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Оригинални научни рад

Engagement in sports and children's cognitive abilities: an analysis of executive functions[2]

Summary: *Studies examining the correlation between children's participation in sports activities and their executive functions (EFs) are relatively scarce, especially those that control the impact of participants' intelligence. This research aimed to compare the EFs of children engaged in sports with those of their non-athletic peers, while controlling the impact of intelligence. Additionally, it compared the EFs of children participating in open skills sports (OSS) with those practicing closed skills sports (CSS). The sample included 83 participants (53% girls), aged 9-11 years, of whom 40 engaged in sports during their leisure time. Intelligence was evaluated using Raven's Progressive Matrices, while working memory was assessed using tasks such as Digit Span Backward and Figure Span Backward. Inhibitory control was measured using the Dodrill's Stroop Test and the Go/No-Go task, while cognitive flexibility was evaluated with the Wisconsin Card Sorting Test. Planning skills were assessed using the Twenty Questions Task and the Tower of London. The results revealed that children engaged in sports achieved better outcomes only in nonverbal working memory compared to the non-athletes. Involvement in OSS, rather than CSS, is associated with superior performance in nonverbal working memory. The findings suggest that engaging in cognitively stimulating physical activities holds potential benefits for the cognitive development of typically developing children. The observed relationship between sports activities and working memory further implies potential benefits for children with neurodevelopmental disorders. This underscores the necessity for additional research aimed at exploring specific mechanisms and adapting interventions to foster cognitive development in this group of children.*

Keywords: *executive functions, nonverbal working memory, sport, open skills sports, closed skills sports.*

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Introduction

Regular physical activity, encouraged from an early childhood, is essential for a healthy lifestyle, as it helps alleviate common health problems such as obesity, hypertension, anxiety, and depression, while also reducing the risk of the cardiovascular disease-related morbidity and mortality (Fitzgerald et al., 2022). This emphasis on the benefits of physical activity extends to brain health and cognitive functions. Research findings link physical activity and fitness to cognitive development in neurotypical children and adolescents, particularly regarding executive functions (EFs) (e.g. de Greeff et al., 2018; Xue et al., 2019), which consequently influences academic performance as well (Giordano et al., 2021). The positive influence on cognitive functioning arises not only from biological changes in the brain, but also from improvements in emotional well-being (Popov & Jakovljev, 2017).

Executive functions

EFs represent higher-level cognitive processes that manage the functioning of the lower-level processes, facilitating goal-directed behavior (Friedman & Miyake, 2017). They are activated during social interactions and in novel, non-routine, and complex tasks in everyday life situations. Executing complex, goal-directed behavior requires adjusting thoughts and actions flexibly, overriding habitual behaviors, and holding relevant information in mind while pursuing goals (Diamond, 2013). There is a consensus on three fundamental EFs: inhibitory control, working memory, and cognitive flexibility (Friedman & Miyake, 2017). These core EFs are the building blocks of complex functions such as reasoning, problem-solving, and planning (Diamond, 2020).

Inhibitory control is thought to be responsible for stopping inappropriate actions, suppressing outdated or unwanted mnemonic representations, and avoiding distractions from an active focus of attention (see Wessel & Anderson, 2024). It includes interference control (selective attention and cognitive inhibition) and response inhibition (resisting temptations and suppressing impulsive behavior) (Diamond, 2020). While both aspects of inhibition are crucial for academic performance (Coulanges et al., 2021; Isbell et al., 2018) and mental health (e.g., Diaz-Marsa et al., 2023; Harfmann et al., 2019), response inhibition specifically predicts involvement in undesirable behaviors like unhealthy diet (e.g., McGreen et al., 2023), internet gaming addiction (e.g., Ding et al., 2014), excessive social networking (e.g., Gao et al., 2019), cigarette smoking (e.g., Mashhoon et al., 2018), and substance abuse (e.g., Dousset et al., 2022).

Working memory (verbal and visual-spatial) involves retaining and mentally manipulating information. It is essential for understanding language (written and spoken), translating instructions into plans, assimilating new information, exploring options, and linking information to infer principles or relationships between various pieces of information or ideas (Diamond, 2013). It impacts academic achievement (Giofre et al., 2018) and is linked to health issues such as childhood obesity (Wu et al., 2017), psychiatric disorders (Chai et al., 2018; Yamashita et al., 2018), and neurodevelopmental disorders (Alloway, 2018).

