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Cognitive Functions of Youth Water Polo Players

Neven Kovačević[1,2], Frane Mihanović[3], Linda Lušić Kalcina[4], Vladimir Pavlinović[1], Nikola Foretić[1], Tea Galić[4,5]

[1]University of Split, Faculty of Kinesiology, Split, Croatia, [2]Croatian Water Polo Federation, Zagreb, Croatia, [3]University of Split, Department of Health Sciences, Split, Croatia, [4]University of Split School of Medicine, Department of Neuroscience, Split, Croatia, [5]University of Split School of Medicine, Department of Prosthodontics, Split, Croatia

Abstract

Some previous studies suggested that children's engagement in sports has been associated with the improvement of cognitive functions, especially working memory, visual-spatial memory, motor coordination and cognitive flexibility. The aim of this study was to compare cognitive functions between female and male youth water polo players and the control subjects – school children of the same chronological age who did not participate in organized sports activity. There were 23 female (14.65±1.11 years old) and 23 male (14.52±0.51 years old) water polo players (WP), members of Croatian National team enrolled in this study for cognitive testing (Stroop test). The control group consisted of 8 female (14.75±0.89 years old) and 18 male (14.28±0.89 years old) school students who did not participate in organized sports activity. There were no significant differences in psychomotor speed (Stroop Off), while youth water polo players showed better response inhibition (Stroop On) (WP 65.33±9.09 s vs. control subjects 72.78±11.97 s, P=0.030) and psychomotor ability (OnTime minus OffTime) (WP 7.22±5.18 s vs. control subjects 14.13±9.22 s) (P<0.001) than control subjects. The findings of this study suggest that children who participate in high-level water polo develop better cognitive flexibility than school students who do not participate in organized sports activity.

Keywords: *team sport games, school children, psychomotor ability, inhibition*

Introduction

Regular physical activity is known to have numerous physical benefits including prevention of the most prevalent lifestyle chronic diseases: coronary heart disease, stroke, obesity, type II diabetes and specific types of cancer, as well as enhancing cognitive function (World Health Organization, 2010). Participating in physical activities and exercise can improve the physical, perceptual, and cognitive well-being (Mandolesi et al., 2018). Moreover, superior performance of athletes with the result of the long-term practice has also been observed in some perceptual motor skills, like reaction time (Mann et al., 2007; Best & Miller, 2010; De Waelle et al., 2021). To date, the literature supports the causal link between regular physical activity and brain development particularly in the prefrontal cortical area (Best & Miller, 2010). It is well known that children's engagement in sports has been associated with the improvement of cognitive functions (De Waelle et al., 2021). Also, it has been proven that playing high-level team sport games demands well-developed cognitive functions (Kamijo et al., 2011; Bizdan-Bluma & Lipowska, 2018; De Waelle et al., 2021).

Cognitive functions include memory, attention, visual-spatial and executive functions, while language and thinking (abstract, cause and effect, creative thinking and planning) represent complex cognitive processes. Executive functions (EF) include specific mental skills such as inhibition (inhibitory control, including self-control and interference control – selective attention and cognitive inhibition), working memory and cognitive flexibility (Halligan et al., 2003; Bizdan-Bluma & Lipowska, 2018). They represent skills essential for mental and physical health; success in school and in life; and cognitive, social, and psychological development. Inhibitory control involves being able to control one's attention, behavior, thoughts, and/or emotions to override a strong internal predisposition or external stimulus, and instead do what is more appropriate or needed.

Correspondence:

N. Kovačević
University of Split, Faculty of Kinesiology, Nikole Tesle 6, 21 000 Split, Croatia
e-mail: nevenkovacevic@hotmail.com

Inhibitory control of attention (interference control at the level of perception) enables us to selectively attend, focusing on what we choose and suppressing attention to other stimuli, which might be useful in sports (Best & Miller, 2010; Diamond, 2013). Another EF is working memory, divided in verbal and non-verbal – visual-spatial working memory, also involved during sports activities (Diamond, 2013). And third component of EF is cognitive flexibility, meaning being able to change perspectives spatially or interpersonally. EF make it possible for us to mentally play with ideas, quickly and flexibly adapt to changed circumstances, take time to consider what to do next, resist temptations, stay focused, and meet novel, unanticipated challenges which is necessary for playing many complex team sport games on high level (Diamond, 2013).

