Teaching Innovations, Volume 37, Issue 4, pp. 17–34
DOI: 10.5937/inovacije2404017B

Nataša S. Buha[1]
Bojan Z. Dučić
Mirjana M. Japundža-Milisavljević
University of Belgrade, Faculty of Special Education and Rehabilitation, Belgrade, Serbia

Original research paper

Paper received: Jul 13 2024
Paper accepted: Nov 6 2024
Article Published: Dec 20 2024

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

Extended summary

Executive functions (EF) are higher-order cognitive processes that facilitate goal-directed behavior, and are activated during social interactions and in new, complex situations. Scholars agree that the basic aspects of EF are inhibitory control, working memory, and cognitive flexibility (Friedman & Miyake, 2017), which are building blocks of complex functions such as reasoning, problem solving, and planning (Diamond, 2020). Basic and complex EFs are highly relevant to academic achievement (e.g., De Santana et al., 2022) and mental health (e.g., Diaz-Marsa et al., 2023). Considering that some external factors can modulate performance in the domain of EF, it is of great importance to investigate the factors that contribute to their optimal development.

Recent research indicates a significant correlation between physical activity and cognitive abilities, especially EF (Hernández-Mendo et al., 2019). A current research trend examines how the type of movement in specific sports and the predictability of the sports environment influence the improvement of EF. Sports can be classified into activities that require open or closed-type skills, with each type activating specific cognitive abilities depending on the characteristics of the environment (Knapp, 2024). Open-skill (OS) sports, such as basketball, require perception, attention, planning, and decision-making in a dynamic and unpredictable environment, while closed-skill (CS) sports, such as running, typically require less cognitive engagement and are performed in predictable contexts.

1 natasabuha@fasper.bg.ac.rs
https://orcid.org/0000-0002-8568-6309

2 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 (no 451-03-66/2024-03/ 200096).

The results of the previous research indicate that people who engage in OS sports, especially team sports from this group, have better EF compared to those who are engaged in CS sports (Krenn et al., 2018). However, research findings are not uniform; some authors find no significant differences between the sport groups, while others report the opposite results. The discrepancy in the findings, both in adults and children, may be due to an insufficient control of the variables associated with performance in the EF domain. One of these variables is the level of intellectual functioning, as individuals with higher IQ tend to have better EF, making the control of this factor important for understanding the relationship between physical activity and EF. Therefore, the aim of this research is to examine the level of development of the basic and complex EF in children aged 9–11, depending on whether they play sports in their free time or not, while controlling for the influence of intelligence. Additionally, this research will compare the EF of the children who practice OS and CS sports.

The research included 83 children (53% girls), students of an elementary school in Belgrade. Out of the total number of children, 48.2% play sports in their free time. These respondents were further divided into two groups: (a) children engaged in OS sports (56.8%) and (b) children engaged in CS sports (43.2%), who train at least twice a week.

Intelligence was assessed with Raven's progressive matrices; working memory with backward span tasks (numbers and figures backwards); inhibitory control with the Stroop test and the Go/Stop task, and cognitive flexibility with the Wisconsin card sorting test. Planning was analyzed with the 20-question Test and the Tower of London (details about the tasks can be found in: Buha & Gligorović (2012; 2015; 2016) and Gligorović & Buha (2013)).

The obtained results indicate that playing sports is associated with better achievement in the domain of non-verbal working memory. Intelligence as a covariate did not significantly change the results, nor did it influence the change in effect size. Both independent variables together (intelligence and involvement in sports) explain about 15% of the variability of the results, $R2=.148$, $F(2, 80)=6.96$, $p=.002$. Additional analysis revealed that respondents who play OS sports have a higher capacity of non-verbal working memory, $F(1, 76)=3.82$, $p=.026$, partial $\eta2=.09$. Both independent variables together explain about 17% of the variance, $R2=.167$, $F(3, 76)=5.09$, $p=.003$. Differences in other EF domains and modalities are not present.

Although sports activities affect certain cognitive abilities in children, these effects cannot be generalized to all domains of EF. The correlation between sports activities and working memory suggests that such activities could also benefit children with neurodevelopmental disorders, which emphasizes the need for additional research aimed at understanding specific mechanisms and adapting interventions to support their cognitive development.

The results of this research can help policy makers in health and education to recognize the importance of sports activities, especially those involving open-ended skills, in improving cognitive functions (working memory), and thus the academic success of children. In education policy, these findings emphasize the need to include in the curriculum the physical activities that require cognitive engagement - educators can advocate structured physical education programs, the introduction of active school holidays, and specifically designed after-school activities. Also, policy makers should support extracurricular sports programs to ensure equal access for all students.