Cognitive flexibility, as opposed to rigidity, builds upon inhibition and working memory, facilitating active switching between rules or aspects of complex tasks and situations. It allows individuals to adapt objectives and behaviors in response to changing environments, i.e. to shift perspectives spatially and interpersonally, think innovatively, adapt to new demands or priorities, and seize unexpected opportunities (Diamond, 2020). This ability significantly impacts math performance (de Santana et al., 2022), reading comprehension (Cartwright et al., 2017), social contexts navigation and irony interpretation (Zajączkowska & Abbot-Smith, 2020), metaphor use (Willinger et al., 2019), and humor development (Curran et al., 2021). Lower cognitive flexibility in children has been linked to internalizing behavior problems (Patwardhan et al., 2021) and, in adults, to burnout (Lemonaki et al., 2021), post-traumatic stress disorder symptom severity (Ben-Zion et al., 2018), and obsessive-compulsive disorder (Liu et al., 2023), among others.

Complex EFs, enhanced by inhibition, working memory, and flexibility (Friedman & Miyake, 2017), include planning, problem-solving, reasoning, and navigating unfamiliar situations (Diamond, 2020). Suboptimal core EFs lead to difficulties in tasks with higher cognitive demands, potentially hindering overall cognitive performance and adaptive functioning.

Cognitive benefits of physical activity

Examining physical activity benefits during childhood and adolescence is crucial, shaping future lifestyles with a significant impact on lifelong health. Recent studies highlight the strong link between physical activity and attention, concentration, processing speed, memory, and language processing in this population (see Hernández-Mendo et al., 2019). Increasing evidence suggests that organized sports offer greater benefits for EFs compared to mere physical activity (Contreras-Osorio et al., 2021). Current research trends explore how EFs improvements through sports vary based on movement characteristics involved in different activities.

Sports can be classified as open or closed skills, each imposing distinct cognitive demands influenced by the environment (Knapp, 2024). Open skills sports (OSS) such as basketball, football, tennis or boxing require perception, attention, planning, and decision-making in dynamic, unpredictable settings. In contrast, closed skills sports (CSS), such as running, gymnastics, and swimming, involve fewer cognitive demands, are typically performed in predictable environments, and are usually self-paced.

In adults, athletes in OSS generally show higher EFs scores than those in CSS (Heilmann et al., 2022). Additionally, team sports seem to have a stronger EFs impact compared to individual OSS (Krenn et al., 2018). However, conflicting findings exist; some studies report no difference between sport types, while others suggest CSS could have a greater influence on EFs (see Heilmann et al., 2022).

As far as children are concerned, research is limited and results are inconclusive as well. However, recent meta-analytic studies indicate positive effects of longitudinal/chronic physical activity programs on EFs in children (e.g. de Greeff et al., 2018; Xue et al., 2019). These effects are moderate to large for cognitively engaging activities and small to moderate for aerobic activities (de Greeff et al., 2018). Another meta-analysis (Feng et al., 2023) supports these findings, showing that sports activities have varying effects on EFs in children aged 3 to 13 years, with OSS generally showing greater benefits.

Despite the promising findings, it is important to consider potential confounding variables. Inconsistencies in research findings across adult and pediatric populations may stem from an insufficient control of variables influencing EFs task performance. Apart from the studied factors, other variables could contribute to varying results among studies. Research consistently indicates a significant correlation between intelligence and EFs (e.g. Ardila et al., 2000; Buczyłowska et al., 2020; Buha & Gligorović, 2016; Friedman & Miyake, 2017), showing that individuals with higher intelligence tend to perform better on EFs tasks. Given this relationship, controlling the impact of intelligence may be necessary for clarifying the association between physical activity and EFs. Therefore, this study aims to examine EFs performance on core and complex EF tasks in children aged 9-11, both engaged in sports and those who are not, while controlling the impact of intelligence. It also seeks to compare EFs performance of the children participating in OSS and CSS.

The significance of this research lies in its novelty as it is the, to our knowledge, the first research in Serbia to examine the relationship between EFs and physical activities in children aged 9-11 years.

Method

This study employs a cross-sectional design to examine the relationship between parent-reported sports activities and cognitive performance as assessed by a comprehensive set of EFs tests/tasks.

With the headmaster's approval, parents were briefed on the research goal and procedure at a parent-teacher meeting. Their questions were addressed, and they signed a consent form after discussing it with their children. Intelligence was assessed in group classroom testing, and EFs were evaluated individually in a quiet school room during regular hours by the researchers. All children were assessed on EFs tasks in the same sequence, beginning with working memory, followed by inhibitory control, cognitive flexibility, and concluding with planning ability. Participants were selected based on the criteria excluding those with chronic illnesses preventing sports participation, severe head trauma, neurodevelopmental disorders, and sensory or motor impairments.

This study is part of the project "Creating a Protocol for Assessing Educational Potentials of Children with Disabilities" funded by the Ministry of Science, Technological Development and Innovation of Serbia. It was conducted in accordance with the Declaration of Helsinki principles.