Interestingly, it has been shown that elite athletes outperform non-elite athletes on more complex nonsport-specific neurocognitive functions such as inhibition (Mann et al., 2007; Vestberg et al., 2012). In the study of Vestberg and colleagues (2012), it was reported that EF even predicted later performance in soccer in terms of scoring goals and providing assists. Also, it has been proven that team sport games players have better EF compared to players from other sports (Kamijo et al., 2011).

One of the sports that requires a high level of perceptual and motor performance is water polo, as a highly demanding physical contact team sport taking place in water, not natural environment for human being, mainly including opened skills (Smith, 1998; Botonis et al., 2015). Water polo players need to process real-time actions with regard to teammate positions and ball path while constantly updating that information in working memory. They need to be able to inhibit planned actions, for example passing the ball instead of scoring themselves and they need to have well developed cognitive flexibility for better and faster adaptation to the game dynamics of one specific high-level game (Botonis et al., 2015; Diamond & Ling, 2016; De Waelle et al., 2021).

Water polo as a game includes cognitive components such as anticipation, problem solving and decision making, similar as in other team sport games (Smith, 1998; Botonis et al., 2015). In the study of Falk et al. (2004) those cognitive functions were subjectively evaluated by the coaches during only 2-3 games each season, indicating better scores by the players selected to the youth national team. Also, Kovačević et al. (2023) showed better cognitive functions of the selected players, objectively evaluated using the Stroop test. Still, both studies evaluated only cognitive functions of youth water polo players, without the comparison with the control subjects, presenting the research gap and the need for more studies about cognitive functions of youth water polo players.

Water polo has been chosen in this study because it challenges physical, perceptual and cognitive performance and the literature on the association of the cognitive performance and development in children practicing water polo is limited. Therefore, the aim of this study was to compare cognitive functions between female and male youth water polo players and the control subjects – school children of the same chronological age who did not participate in organized sports activity. It was hypothesized that children who play water polo at a high level would show better cognitive functions, especially concerning cognitive flexibility and inhibition.

Methods

Participants

There were 46 water polo players (23 female / 50%) between 12 and 16 years old (M_{age}=14.59±0.86) and 26 school children who did not participate in organized sports activity (8 female / 30.8%) between 13 and 16 years old (M_{age}=14.42±0.90) included in this study. Water polo players self-reported mean of 5 years of training experience with at least 5 training sessions per week, lasting approximately 2 hours, while control subjects self-reported no training experience in organized sports activity. The inclusion criteria for water polo group was selection to the national water polo team and for the control group no training experience in any sports. Measurements for this study were conducted from the season 2020/2021 until 2022/2023.

This study was conducted in full accordance with the ethical principles, including the World Medical Association Declaration of Helsinki and it was approved by the Ethical Committee of the University of Split School of Medicine, Split, Croatia (No: 2181-198-03-04-19-0053). Informed consent was obtained from parents or legal guardians of children participating in the study after they were introduced to the background and the aim of the study.

Measurements and procedures

Anthropometric variables included body mass and height which were measured using a stadiometer and a digital scale, respectively, while the subjects wore only light clothes. Body mass index (BMI) was calculated as body mass (kg) divided by height squared (m^2).

The detail of the experimental setup was previously explained (Kovačević et al., 2023). Cognitive functioning of the participants was measured using The EncephalApp_Stroop application (MacLeod, 1991; Homack & Riccio, 2004; Bajaj et al., 2013) which was downloaded from the Google Play app store (EncephalApp Stroop) on the 7" HD C80 MeanIT tablets (MeanIT, China). The reliability and validity of the application has been well reported previously (Bajaj et al., 2015; Luo et al., 2020). In addition, the reliability of The EncephalApp_Stroop application has been confirmed in our previous study, in a sample of 24 water polo players and test-retest showed correlation coefficient for OffTime r=0.872 (95% CI 0.723-0.944) and OnTime r=0.890 (95% CI 0.760-0.952), respectively (Kovačević et al., 2023).