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

References

- Alesi, M., Bianco, A., Luppina, G., Palma, A., & Pepi, A. (2016). Improving children's coordinative skills and executive functions: the effects of a football exercise program. *Perceptual and Motor Skills*, *122*(1), 27–46. https://doi.org/10.1177/0031512515627527
- Alloway, T. (2018). *Working memory and clinical developmental disorders: Theories, debates and interventions*. Routledge.
- Ardila, A., Pineda, D., & Rosselli, M. (2000). Correlation between intelligence test scores and executive function measures. *Archives of Clinical Neuropsychology*, *15*(1), 31–36. https://doi.org/10.1016/S0887-6177(98)00159-0
- Becker, D. R., McClelland, M. M., Geldhof, G. J., Gunter, K. B., & MacDonald, M. (2018). Open-skilled sport, sport intensity, executive function, and academic achievement in grade school children. *Early Education and Development*, *29*(7), 939–955. https://doi.org/10.1080/10409289.2018.1479079
- Ben-Zion, Z., Fine, N. B., Keynan, N. J., Admon, R., Green, N., Halevi, M., ... & Shalev, A. Y. (2018). Cognitive flexibility predicts PTSD symptoms: observational and interventional studies. *Frontiers in Psychiatry*, *9*, 477. https://doi.org/10.3389/fpsyt.2018.00477
- Bryant, L. M., Duncan, R. J., & Schmitt, S. A. (2021). The cognitive benefits of participating in structured sports for preschoolers. *Early Education and Development*, *32*(5), 729–740. https://doi.org/10.1080/10409289.2020.1799619
- Buczyłowska, D., Petermann, F., & Daseking, M. (2020). Executive functions and intelligence from the CHC theory perspective: Investigating the correspondence between the WAIS-IV and the NAB Executive Functions Module. *Journal of Clinical and Experimental Neuropsychology*, *42*(3), 240–250. https://doi.org/10.1080/13803395.2019.1705250
- Buha, N., & Gligorović, M. (2016). Executive functions and intelligence in typically developing children. *Specijalna edukacija i rehabilitacija*, *15*(3), 215–238. https://doi.org/10.5937/specedreh15-12297
- Buha, N., & Gligorović, M. (2015). Selekcija i odlaganje motoričkog odgovora kod dece sa lakom intelektualnom ometenošću. U Kaljača S. (ur). *Teškoće u mentalnom razvoju* (str. 40–70). FASPER – ICF.
- Buha, N., & Gligorović, M. (2012). Sposobnost planiranja kod dece sa lakom intelektualnom ometenošću. *Specijalna edukacija i rehabilitacija*, *11*(3), 365–382. https://doi.org/10.5937/specedreh11-2320
- Cartwright, K. B., Bock, A. M., Coppage, E. A., Hodgkiss, M. D., & Nelson, M. I. (2017). A comparison of cognitive flexibility and metalinguistic skills in adult good and poor comprehenders. *Journal of Research in Reading*, *40*(2), 139–152. https://doi.org/10.1111/1467-9817.12101
- Chai, W. J., Abd Hamid, A. I., & Abdullah, J. M. (2018). Working memory from the psychological and neurosciences perspectives: A review. *Frontiers in Psychology*, *9*, 401. https://doi.org/10.3389/fpsyg.2018.00401
- Chikha, A. B., Hawani, A., & Khanfir, A. (2021). The effect of play on cognitive functions and agility in a football cycle in children aged 11 to 12 years. *Journal of Advances in Sports and Physical Education*, *4*(5), 131–137. https://doi.org/10.36348/jaspe.2021.v04i05.008