Participants

A total of 83 children, out of which 53% girls, of age ranging from 9 to 11 years (M = 9.72, SD = 0.55), were selected from one elementary school in Belgrade, Serbia. Of these children, 40 (48.2%) participated in sports during their leisure time. Non-athletes (N = 43; 51.8%) did not engage in sports activities, other than attending physical education classes at school.

For a detailed analysis, participants engaged in sports were categorized into two groups (Knapp, 2024): (a) OSS (56.8%) and (b) CSS (43.2%), each for at least twice a week. There are three missing data points in the dataset (detailed in Table 1 and Table 2), resulting in a total of 37 children in the sport sample for further analysis.

There were no significant age differences between boys and girls (F = 0.00, df = 1, p = .998), with both genders evenly represented in the sport and non-sport groups (χ^2 = 3.42, df = 1, p = .064). However, boys were more involved in OSS, while girls were more involved in CSS (χ^2 = 7.47, df = 1, p = .006). Both sport and non-sport groups had similar age distributions (F = 0.75, df = 1, p = .390), as did the OSS and CSS groups (F = 0.01, df = 1, p = .907).

Table 1. Demographic characteristics of the sample.

Groups of participants	Age M (SD)	Gender N (%)	Total N (%)
Non-sport	9.67 (0.57)	girls = 27 (62.8) boys = 16 (37.2)	43 (51.8)
Sport	9.77 (0.54)	girls = 17 (42.5) boys = 23 (57.5)	40 (48.2)
Open skills sport	9.73 (0.56)	girls = 5 (23.8) boys = 16 (76.2)	21 (56.8)
Closed skills sport	9.71 (0.51)	girls = 11 (68.8) boys = 5 (31.3)	16 (43.2)

Table 2. The type of sports children are engaged in.

Type of sport	N	Classification
Football	9	Open skills sport
Folk dance	6	Closed skills sport
Taekwondo	5	Closed skills sport
Basketball	4	Open skills sport
Volleyball	3	Open skills sport
Rhythmic gymnastics	2	Closed skills sport
Karate	2	Closed skills sport
Handball	2	Open skills sport
Water polo	2	Open skills sport
Athletics	1	Closed skills sport
Horse riding	1	Open skills sport
Total	37	

Measures

A demographics questionnaire, completed by parents, gathered information on age, sex, developmental and health status of the child, as well as information regarding sport involvement.

Intelligence was assessed using Raven's Progressive Matrices (RPM; for details see Buha & Gligorović, 2016).

Due to task impurity, individual EFs tasks often show low correlations (Miyake, 2000). Thus, multiple measures are needed for a more precise assessment of EFs (Friedman & Miyake, 2017). Consequently, various tasks were used to assess both basic and complex aspects of executive functioning.

Working memory assessment included a nonverbal task, such as Figure Span Backward and a verbal task, Digit Span Backward. Detailed descriptions are in Buha & Gligorović (2016). The outcome variable for each test was the number of correct answers.

To evaluate *inhibitory control*, Dodrill's Stroop test and the Go/No-Go paradigm were used (for details see Buha & Gligorović, 2016, 2015). The Stroop test measured reading color words (Stroop1) and naming ink color (Stroop2), with the difference (StroopDiff = Stroop2 - Stroop1) indicating verbal inhibitory control. Lower values indicate better performance. The Go/No-Go task, focusing on the Conflicting Responses set, assessed motor inhibitory control, with the total number of errors as the outcome variable.

To assess *shifting performance (cognitive flexibility)*, we employed the Wisconsin Card Sorting Test (WCST; for details see Buha & Gligorović, 2016). The participants were required to discover the sorting principle, considering the examiner's feedback (correct/incorrect) from their previous attempts, and flexibly switch to another sorting principle based on the examiner's cue. For the purpose of this study, we utilized the percentage of perseverative errors, a common indicator of cognitive flexibility, from a set of 10 variables.

Planning ability was assessed using the Twenty Questions Task for the verbal aspect (20QT, for details see Gligorović & Buha, 2013) and the adapted Tower of London for the nonverbal aspect of problem-solving (ToL, for details see Buha & Gligorović, 2012). The 20QT measured constraint-seeking questions (category-based vs. specific-based). The ToL measured preplanning time (ToLt), indicating planning efforts (i.e., the duration between observing the discs and initiating the first movement; longer time indicates better performance), and total correct score (ToLc), indicating planning success.

Statistical method

Normality assumption was confirmed by z-scores of skewness and kurtosis (< ± 3.29 for sample size; Kim, 2013). Demographic characteristics were compared using one-way ANOVA and χ^2 test. Confounding variables (age, gender, intelligence) were assessed with ANOVA and Pearson correlation. Intelligence correlated with EFs (ranging from .21 to .48, $p \leq .05$). Gender did not significantly affect EFs or intelligence ($p < .05$), thus it was not considered a confounding variable. Age correlated significantly only with the Stroop task ($r = -.244$, $p = .026$). Therefore, age was controlled for, along with intelligence, in examining the relationship between sport engagement and verbal inhibitory control.

