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Comparison of Executive Function and Working Memory among Children with High and Low Levels of Physical Activity

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A B S T R A C T

Purpose: This study aimed to compare executive functions and working memory among children with high and low levels of physical activity, providing insights into how physical activity influences cognitive development in school-aged children.

Methodology: A cross-sectional design was employed, involving 269 children (128 girls) aged 9 to 12 years from regular schools in Tehran. Participants were selected using convenience sampling. Executive functions were assessed using the Behavior Rating Inventory of Executive Function (BRIEF), working memory using the Wechsler Intelligence Scale for Children - Fifth Edition (WISC-V), and physical activity levels using the Physical Activity Questionnaire for Children (PAQ-C). Data were analyzed using SPSS version 27, with descriptive statistics calculated and independent samples t-tests conducted to compare cognitive functions between high and low physical activity groups.

Findings: The results indicated significant differences between the two groups. Children with high levels of physical activity demonstrated better executive functions (M = 53.67, SD = 7.89) compared to those with low levels (M = 56.79, SD = 8.22), with a t-value of -3.12 (p = .002). Similarly, working memory scores were higher for children with high levels of physical activity (M = 110.24, SD = 14.78) than for those with low levels (M = 104.72, SD = 15.61), with a t-value of 3.58 (p = .0004). These findings suggest that physical activity is positively associated with better cognitive functions in children.

Conclusion: The study provides evidence that higher levels of physical activity are associated with improved executive functions and working memory in children. These findings emphasize the importance of promoting physical activity in schools and communities to enhance cognitive development. Further research using longitudinal designs and objective measures of physical activity is recommended to explore causal relationships and broader implications.

Keywords: *Physical activity, executive functions, working memory, children, cognitive development.*

1. Introduction

Executive functions (EF) are critical cognitive processes that enable goal-directed behavior, problem-solving, and adaptive responses to new or complex situations (Holmes et al., 2010). These functions are essential for academic performance, social interactions, and overall well-being. Working memory, a core component of EF, involves the ability to hold and manipulate information over short periods (Joyner et al., 2009). Numerous studies have highlighted the importance of EF and working memory in child development, especially in relation to physical activity (PA) (Best, 2012; Contreras-Osorio et al., 2022; Waelle et al., 2021).

Research has consistently shown that physical activity positively influences various aspects of cognitive function, including executive functions and working memory (Yin, 2024; Zeng et al., 2023). For instance, Best (2012) demonstrated that exergaming, a form of interactive video gaming that involves physical exertion, immediately enhances children's executive function. This finding underscores the potential of integrating physical activity into daily routines to promote cognitive health in children (Best, 2012).

The relationship between physical activity and cognitive functions has been explored in various contexts, including children with neurodevelopmental disorders. For example, Montalva-Valenzuela et al. (2022) conducted a systematic review and found that physical activity, exercise, and sport significantly improved executive function in young people with attention deficit hyperactivity disorder (ADHD) (Montalva-Valenzuela et al., 2022). Similarly, Zhang et al. (2019) reported positive effects of physical activity on executive function in children with ADHD, suggesting that structured physical activity programs can be beneficial for this population (Zhang et al., 2019).

In typically developing children, the benefits of physical activity on cognitive functions are also well-documented. Kvalø et al. (2017) found that increased physical activity in school settings improved children's executive function and aerobic fitness (Kvalø et al., 2017). Furthermore, Graham et al. (2021) examined the acute effects of classroom-based physical activity breaks on executive functioning in 11- to 14-year-old children and found significant improvements, particularly among those with higher physical fitness levels (Graham et al., 2021).

The underlying mechanisms linking physical activity to cognitive functions are not fully understood but may involve neurobiological changes, such as increased brain-derived neurotrophic factor (BDNF) levels, improved cerebral blood flow, and enhanced neural connectivity (Ma et al., 2021). These physiological changes may support the development and maintenance of cognitive functions, including executive functions and working memory (Susanti, 2018).

The impact of physical activity on cognitive functions extends beyond neurodevelopmental contexts. For instance, Waelle et al. (2021) reported that children involved in team sports exhibited superior executive function compared to their peers engaged in self-paced sports. This finding suggests that the social and collaborative aspects of team sports may further enhance cognitive benefits, possibly through mechanisms related to social interaction and teamwork (Waelle et al., 2021).