- Contreras-Osorio, F., Campos-Jara, C., Martínez-Salazar, C., Chirosa-Ríos, L., & Martínez-García, D. (2021). Effects of sport-based interventions on children's executive function: A systematic review and meta-analysis. *Brain Sciences*, *11*(6), 755. https://doi.org/10.3390/brainsci11060755
- Contreras-Osorio, F., Guzmán-Guzmán, I. P., Cerda-Vega, E., Chirosa-Ríos, L., Ramírez-Campillo, R., & Campos-Jara, C. (2022). Effects of the type of sports practice on the executive functions of schoolchildren. *International Journal of Environmental Research and Public Health*, *19*(7), 3886. https://doi.org/10.3390/ijerph19073886
- Coulanges, L., Abreu-Mendoza, R. A., Varma, S., Uncapher, M. R., Gazzaley, A., Anguera, J., & Rosenberg-Lee, M. (2021). Linking inhibitory control to math achievement via comparison of conflicting decimal numbers. *Cognition*, *214*, 104767. https://doi.org/10.1016/j.cognition.2021.104767
- Curran, T., Janovec, A., & Olsen, K. (2021). Making others laugh is the best medicine: humor orientation, health outcomes, and the moderating role of cognitive flexibility. *Health Communication*, *36*(4), 468–475. https://doi.org/10.1080/10410236.2019.1700438
- De Greeff, J. W., Bosker, R. J., Oosterlaan, J., Visscher, C., & Hartman, E. (2018). Effects of physical activity on executive functions, attention and academic performance in preadolescent children: A meta-analysis. *Journal of Science and Medicine in Sport*, *21*(5), 501–507. https://doi.org/10.1016/j.jsams.2017.09.595
- De Santana, A. N., Roazzi, A., & Nobre, A. P. M. C. (2022). The relationship between cognitive flexibility and mathematical performance in children: A meta-analysis. *Trends in Neuroscience and Education*, *28*, 100179. https://doi.org/10.1016/j.tine.2022.100179
- Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750
- Diamond, A. (2020). Executive functions. In Gallagher A., Bulteau C., Cohen D., & Michaud J. L. (Eds.). *Handbook of clinical neurology*, *Vol. 173* (pp. 225–240). Elsevier.
- Diaz-Marsa, M., Pemau, A., De La Torre-Luque, A., Vaz-Leal, F., Rojo-Moreno, L., Beato-Fernandez, L., ... & Carrasco, J. L. (2023). Executive dysfunction in eating disorders: Relationship with clinical features. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *120*, 110649. https://doi.org/10.1016/j.pnpbp.2022.110649
- Ding, W. N., Sun, J. H., Sun, Y. W., Chen, X., Zhou, Y., Zhuang, Z. G., ... & Du, Y. S. (2014). Trait impulsivity and impaired prefrontal impulse inhibition function in adolescents with internet gaming addiction revealed by a Go/No-Go fMRI study. *Behavioral and Brain Functions*, *10*(1), 1–9. https://doi.org/10.1186/1744-9081-10-20
- Dousset, C., Chenut, C., Kajosch, H., Kornreich, C., & Campanella, S. (2022). Comparison of neural correlates of reactive inhibition in cocaine, heroin, and polydrug users through a contextual Go/No-Go task using event-related potentials. *Biology*, *11*(7), 1029. https://doi.org/10.3390/biology11071029
- Egger, F., Benzing, V., Conzelmann, A., & Schmidt, M. (2019). Boost your brain, while having a break! The effects of long-term cognitively engaging physical activity breaks on children's executive functions and academic achievement. *PloS One*, *14*(3), e0212482. https://doi.org/10.1371/journal.pone.0212482

- Feng, X., Zhang, Z., Jin, T., & Shi, P. (2023). Effects of open and closed skill exercise interventions on executive function in typical children: A meta-analysis. *BMC Psychology*, *11*(1), 420. https://doi.org/10.1186/s40359-023-01317-w
- Fitzgerald, S. A., Fitzgerald, H. T., Fitzgerald, N. M., Fitzgerald, T. R., & Fitzgerald, D. A. (2022). Somatic, psychological and economic benefits of regular physical activity beginning in childhood. *Journal of Paediatrics and Child Health*, *58*(2), 238–242. https://doi.org/10.1111/jpc.15879
- Formenti, D., Trecroci, A., Duca, M., Cavaggioni, L., D'Angelo, F., Passi, A., ... & Alberti, G. (2021). Differences in inhibitory control and motor fitness in children practicing open and closed skill sports. *Scientific Reports*, *11*(1), 4033. https://doi.org/10.1038/s41598-021-82698-z
- Friedman, N. P., & Miyake, A. (2017). Unity and diversity of executive functions: Individual differences as a window on cognitive structure. *Cortex*, *86*, 186–204. https://doi.org/10.1016/j.cortex.2016.04.023
- Gao, Q., Jia, G., Zhao, J., & Zhang, D. (2019). Inhibitory control in excessive social networking users: Evidence from an event-related potential-based Go-Nogo task. *Frontiers in Psychology*, *10*, 1810. https://doi.org/10.3389/fpsyg.2019.01810
- Giofre, D., Donolato, E., & Mammarella, I. C. (2018). Verbal and visuospatial WM & academic achievement. *Trends in Neuroscience and Education*, *12*, 1–6. http://dx.doi.org/10.1016/j.tine.2018.07.001
- Giordano, G., Gómez-López, M., & Alesi, M. (2021). Sports, executive functions and academic performance: A comparison between martial arts, team sports, and sedentary children. *International Journal of Environmental Research and Public Health*, *18*(22), 11745. https://doi.org/10.3390/ijerph182211745
- Gligorović, M., & Buha, N. (2013). Verbalne strategije rešavanja problema kod dece sa lakom intelektualnom ometenošću. *Specijalna edukacija i rehabilitacija*, *12*(1), 11–23. https://doi.org/10.5937/specedreh12-3333
- Harfmann, E. J., Rhyner, K. T., & Ingram, R. E. (2019). Cognitive inhibition and attentional biases in the affective go/no-go performance of depressed, suicidal populations. *Journal of Affective Disorders*, *256*, 228–233. https://doi.org/10.1016/j.jad.2019.05.022
- Heilmann, F., Weinberg, H., & Wollny, R. (2022). The impact of practicing open-vs. closed-skill sports on executive functions—A meta-analytic and systematic review with a focus on characteristics of sports. *Brain Sciences*, *12*(8), 1071. https://doi.org/10.3390/brainsci12081071
- Hernández-Mendo, A., Reigal, R. E., López-Walle, J. M., Serpa, S., Samdal, O., Morales-Sánchez, V., ... & Falco, C. (2019). Physical activity, sports practice, and cognitive functioning: The current research status. *Frontiers in Psychology*, *10*, 2658. https://doi.org/10.3389/fpsyg.2019.02658
- Isbell, E., Calkins, S. D., Swingler, M. M., & Leerkes, E. M. (2018). Attentional fluctuations in preschoolers: Direct and indirect relations with task accuracy, academic readiness, and school performance. *Journal of Experimental Child Psychology*, *167*, 388–403. https://doi.org/10.1016/j.jecp.2017.11.013
- James, R. (1995). *The techniques of instruction*. Aldershot: Gower Publishing Ltd.