Group differences in EFs were analyzed using one-way ANOVA and ANCOVA. Homogeneity of variances was assessed with Levene's test. For groups showing heterogeneity, the Welch approximation was applied. Homogeneity of regression slopes was verified prior to ANCOVA. Significance was set at $p \leq .05$. Post-hoc comparisons with Bonferroni correction identified specific group differences. The results included unstandardized beta coefficients (B) and partial eta square effect sizes (partial η^2).

Results

Table 3 presents an overview of the mean scores and other descriptive data for each test/task within both the sport and non-sport groups.

The intelligence scores (RPM) of the sport and non-sport groups did not show significant differences, as indicated by $F(1) = 0.578$, $p = .449$. Descriptive data suggest that individuals in the sport group exhibit slightly stronger performance in various EF tasks (VWM, NWM, Stroop test, and WCST). However, one-way ANOVA results showed no statistically significant differences ($p > .05$) between sport and non-sport groups. The exception was observed in the NWM task, indicating better nonverbal working memory among children engaged in sports activities, $F(1) = 5.57$, $p = .021$, partial $\eta^2 = .06$.

These findings, consistent across both NWM [$F(1, 80) = 4.90$, $p = .030$, partial $\eta^2 = .06$] and other EFs were obtained after controlling the impact of intelligence by using ANCOVA: VWM [$F(1, 80) = 0.66$, $p = .418$], Go/No-go C [$F(1, 80) = 1.14$, $p = .290$], WCST [$F(1, 80) = 0.08$, $p = .772$], ToLc [$F(1, 80) = 0.26$, $p = .612$], ToLt [$F(1, 80) = 0.81$, $p = .372$], and 20QT [$F(1, 80) = 0.07$, $p = .794$]. Similarly, sports participation did not make a difference on Stroop variable [$F(1, 79) = 0.00$, $p = .991$] after controlling the age effects alongside intelligence.

Intelligence showed significant correlations with most outcome variables: VWM [$F(1, 80) = 23.98$, $p < .0001$, $B = .13$], NWM [$F(1, 80) = 7.87$, $p = .006$, $B = 0.06$], StroopDiff [$F(1, 80) = 4.88$, $p = .030$, $B = -1.35$], Go/No-go C [$F(1, 80) = 8.99$, $p = .004$, $B = -0.13$], WCST [$F(1, 80) = 10.22$, $p = .002$, $B = -0.30$], ToLc [$F(1, 80) = 4.81$, $p = .031$, $B = 0.06$], and ToLt [$F(1, 80) = 4.91$, $p = .029$, $B = 1.36$].

In summary, participation in sports only appears to be related to enhanced nonverbal working memory. When considering both independent variables together (intelligence and sports involvement), they accounted for approximately 15% of the variance, with $R^2 = .148$, $F(2, 80) = 6.96$, $p = .002$.

EFs in relation to the type of sport

For a more comprehensive understanding of the data, we conducted further analysis on specific sports types within the variables to determine if significant differences exist between them (Table 4).

Table 3. Descriptive data on the selected measures for sport and non-sport groups.

		Min	Max	M	SD
RPM	Sport	19	48	34.50	7.49
	Non-sport	16	51	33.21	7.94
VWM	Sport	2	12	6.13	2.41
	Non-sport	2	11	5.60	1.94
NWM	Sport	1	10	3.70	1.83
	Non-sport	1	5	2.88	1.29
StroopDiff	Sport	62	252	145.35	47.46
	Non-sport	81	247	148.65	40.28
Go/No-go C	Sport	0	13	4.65	3.34
	Non-sport	0	11	4.09	3.18
WCST	Sport	5	34	14.35	6.54
	Non-sport	6	34	15.16	7.30
ToLc	Sport	5	14	8.78	2.02
	Non-sport	6	15	8.91	1.76
ToLt	Sport	16	269	55.70	56.77
	Non-sport	17	132	45.49	26.27
20QT	Sport	0	80	26.68	24.85
	Non-sport	0	83	27.19	23.91

Legend: RPM= Raven's Progressive Matrices; VWM = verbal working memory; NWM = non-verbal working memory; StroopDiff = difference between reading and naming on Stroop test; Go/No-go C = total number of errors on Conflicting Responses set; WCST = Wisconsin Card Sorting Test; ToLc = Tower of London – total correct score; ToLt = Tower of London – preplanning time; 20QT = Twenty Questions Task.

Table 4. Descriptive data on the selected measures for open/closed skills sports groups and non-athletes.

