old boys. It appears that the impact of training containing CRT stimuli, typical for team sports such as football, is predominant especially in younger age groups. At the age of 12 years, soccer players have been involved in controlled training for approximately 5 years. With increasing age, non-sporting individuals are more frequently exposed to stimuli requiring a response to an unanticipated stimulus in both school and out-of-school environments (in the context of both the physical education content and greater independence in extracurricular physical or other activities) and thus the distinctions between trained and untrained individuals become blurred. In both groups (sporting and non-sporting group), increasing levels of CRT with age were observed. While in the non-sporting group, Figure 1 identifies a sharp increase in performance when compared 12- and 13-year olds with confirmation of significance and subsequent stagnation of performance, in the sporting group, performance improved gradually in the context of age with significant changes in CRT levels in a two-year interval (comparison of 12- and 14-year olds). The results of a group of soccer players are in line with Beavan et al. (2020), who confirmed a positive relationship between age and executive functions in a large cohort of elite youth soccer players. Similarly, Hielmann et al. (2021) reported increasing levels of CRT across the U12 - U17 categories.

Visuospatial working memory (Corsi Block-Tapping test)

Working memory is described as the ability to temporarily store and process information, and as reported by Gathercole et al. (2004), its level increases linearly from childhood to adolescence. This is consistent with results in a group of soccer players, where in the Corsi block test results, an increasing level of short-term working memory with increasing age (both in terms of means and lower limit of performance 95% CIs) were observed. In the case of non-athletes, results of the age comparison are not clear. When comparing groups in the context of the physical activity factor, higher levels of short-term working memory in soccer players compared to non-sporting boys were found across all age groups (Table 3). There are studies that confirm the positive impact of physical activity on working memory (Samuel et al., 2017; Hsieh et al. 2017; Drozdowska et al., 2021). However, the differences captured were not large enough to be confirmed by statistical significance or by effect size (Table 2).

Speed of visual search and executive function (TMT-A and TMT-B)

"Lower order" cognitive processes are necessary for basic information processing. In the TMT-A test, with the exception of the 12-year old group, better results were found in soccer players compared to non-athletes. Our results are consistent with studies by Alves et al. (2013) and Nakamoto & Mori (2012), where difference in lower-order cognitive functions between the sporting and non-sporting population was not confirmed. However, even in the TMT-B test, which is classified as a test of a higher-order cognitive process, no significant differences between soccer players and non-athletic peers were found. This result is contrary to the study by Huijgen et al. (2015), who in a group of slightly older soccer players (mean age ~ 15.3) confirmed a difference in "higher-order" cognitive processes, especially in metacognition and cognitive flexibility, in terms of the level of sporting activity (elite and sub-elite soccer players), thus, figuratively, we assume there also would be a difference in comparison to the non-sporting population.

Soccer players gradually improved in TMT-A as they got older, but the differences are minimal. In the case of non-athletes, the result does not allow an age trend to be determined. Overall, no significant differences in this test in terms of either age or sport activity were observed. In the TMT-B test, a performance plateau followed by a sharp rise in performance by age 13 was recorded in athletic subjects. In the non-sporting group, performance in the TMT-B test improved with age. In summary, it can be concluded that age has a positive effect on speed of visual search and executive functions regardless of sport activity in adolescent boys.

Several limitations have been identified in the study. The first is the non-randomized cross-sectional study design, which may be prone to selection bias. However, we do not anticipate an effect on the results of this study. The second is the group size of the primarily non-sporting population. Our study group represents only a small proportion of the total cohort of non-sporting individuals in the observed age range. Therefore, the interpretation of the results is limited to the group tested and the generalisation of the study outcomes may not be adequate. A third limitation is the selection of tests assessing cognitive ability with respect to a specific sporting population (soccer players). The tests implemented are generic without corresponding specificities to the demands of soccer. On the other hand, it was necessary to choose diagnostic procedures that would not be limiting for the non-sporting group and which execution would not be dependent on the level of motor prerequisites. Last, the motivation of the participants is an essential condition for testing cognitive abilities. In the diagnostic process, participants, regardless of group affiliation, were encouraged to take the tests with as much focus and effort as possible to achieve the highest possible result.

Conclusion

The results indicate the influence of age and training process, especially in sports games, on reaction abilities. Short-term memory and visual control, perception, working memory, and cognitive flexibility are not significantly affected by participation in sport.

The test protocol used to assess general cognitive function appears to be insufficient to detect differences in cognitive function between individuals with different levels of physical activity. Previous research also suggests an improved level of cognition in individuals performing aerobic activity compared to non-sporting individuals. Therefore, we recommend that research should focus on monitoring cognition in groups with different types of physical activity. In addition, for further follow-up in this area, it would be advisable to include methods involving higher levels of motor expression in the performance of test items.

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Disclosure statement

The authors declare that there is no conflict of interest with any financial organization in relation to the research problem discussed in the manuscript.

Ethical Approval Information

Measurements were taken according to the ethical standards of the Declaration of Helsinki. The research was approved by Ethical Commission of University of Prešov (ECUP-032023PO). Participation in the study was fully voluntary and anonymous. A participant’s legal guardian received a written description of the study procedures before testing and submitted a written informed consent to participate in this study.

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