- Jaschke, A. C., Honing, H., & Scherder, E. J. (2018). Longitudinal analysis of music education on executive functions in primary school children. *Frontiers in Neuroscience*, *12*, 307064. https://doi.org/10.3389/fnins.2018.00103
- Kim, H. Y. (2013). Statistical notes for clinical researchers: Assessing normal distribution (2) using skewness and kurtosis. *Restorative Dentistry & Endodontics*, *38*(1), 52–54. https://doi.org/10.5395/rde.2013.38.1.52
- Knapp, B. (2024). *Skill in sport: The atrainment of proficiency*. Routledge.
- Krenn, B., Finkenzeller, T., Würth, S., & Amesberger, G. (2018). Sport type determines differences in executive functions in elite athletes. *Psychology of Sport and Exercise*, *38*, 72–79. https://doi.org/10.1016/j.psychsport.2018.06.002
- Lemonaki, R., Xanthopoulou, D., Bardos, A. N., Karademas, E. C., & Simos, P. G. (2021). Burnout and job performance: a two-wave study on the mediating role of employee cognitive functioning. *European Journal of Work and Organizational Psychology*, *30*(5), 692–704. https://doi.org/10.1080/1359432X.2021.1892818
- Liu, Q., Gao, F., Wang, X., Xia, J., Yuan, G., Zheng, S., ... & Zhu, X. (2023). Cognitive inflexibility is linked to abnormal frontoparietal-related activation and connectivity in obsessive-compulsive disorder. *Human Brain Mapping*, *44*(16), 5460–5470. https://doi.org/10.1002/hbm.26457
- López-Vicente, M., Garcia-Aymerich, J., Torrent-Pallicer, J., Forns, J., Ibarluzea, J., Lertxundi, N., ... & Sunyer, J. (2017). Are early physical activity and sedentary behaviors related to working memory at 7 and 14 years of age?. *The Journal of Pediatrics*, *188*, 35–41. https://doi.org/10.1016/j.jpeds.2017.05.079
- Mashhoon, Y., Betts, J., Farmer, S. L., & Lukas, S. E. (2018). Early onset tobacco cigarette smokers exhibit deficits in response inhibition and sustained attention. *Drug and Alcohol Dependence*, *184*, 48–56. https://doi.org/10.1016/j.drugalcdep.2017.11.020
- Mazzoccante, R. P., de Luca Corrêa, H., de Sousa, I. R. C., Camarâ, M. A., de Sousa Alves, G., de Sousa, B. R. C., ... & de Melo, G. F. (2020). The influence of sports practice in children aged 6 to 7 years on physical fitness, motor coordination and executive functions. *Revista de Psicología del Deporte*, *29*(4), 175–184.
- McGreen, J., Kemps, E., & Tiggemann, M. (2023). The relationship between inhibitory control and food consumption or choice: A systematic review and meta-analysis. *Appetite*, 106466. https://doi.org/10.1016/j.appet.2023.106466
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734
- Möhring, W., Klupp, S., Ludyga, S., & Grob, A. (2022). Executive functions in children engaging in open-and closed-skilled sports. *Psychology of Sport and Exercise*, *61*, 102218. https://doi.org/10.1016/j.psychsport.2022.102218
- Patwardhan, I., Nelson, T. D., McClelland, M. M., & Mason, W. A. (2021). Childhood cognitive flexibility and externalizing and internalizing behavior problems: Examination of prospective bidirectional associations. *Research on Child and Adolescent Psychopathology*, *49*, 413–427. https://doi.org/10.1007/s10802-020-00757-x