The tablet screens were used to administer the task to all subjects. Tests were performed in the quiet, bright room with separate desks and it was performed in groups of 8 to 10 participants. Before the test, participants received a detailed explanation of the test battery. A trained researcher was present to ensure the test was executed correctly, without any noise, and to answer any additional questions. The participants did not report prior experiences in Stroop test.

The Stroop test comprises two components: "Off" state presenting congruent stimuli and "On" state presenting incongruent stimuli. Both components were administered after two training runs. In the easier "Off" state, the participants viewed a neutral stimulus, hashtag signs (###) presented in red, green or blue, one at a time and had to respond as quickly as possible by touching the matching color of the stimulus to the colors displayed at the bottom of the screen. The colors at the bottom of the screen were randomized and not fixed to their respective positions. In more challenging “On” state, nine of the ten presented stimuli were incongruent. The participants had to accurately touch the color of the word presented on the screen which was contradictory to the actual color, for example the word “blue” was displayed in green color and the correct response was “green”, not “blue”. Both parts of the test consisted of five runs with 10 different tasks in each run and if the participant made a mistake, pressed a wrong color, the run stopped and had to restart again until completing all five runs correctly (Bajaj et al., 2013; Scarpina & Tagini, 2017).

The specific outcomes of the Stroop test were OffTime – total time for five correct runs in the “Off” state, primarily assessing psychomotor ability; OnTime – total time for five correct runs in the “On” state which is a measure of response inhibition and motor speed. OnTime minus OffTime presented a measure of cognitive processing controlling for psychomotor speed and OffTime plus OnTime showed a composition measure of psychomotor speed and response inhibition (Bajaj et al., 2013; Scarpina & Tagini, 2017).

Statistical analyses

Data analyses were performed using statistical software MedCalc for Windows, version 19.4. (MedCalc Software, Ostend, Belgium). Continuous data were presented as mean±standard deviation while categorical variables were presented as whole number and percentage. The Kolmogorov-Smirnov test was used to assess normality of data distribution. Differences in cognitive performance between youth water polo players and school children who did not participate in organized sports activity were tested using Mann-Whitney *U* test. Additionally, a multiple regression analysis was used to determine a relationship between selected independent variables (participation in sports coded as 0-no participation and 1-currently participating in sports, age, gender, BMI) with the outcomes of the Stroop test as dependent variables (StroopOn time, StroopOff time, Ontime minus Offtime, Offtime plus Ontime). The statistical significance was set at $p<0.05$.

Results

There were 46 water polo players (WP), 23 females (50%) and 18 males (50%), with the mean age 14.59±0.74 years (median 14, 12-16 years) and 26 control subjects (C) – school children who did not participate in sports regularly, 8 females (30.8%) and 18 males (69.2%), with the mean age 14.37±0.93 years (median 15, 13-16 years) ($p=0.567$). Descriptive statistics of the whole study sample is presented in Table 1. Water polo players performed faster in StroopOn Time (65.33±9.09 s) than control subjects (72.78±11.97 s) ($p=0.030$), as well as in OnTime minus OffTime (WP 7.22±5.18 s vs. C 14.13±9.22 s) ($p<0.001$) (Table 1).