	Type of sport	Min	Max	M	SD
RPM	Open	19	48	34.33	9.00
	Closed	27	44	35.75	4.52
	Non-sport	16	51	33.21	7.94
VWM	Open	2	12	6.19	2.60
	Closed	2	11	6.00	2.22
	Non-sport	2	11	5.60	1.94
NWM	Open	1	10	4.05	2.11
	Closed	2	6	3.31	1.30
	Non-sport	1	5	2.88	1.29
StroopDiff	Open	72	239	147.76	41.80
	Closed	86	252	151.38	53.65
	Non-sport	81	247	148.65	40.28
Go/No-go C	Open	0	13	4.86	3.21
	Closed	1	12	4.81	3.75
	Non-sport	0	11	4.09	3.18
WCST	Open	6	34	14.71	7.17
	Closed	5	25	12.94	12.94
	Non-sport	6	34	15.16	7.30
ToLc	Open	5	12	8.67	1.65
	Closed	5	14	9.13	2.50
	Non-sport	6	15	8.91	1.76
ToLt	Open	18	259	52.57	56.42
	Closed	16	269	63.44	62.36
	Non-sport	17	132	45.49	26.27
20QT	Open	0	80	25.24	25.03
	Closed	0	75	29.44	26.59
	Non-sport	0	83	27.19	23.91

Legend: RPM= Raven's Progressive Matrices; VWM = verbal working memory; NWM = non-verbal working memory; StroopDiff = difference between reading and naming on Stroop test; Go/No-go C = total number of errors on Conflicting Responses set; WCST = Wisconsin Card Sorting Test; ToLc = Tower of London – total correct score; ToLt = Tower of London – preplanning time; 20QT = Twenty Questions Task.

The intelligence scores (RPM) of children did not show significant differences, as indicated by Welch $F(2, 41) = 1.16$, $p = .323$. Additionally, no significant difference was observed between groups on EFs variables ($p > .05$), except for NWM [$F(1) = 3.99$, $p = .022$, partial $\eta^2 = .09$].

After controlling for intelligence, significant differences in NWM remained constant [$F(1, 76) = 3.82$, $p = .026$, partial $\eta^2 = .09$]. The adjusted means did not change significantly showing that levels of NWM were similar between OSS and CSS groups ($p = .314$). However, only OSS group outperformed non-athletes ($p = .022$). The significant relationship between intelligence and nonverbal working memory was determined, NWM [$F(1, 76) = 6.71$, $p = .011$, $B = 0.06$, partial $\eta^2 = .08$]. Both independent variables together accounted for approximately 17% of the variance in NWM, $R^2 = .167$, $F(3, 76) = 5.09$, $p = .003$.

No differences in performance on other EFs variables were detected across groups: VWM [$F(1, 76) = 0.37$, $p = .692$], Go/No-go C [$F(1, 76) = 1.03$, $p = .360$], WCST [$F(1, 76) = 0.31$, $p = .736$], ToLc [$F(1, 76) = 0.24$, $p = .786$], ToLt [$F(1, 76) = 0.65$, $p = .522$], 20QT [$F(1, 76) = 0.11$, $p = .898$], and Stroop [$F(1, 33) = 0.39$, $p = .535$].

Intelligence showed significant relationships with: VWM [$F(1, 76) = 22.64$, $p < .0001$, $B = 0.14$], StroopDiff [$F(1, 33) = 15.12$, $p < .0001$, $B = -3.51$], Go/No-go C [$F(1, 76) = 10.65$, $p = .002$, $B = -0.15$], WCST [$F(1, 76) = 8.00$, $p = .006$, $B = -0.28$], and ToLt [$F(1, 76) = 4.41$, $p = .039$, $B = 1.35$].

Discussion

This study aimed to compare EFs task performance in 9-to-11-year-olds engaged in sports and those who are not, while controlling the impact of intelligence. It comprised two main analyses: one comparing athletes and non-athletes to evaluate the overall impact of sports on EFs, and another examining the specific effects of OSS versus CSS. These analyses aimed to elucidate how various types of sports activities might be differently related to cognitive functions.

Our findings indicate that children involved in sports exhibit an enhanced nonverbal working memory, unaffected by intelligence levels when controlled. Specifically, including intelligence as a covariate did not alter the results or diminish the effect size. Moreover, participation in OSS, compared to CSS, was associated with a superior nonverbal working memory performance. However, our study did not find significant effects of sports participation on other EFs domains or modalities. This suggests that while sports environments may be related to specific cognitive aspects in children, these associations may not generalize uniformly across all EFs domains.