- Popov, S., & Jakovljev, I. D. (2017). Uticaj fizičkog vežbanja na unapređenje kognitivnih funkcija. Tims. *Acta: naučni časopis za sport, turizam i velnes*, *11*(2), 111–120. https://doi.org/10.5937/timsact11-14016
- Russo, G., Ottoboni, G., Tessari, A., & Ceciliani, A. (2021). The positive impact of physical activity on working memory abilities: Evidence from a large Italian pre-adolescent sample. *Journal of Human Sport and Exercise*, *16*(Proc2), 277–288. https://dx.doi.org/10.14198/jhse.2021.16.Proc2.13
- Schmidt, M., Jäger, K., Egger, F., Roebers, C. M., & Conzelmann, A. (2015). Cognitively engaging chronic physical activity, but not aerobic exercise, affects executive functions in primary school children: a group-randomized controlled trial. *Journal of Sport and Exercise Psychology*, *37*(6), 575–591. https://doi.org/10.1123/jsep.2015-0069
- Sinđelić, N. M., Dragan, S., & Pešemiš, V. M. (2023). Relacije između motoričkih sposobnosti i morfoloških karakteristika kao predispozicije učenika za bavljenje sportom. *Inovacije u nastavi*, *36*(2), 142–154. https://doi.org/10.5937/inovacije2302142S
- Ursache, A., Noble, K. G., & Pediatric Imaging, Neurocognition and Genetics Study. (2016). Socioeconomic status, white matter, and executive function in children. *Brain and Behavior*, *6*(10), e00531. https://doi.org/10.1002/brb3.531
- Zajączkowska, M., & Abbot-Smith, K. (2020). "Sure I'll help—I've just been sitting around doing nothing at school all day": Cognitive flexibility and child irony interpretation. *Journal of Experimental Child Psychology*, *199*, 104942. https://doi.org/10.1016/j.jecp.2020.104942
- Yamashita, M., Yoshihara, Y., Hashimoto, R., Yahata, N., Ichikawa, N., Sakai, Y., ... & Imamizu, H. (2018). A prediction model of working memory across health and psychiatric disease using whole-brain functional connectivity. *Elife*, *7*, e38844. https://doi.org/10.7554/eLife.38844
- Wang, Y. H., Zhou, H. H., Luo, Q., & Cui, S. (2022). The effect of physical exercise on circulating brain-derived neurotrophic factor in healthy subjects: A meta-analysis of randomized controlled trials. *Brain and Behavior*, *12*(4), e2544. https://doi.org/10.1002/brb3.2544
- Webster, C. A., Russ, L., Vazou, S., Goh, T. L., & Erwin, H. (2015). Integrating movement in academic classrooms: understanding, applying and advancing the knowledge base. *Obesity Reviews*, *16*(8), 691–701. https://doi.org/10.1111/obr.12285
- Wessel, J. R., & Anderson, M. C. (2024). Neural mechanisms of domain-general inhibitory control. *Trends in Cognitive Sciences*, *28*(2), 124–143. https://doi.org/10.1016/j.tics.2023.09.008
- Willinger, U., Deckert, M., Schmöger, M., Schaunig-Busch, I., Formann, A. K., & Auff, E. (2019). Developmental steps in metaphorical language abilities: The influence of age, gender, cognitive flexibility, information processing speed, and analogical reasoning. *Language and Speech*, *62*(2), 207–228. https://doi.org/10.1177/0023830917746552
- Wu, N., Chen, Y., Yang, J., & Li, F. (2017). Childhood obesity and academic performance: the role of working memory. *Frontiers in Psychology*, *8*, 611. https://doi.org/10.3389/fpsyg.2017.00611
- Xue, Y., Yang, Y., & Huang, T. (2019). Effects of chronic exercise interventions on executive function among children and adolescents: A systematic review with meta-analysis. *British Journal of Sports Medicine*, *53*(22), 1397–1404. https://doi.org/10.1136/bjsports-2018-099825