Table 1. Descriptive Statistics for Total Sample of Participants and Comparison of Results of Anthropometric Variables and Cognitive Performance between Youth Water Polo Players and Control Subjects

	Variables	Total study sample N=72	WP N=46	Control subjects N=26	p
Anthropometric characteristics	Age (years)	14.53±0.87	14.59±0.86	14.42±0.90	0.708
	Body height (cm)	172.13±8.88	174.33±8.60	167.40±7.68	0.003*
	Body mass (kg)	65.28±10.08	67.15±9.95	61.28±9.36	0.029*
	Body mass index (kg/m^2)	21.98±2.59	22.05±2.63	21.82±2.55	0.939
Cognitive functions	StroopOff time (s)	58.31±6.14	58.12±6.39	58.65±5.80	0.673
	StroopOn time (s)	68.02±11.16	65.33±9.09	72.78±11.97	0.030*
	StroopOff+StroopOn time (s)	126.33±16.33	123.45±14.84	131.42±17.84	0.098
	Ontime minus Offtime (s)	9.71±7.62	7.22±5.18	14.13±9.22	<0.001*

Note. Data are presented as mean±standard deviation. *Mann Whitney *U* test; p<0.05. WP - water polo players.

A multiple regression analysis showed that independent variables (participation in sports – water polo, gender, age and BMI significantly predicted StroopOn Time ($F=3,3784$, $p=0.015$, $R^2=0.181$) and OnTime minus OffTime ($F=5,4258$, $p<0.001$, $R^2=0.262$). Out of independent variables included in the model, only participation in sports (water polo) contributed significantly to the prediction of higher cognitive performance measured by StroopOnTime minus OffTime ($p<0.001$, $R^2=0.262$) (Table 2).

Table 2. Multiple Regression Analysis Showing the Predictive Status of Participation in Sports (Water Polo), Age, Gender and Body Mass Index on Cognitive Performance

	β coefficient	SE	t	p
StroopOff time				
Participation in sports	1.395	1.686	0.828	0.411
Gender	-0.476	1.633	-0.037	0.772
Age	-0.676	0.895	-0.755	0.453
Body mass index	0.222	0.304	0.093	0.468
R^2=0.030; R^2-adjusted=-0,033; F=0,474; p=0.755				

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Table 2. Multiple Regression Analysis Showing the Predictive Status of Participation in Sports (Water Polo), Age, Gender and Body Mass Index on Cognitive Performance

StroopOn time				
Participation in sports	10.047	2.886	3.482	<0.001*
Gender	-1.713	2.796	-0.613	0.543
Age	-1.130	1.533	-0.737	0.464
Body mass index	0.313	0.520	0.601	0.550
R^2=0.181; R^2-adjusted=0.128; F=3.378; p=0.015*				
StroopOff+StroopOn time				
Participation in sports	11.443	4.331	2.642	0.010*
Gender	-2.189	4.196	-0.522	0.604
Age	-1.806	2.300	-0.785	0.435
Body mass index	0.535	0.781	0.685	0.496
R^2=0.121; R^2-adjusted=0.064; F=2.107; p=0.091				
StroopOn minus StroopOff time				
Participation in sports	8.652	1.894	4.569	<0.001
Gender	-1.237	1.835	-0.674	0.503
Age	-0.454	1.006	-0.451	0.653
Body mass index	0.091	0.342	0.266	0.791
R^2=0.262; R^2-adjusted=0.214; F=5.426; P<0.001				

Note, β coefficient – multiple correlation coefficient; SE – standard error; t – test statistic; R^2 – coefficient of determination; R^2-adjusted – coefficient of determination adjusted for the number of independent variables in the regression model; F – F-statistic. *Significant difference between the groups, p<0.05.

Discussion

There are three main findings of this study. First, youth water polo players showed a better performance in psychomotor speed, response inhibition and motor speed than school children not participating in organized sports activity. Second, participation in water polo was found to be a significant predictor of cognitive functions in school children at the age of 12 to 16 years. And third, youth water polo players had higher values of body height and weight than their sedentary peers.