Our findings generally align with other studies suggesting that engaging in sports, particularly open-skill exercises, enhances various domains of EFs (Alesi et al., 2016; Chikha et al., 2021; Contreras-Osorio et al., 2022; Egger et al., 2019; Formenti et al., 2021; Mazzoccante et al., 2020; Schmidt et al., 2015). For example, Alesi et al. (2016) observed an improved visuospatial working memory in children participating in OSS such as football compared to sedentary peers. Similarly, López-Vicente et al. (2017) linked a low physical activity during early childhood to reduced visual-spatial working memory throughout elementary school and adolescence, highlighting potential long-term benefits of sports engagement on cognitive development. Active participation in sports may enhance working memory through various mechanisms that operate at different levels, ranging from physiological processes (e.g. Wang et al., 2022) to social interactions and cognitive transfer effect. Alesi et al. (2016) proposed that the multifaceted environment of sports matches, requiring simultaneous processing of multiple cues, fosters working memory development. Players must interpret opponent movements, teammate positions, and ball trajectory, facilitating cognitive transfer to other domains and enhancing overall cognitive function.

In contrast to our findings, previous studies indicate that engagement in OSS, particularly team sports, positively impacts cognitive functions beyond working memory, including planning, inhibition, and cognitive flexibility. Bryant et al. (2021) and Möhring et al. (2022) observed enhanced cognitive flexibility in children participating in team sports. An intervention study by Chikha et al. (2021) showed improvements in inhibitory control and mental flexibility among children engaged in football training compared to controls. Furthermore, Alesi et al. (2016) found that football exercises also enhance planning skills. Similar benefits in EFs were reported in children involved in handball training (Contreras-Osorio et al., 2022) and interventions using floorball and basketball games (Schmidt et al., 2015). According to Alesi et al. (2016), these improvements stem from the cognitive demands inherent in team sports, requiring problem-solving, quick decision-making, and impulse control. Successful participation necessitates adaptation, strategic planning, drawing from experience, and reactive control.

Although the findings from various studies suggest that OSS generally benefit cognitive functions, they do not unanimously agree on which specific functions are affected. For instance, Contreras-Osorio et al. (2022) found no differences in mental flexibility, and Schmidt et al. (2015) reported no significant improvements in verbal working memory and inhibition, consistent with the findings of our research.

Several factors could account for the disparities in results between current and previous research. Methodological differences in EFs assessment tasks may be one such factor. Previous studies often employed tasks such as the trail-making paradigm to measure cognitive flexibility (e.g., Chikha et al., 2021; Mazzoccante et al., 2020), emphasizing a rapid attention redirection. In contrast, current research employs the WCST, focusing on set-shifting and strategy adaptation. While the WCST is widely used to assess cognitive flexibility, tasks like the Trail Making Test might better capture sporting demands, highlighting quick adaptability and attention shifting.

Differences in the findings may also stem from varying categorizations of sports. Classifications such as open and closed skills may oversimplify sports complexities. Sports such as handball and volleyball may seem more predictable than football or basketball. Furthermore, martial arts, like karate and taekwondo, pose classification challenges due to their diverse techniques (James, 1995). Kumite or sparring requires quick, adaptive responses akin to OSS, while kata or taolu involves rehearsed sequences in controlled settings, aligning more with CSS. We classified martial arts as a CSS, considering that children at this stage are still refining their precise movement execution. Conversely, Russo et al. (2021) and Formenti, et al. (2021) treated martial arts as OSS.

The inconsistency in classification across studies complicates the identification of specific effects associated with each sport. Rather than grouping sports broadly, a more detailed understanding of their effects on cognitive functions, as demonstrated in intervention studies, can be achieved by analyzing each sport individually. However, when grouping sports, it would be beneficial to categorize them based on environmental predictability, beyond the open/closed skill spectrum.

Variations in the findings may also stem from an inadequate control over quantitative aspects of physical activities, such as participants' experience levels, intensity, and duration. Studies by Becker et al. (2018) and De Greeff et al. (2018) highlight the importance of controlling for variability in sports participation, including factors like novice status and absenteeism. Our study, like Becker et al. (2018) and Möhring et al. (2022), relied on parental reports of physical activity rather than objective measurements, potentially introducing biases that could impact the accuracy of results. Future research should therefore thoroughly investigate these factors to better understand how sports activities influence cognitive performance.

Limitations and recommendations

This research has several limitations that warrant consideration when interpreting its findings. The research design, which involved collecting data at a single time point, prevents the establishment of causal relationships between children's sports participation and their levels of EFs. A cross-sectional design only captures a snapshot of the data at one specific moment in time, making it difficult to determine the directionality of relationships or identify potential confounding variables. In other words, without tracking the changes in sports participation and EFs over time, it is challenging to ascertain whether sports participation leads to improved EFs, whether EFs influence sports participation, or if other factors altogether drive both variables. Therefore, longitudinal studies would be crucial for unraveling the complex interplay of these variables and drawing more robust conclusions about their relationship.