Cognitive functions

Coordinative activities, such as walking, running, jumping, kneeling, throwing, grasping, have been hypothesized to train and increase the activity in the cerebellum and prefrontal cortex and to improve such executive functions as working memory, focused attention and cognitive flexibility (Budde et al., 2008). In such activities, children must quickly integrate available information to make split-second decisions, as well as to plan and perform a sequence of habitual or unfamiliar actions (Stratton et al., 2004). Considering the nature of water polo, which stimulates components of visual-spatial attention, players need to be able to search and select targets from a spatial field requiring not only visual selective or focal attention, and peripheral visual acuity to move the attentive focus. In addition, water polo also requires more sophisticated metacognitive strategies (Stratton et al., 2004). During a match, players have to process, more or less at the same time, cues including opponents' and teammates' positions and the ball's location and direction of movement. Water polo is categorized as mostly open skills sport, characterized by activities rich in distractors, played in water, an unusual environment for human being. So, this sport should act as a powerful challenge to the ability to inhibit distraction and to stay focused for better and faster adaptation to the game dynamics of one specific high-level game (Smith, 1998; Botonis et al., 2015; Sekulić et al., 2016). Current study reported faster OnTime of water polo players in comparison to control subjects. This is consistent with categorization of water polo among the "thinking games", where the environment constantly changes and movements have to be continuously adapted (Smith, 1998). Actions must be continually updated and changed due to teammates' actions, the ball's movement, the opponents in the swimming pool. These factors are relevant to adapting, planning, problem-solving, the use of cognitive control and inhibition of first inclinations (Diamond, 2013). Youth water polo players showed better performance in psychomotor speed and response inhibition compared to school children who did not participate in organized sports activities, which is consistent with other studies that have examined the difference between athletes and non-athletes in this age group (Alesi et al., 2016; Ishihara et al., 2016; Ishihara et al., 2017). For example, Alesi et al. (2016) showed improvement of executive functions (agility, visuo-spatial working memory, attention, planning and inhibition) by children practicing football compared to the sedentary group, although children in their study were evaluated before and after only 6 months of a Football Exercise Program compared to a control group of sedentary peers.

Ishihara et al. (2016) provided evidence for the relationship between cognitively engaging exercise (i.e., game-based tennis training and coordinative exercise) and improved executive functions in 6 to 12 years old children. A longer duration of game-based exercise was positively correlated with inhibitory control and physical fitness. Coordination training was associated with improved working memory. Non-physical activity was inversely correlated with inhibitory control, working memory, and physical fitness. The results suggest that game-based tennis lessons have beneficial effects on inhibitory control and physical fitness levels, and a longer duration of coordination training is associated with better working memory (Ishihara et al., 2016). In another study of Ishihara et al. (2017) findings suggest that tennis play is associated with the development of three foundational aspects of executive function – inhibitory control, working memory and cognitive flexibility, in children 6 to 15 years old. Especially, frequent participation in tennis play is related to better inhibitory control and working memory, while longer experience of tennis play is associated with better cognitive flexibility (Ishihara et al., 2017). Although tennis belongs to self-paced sports including mostly closed skills, the results of the present study are in accordance to these findings, so additional research is needed to compare executive functions development among youth water polo players and children practicing other team sport games, as well as self-paced sports.

It has been suggested that water polo may affect the development of EF through multiple pathways: as an exciting and enjoyable activity (increasing enjoyment); by producing an "enriched environment" that places demands on multiple EF, thereby challenging and improving them; by creating opportunities for social interaction, cooperation with others, sharing leisure experiences, and receiving the encouragement of peers, increasing a sense of belonging and social support and a sense of ability and competence; and by improving motor skills and physical fitness (Alesi et al., 2016).

To the best of our knowledge, there are only few studies investigating cognitive functioning in children practicing water polo, but those studies considered only influence of cognitive functions on the selection and identification of the talented players (Falk et al., 2004; Kovačević et al., 2023). Specifically, water polo as a complex team sport employs exercises in a cognitively-engaging context and implies sophisticated and complex moves which are regulated by the prefrontal neural network. It requires high cognitive engagement and impacts many of the same processing components as those implied in executive functioning tasks: involving in a relevant task, shifting the focus of processing activities, updating of information, monitoring mental representations and inhibiting irrelevant responses. Moreover, water polo stimulates strategic and goal-directed behaviours when faced to constantly changing situations and movements (Best & Miller, 2010). The impact of water polo on the cognitive development has been explained through multiple pathways: 1) neuro-physiological by inducing changes in the brain structure; 2) contextual by producing an "enriched environment"; 3) social by creating opportunities of social interaction, cooperation with teammates, respecting rules, sharing leisure experiences, receiving the encouragement of peers; 4) motivational by increasing self-concept and self-awareness (Barenberg et al., 2011; Alesi & Pepi, 2013).

Many previous studies demonstrated the positive relationship of sports participation to multiple aspects of executive functions in children, suggesting that the frequency of participating in sports activity may be an important factor for development of inhibitory control and working memory (Ishihara et al., 2017). Such results may also be supported by our findings showing better cognitive functions of high-level water polo players, members of youth national teams, in comparison to children of the same age with no training experience in organized sports activity. Sensorimotor learning in sports and cognitive engagement during exercise has been postulated as a key mechanism linking training and cognitive enhancement, and water polo requires both, cognitive engagement and sensorimotor learning (Best & Miller, 2010; Diamond, 2013).

Anthropometric characteristics

Concerning the anthropometric variables, water polo players showed higher values of body height and weight which might be explained by specificity of the game. It has been indicated in previous studies that physical abilities and anthropometric characteristics are important factors to achieve a good level of quality in technical-tactical actions, both for young and adult water polo players, especially considering constant physical contact during the game (Sekulić et al., 2016, Vieiro et al., 2020, Kovačević et al., 2023, Kovačević et al., 2023). Greater body height and longer extremities allow players to reach for the ball more easily, to shoot and to perform blocks more efficiently (Idrizović et al., 2014, Dimitrić et al., 2022). Similar results have been presented in different sports such as volleyball or football (Tatar & Cupic, 2011).

Strengths and limitations

Considering that studied variables are strongly influenced by the age of the subjects, given the existing developmental differences in functioning of the cognitive-motor areas, unique age distribution in both studied groups is one of the main strengths of this study, showing benefits of sports activities on cognitive development of children. The main limitation is the inclusion of unequal sample of participants (46 water polo players and 26 school children who did not participate in organized sports activity). Also, there is a need for use a larger battery of cognitive tests for assessment of different EF components as in the study of Alesi et al. (2016) or Ishihara et al. (2017). Future studies using longitudinal or interventional designs and more diverse measures (e.g. age and gender differences, socioeconomic status, different sports) should investigate the associations among EF, sports activity, and gender specificity of these relationships. Additionally, since it has been shown that more frequent tennis play is associated with better working memory, the importance of increasing the frequency of sports activity participation in the development of EF has been emphasized even in physically active children (Ishihara et al., 2017). Therefore, future studies should assess the relevance of the full timeline of training experience in the investigated outcomes regarding water polo players. Finally, since a gender specificity of the relationships between certain sports training exposure and EF has also been suggested (Ishihara et al., 2017), larger samples including both genders are necessary in order to assess this issue in water polo players.

Conclusion

The present study supported the hypothesis that a more frequent and longer experience of participating in sports activity is associated with better inhibitory control, working memory and cognitive flexibility. High-level youth water polo players showed better results in psychomotor speed, inhibitory control and motor speed than sedentary children, taking both age gender into account. Still, well-developed cognitive functions may serve only as one of the crucial factor along with other components of athlete's development in order to become an elite water polo player. Despite the limitations of this study, the presented results contribute to the issue of sport activities as a tool in the stimulation of cognitive development. Considering that EFs are skills essential for mental and physical health, success in school and in life, and cognitive, social, and psychological development based on the results of this study it would be advantageous to encourage children to participate in organized sports activities. Still, additional research is needed to compare executive skills development among youth water polo players and children practicing individual open skills sports (e.g., martial arts, dancing, tennis) where the teammates' support and shared responsibility are not present. Examination of the effects of exercise programs built on closed skills sports (e.g., swimming, running) would also be of interest, because the environment is relatively fixed and predictable.

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Conflict of interests:

The authors declare that there is no conflict of interests.

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