The limited number of participants in this cross-sectional study restricts the ability to generalize the findings. Additionally, the small number of participants in sport subsamples may have influenced the findings. Due to uneven distribution of boys and girls in different sports categories and varying sample sizes, analyzing gender differences was deemed inappropriate. Future research could explore this aspect more thoroughly.

Classifying sports into open and closed skill types can lead to interpretational challenges, as some sports, like martial arts, possess characteristics of both categories. This duality complicates analysis and oversimplifies the complexities of various sports with regard to their specific influences on children's cognitive development. A more nuanced examination of individual sports (e.g., football, athletics, martial arts, etc.) would be beneficial for understanding their impact on cognitive functions. Furthermore, categorizing participants based on a minimum training frequency may obscure results, as those who train more frequently could affect group homogeneity and influence study findings. Future research should consider more specific training frequency categories to better understand the effects of training intensity on outcomes.

The exclusive focus on participants from a single school in a major Serbian city implies that additional variables related to their daily routines, school environment, and home life could have influenced the outcomes. For example, recent studies have shown that children engaged in musical training demonstrate improvements in various aspects of EFs (e.g. Jaschke et al., 2018). Future studies should therefore consider controlling for leisure-time activities among non-athletes. Moreover, the research underscores the impact of the socioeconomic environment on children's cognitive development and brain function (Ursache et al., 2016), as well as the influence of the body mass index on EFs and the effects of exercise interventions (Xue et al., 2019), highlighting the need for future studies to address these factors as well. While a higher body mass can hinder the selection of the students for sports activities such as football, basketball, volleyball, and handball (Sinđelić et al., 2023), the findings suggest that the most significant effects of physical activity on EFs are identified in children with a higher body mass index (Xue et al., 2019).

Despite these limitations, to our knowledge, this study is the first to explore EFs differences across various sports in children, examining domain-specific and domain-general effects while considering intelligence. We used age-appropriate tasks, widely recognized for assessing EFs.

This research underscores the importance of the structured sports activities for enhancing children's nonverbal working memory. Highlighting the potential significant impact of OSS on cognitive development can inform the selection of school and extracurricular activities to support cognitive growth. Integrating classroom-based physical activities that engage cognition and physical exertion shows promise for improving EFs and academic performance, particularly in mathematics (Egger et al., 2019). These activities can be integrated into academic lessons or implemented during recess (see Webster et al., 2015).

The observed link between sports and working memory suggests potential benefits for children with neurodevelopmental disorders as well, highlighting the need for further research to explore mechanisms and tailor interventions for cognitive development in this group of children.

Conclusion

The study highlights a potential link between sports activities and cognitive functions in developmental stages. It emphasizes that physical activity, especially open skill exercises, may be associated with cognitive abilities, primarily focusing on nonverbal working memory. The findings indicate varying associations between sports participation and different aspects of working memory, with nonverbal (visual-spatial) memory showing a significant relationship while verbal memory does not. This suggests a potential domain-specific connection between sports and working memory, implying that certain cognitive functions may be more influenced by physical activity than others. Further research is needed to fully understand the nature of this relationship, including its domain-specific versus domain-general aspects.

The research findings can inform policymakers in health and education sectors. By clarifying the link between sports activities, especially those involving open skill exercises, and cognitive functions such as working memory, policymakers can prioritize physical activity interventions. Promoting participation in such sports could enhance cognitive abilities, potentially improving academic performance and overall well-being among children.

In the realm of education policy, these findings emphasize integrating cognitively demanding physical activities into school curricula. Recognizing the specific link between sports and working memory, the educators can advocate for structured physical education programs targeting cognitive functions. The policymakers should consider initiatives supporting extracurricular sports programs to ensure equitable access for all students.

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АНГАЖОВАЊЕ У СПОРТУ И КОГНИТИВНЕ СПОСОБНОСТИ ДЕЦЕ: АНАЛИЗА ЕГЗЕКУТИВНИХ ФУНКЦИЈА

Егзекутивне функције (ЕФ) когнитивни су процеси вишег реда који олакшавају ка циљу усмерено понашање, а активирају се током социјалних интеракција и у новим, комплексним ситуацијама. Међу научницима постоји сагласност да базичне аспекте ЕФ чине инхибиторна контрола, радна меморија и когнитивна флексибилност (Friedman & Miyake, 2017), који представљају градивни елемент комплексних функција као што су закључивање, решавање проблема и планирање (Diamond, 2020). Базичне и комплексне ЕФ су од велике важности за академско постигнуће (на пример, De Santana et al., 2022) и ментално здравље (на пример, Diaz-Marsa et al., 2023). Имајући у виду да неки спољашњи фактори могу модулирати перформансу у домену ЕФ, од велике је важности истражити факторе који доприносе њиховом оптималном развоју.

Новија истраживања указују на значајну повезаност између физичке активности и когнитивних способности, посебно ЕФ (Hernández-Mendo et al., 2019). Актуелни истраживачки тренд испитује како врста покрета у одређеним спортовима и предвидљивост спортског окружења утичу на унапређење ЕФ. Спортови се могу класификовати у активности које захтевају вештине отвореног или затвореног типа, при чему сваки тип активира специфичне когнитивне способности у зависности од карактеристика окружења (Кнарр, 2024). Спортови засновани на отвореним вештинама (ОВ), попут кошарке, захтевају перцепцију, пажњу, планирање и доношење одлука у динамичном и непредвидљивом окружењу, док спортови са затвореним вештинама (ЗВ), попут трчања, обично захтевају мање когнитивно ангажовање и изводе се у предвидљивим контекстима.

Резултати досадашњих истраживања указују на то да особе које се баве ОВ спортовима, посебно тимским спортовима из ове групе, имају боље ЕФ у поређењу са онима који су ангажовани у ЗВ спортовима (Krenn et al., 2018). Међутим, истраживачки налази нису униформни; неки аутори не налазе значајне разлике између група спортова, док други извештавају о супротним резултатима. Несклад у налазима, како код одраслих, тако и код деце, може бити последица недовољне контроле варијабли које су повезане са перформансама у домену ЕФ. Једна од ових варијабли је ниво интелектуалног функционисања, јер особе са вишим коефицијентом интелигенције обично имају боље ЕФ, што чини контролу овог фактора важном за разумевање односа између физичке активности и ЕФ. Стога је циљ овог истраживања да испита ниво развоја базичних и комплексних ЕФ код деце узраста 9–11 година, у зависности од тога да ли се баве спортом у слободно време или не, уз контролу утицаја интелигенције. Додатно, овим истраживањем ће бити поређене ЕФ деце која тренирају ОВ и ЗВ спортове.

Истраживањем су обухваћена 83 детета (53% девојчица), ученика једне основне школе у Београду. Од укупног броја деце 48,2% се бави спортом у слободно време. Ови испитанци су додатно подељени у две групе: (а) деца ангажована у ОВ спортовима (56,8%) и (б) деца ангажована у ЗВ спортовима (43,2%), која тренирају најмање два пута недељно.

Интелигенција је процењена Равеновим прогресивним матрицама; радна меморија задацима распона уназад (бројеви и фигуре уназад); инхибиторна контрола Струп тестом и задатком Крени/стани, а когнитивна флексибилност Висконсин тестом сортирања карата. Планирање је анализирано Тестом 20 питања и Лондонском кулом (детаљи о задацима могу се наћи у: Buha & Gligorović (2012; 2015; 2016) и Gligorović & Buha (2013)).

Добијени резултати указују на то да је бављење спортом повезано са бољим постигнућем у домену невербалне радне меморије. Интелигенција као коваријат није значајно изменила резултате, нити је утицала на промену величине ефекта. Обе независне варијабле заједно (интелигенција и ангажовање у спорту) објашњавају око 15% варијабилности резултата, $R2=.148$, $F(2, 80)=6.96$, $p=.002$. Додатном анализом утврђено је да испитаници који се баве ОВ спортовима имају већи капацитет невербалне радне меморије, $F(1, 76)=3.82$, $p=.026$, partial $\eta 2=.09$. Обе независне варијабле заједно објашњавају око 17% варијансе, $R2=.167$, $F(3, 76)=5.09$, $p=.003$. Разлике у осталим доменима и модалитетима ЕФ нису присутне.

Иако спортске активности утичу на одређене когнитивне способности код деце, ови ефекти се не могу генерализовати на све домене ЕФ. Повезаност између спортских активности и радне меморије сугерише да би овакве активности могле користити и деци са неуроразвојним поремећајима, што наглашава потребу за додатним истраживањима усмереним на разумевање специфичних механизама и прилагођавање интервенција за подршку њиховом когнитивном развоју.

Резултати ове студије могу помоћи доносиоцима политика у здравству и образовању да препознају значај спортских активности, нарочито оних које укључују вештине отвореног типа, у побољшању когнитивних функција (радне меморије), а самим тим и академског успеха деце. У образовној политици ови налази наглашавају потребу за укључивањем физичких активности које захтевају когнитивни ангажман у школски програм – просветни радници могу заговарати структуриране програме физичког васпитања, увођење активних школских одмора и специфично дизајнираних активности у продуженом боравку. Такође, доносиоци политика би требало да подрже ваншколске спортске програме како би свим ученицима обезбедили равноправан приступ.

Кључне речи: *егзекутивне функције, невербална радна меморија, спорт, отворене вештине, затворене вештине*