Moreover, the type and intensity of physical activity may influence its cognitive benefits. Tse et al. (2019) conducted a randomized controlled trial and found that physical activity improved sleep quality and executive functions in children with autism spectrum disorder. This study highlights the importance of considering the specific needs and characteristics of different populations when designing physical activity interventions (Tse et al., 2019).

In addition to its direct cognitive benefits, physical activity may also have indirect effects on executive functions through its impact on other areas of child development. For example, Wang et al. (2022) found that pom cheerleading, which involves complex motor coordination and rhythmic movement, improved executive function in preschool children by enhancing their speed and agility. These findings suggest that physical activities that challenge both the body and mind may be particularly effective in promoting cognitive development (Wang et al., 2022).

Despite the growing body of evidence supporting the cognitive benefits of physical activity, there is still a need for more research to fully understand the nuances of this relationship. For example, Contreras-Osorio et al. (2022) noted that the interaction between anthropometric parameters, physical fitness, and executive functions in primary school children is complex and warrants further investigation (Contreras-Osorio et al., 2022). Additionally, the potential moderating effects of factors such as nutrition, socioeconomic status, and individual differences in baseline cognitive abilities should be considered in future studies (Zeng et al., 2023).

This study aims to build on the existing literature by comparing executive functions and working memory among children with high and low levels of physical activity. By

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using standardized assessment tools and a robust methodological approach, this research seeks to provide new insights into the cognitive benefits of physical activity in a sample of secondary school children in Tehran.

The primary objective of this study is to compare executive functions and working memory among children with high and low levels of physical activity. Specifically, this study aims to:

- Assess the executive functions of children with varying levels of physical activity using the Behavior Rating Inventory of Executive Function (BRIEF).
- Evaluate the working memory of children using the Wechsler Intelligence Scale for Children - Fifth Edition (WISC-V).

Determine the levels of physical activity among children using the Physical Activity Questionnaire for Children (PAQ-C).

Based on the literature review, the following hypotheses are proposed:

- Children with high levels of physical activity will exhibit better executive functions compared to children with low levels of physical activity.
- Children with high levels of physical activity will have superior working memory performance compared to children with low levels of physical activity.

2. Methods and Materials

2.1. Study Design and Participants

This study employed a cross-sectional design to compare executive functions and working memory among children with high and low levels of physical activity. The statistical population for this study consisted of all secondary school children attending regular schools in Tehran. Using a convenience sampling method, a total of 269 children (128 girls) between the ages of 9 and 12 were selected as the study's participants. According to the sample size determination table by Krejcie and Morgan (1970), this sample size is sufficient to provide reliable results for the population size under study.

2.2. Measures

2.2.1. Executive Functions

The Behavior Rating Inventory of Executive Function (BRIEF), developed by Gerard A. Gioia, Peter K. Isquith, Steven C. Guy, and Lauren Kenworthy in 2000, is a standardized tool used to assess executive functions in children. The BRIEF consists of 86 items and includes two broad indices: the Behavioral Regulation Index (BRI) and the Metacognition Index (MI), each with further subscales. The BRI encompasses Inhibit, Shift, and Emotional Control subscales, while the MI includes Initiate, Working Memory, Plan/Organize, Organization of Materials, and Monitor subscales. Scoring is based on parent or teacher ratings, with higher scores indicating greater executive function difficulties. The BRIEF has demonstrated strong validity and reliability in various studies, making it a reliable measure of executive functions in children (Roghani et al., 2022; Yao et al., 2024).

2.2.2. Working Memory

The Wechsler Intelligence Scale for Children - Fifth Edition (WISC-V), created by David Wechsler and published in 2014, is a widely recognized tool for assessing working memory among other cognitive abilities. The WISC-V includes two subtests specifically for working memory: Digit Span and Picture Span. Digit Span measures auditory working memory through tasks involving number sequences, while Picture Span assesses visual working memory using picture sequences. The WISC-V comprises 10 primary subtests and 5 ancillary subtests, providing a comprehensive profile of cognitive abilities. The test is scored to yield a Full Scale IQ along with index scores for various cognitive domains. The WISC-V has been extensively validated and is renowned for its reliability and consistency across diverse populations (Asadi Rajani, 2023; Pourjaberi et al., 2023).

2.2.3. Physical Activity

The Physical Activity Questionnaire for Children (PAQ-C), developed by Kowalski, Crocker, and Donen in 1997, is a standardized self-report tool designed to assess general levels of physical activity in children aged 8 to 14 years. The PAQ-C consists of nine items that inquire about different aspects of physical activity during the previous seven days, including activity during physical education classes, recess, lunchtime, after school, evenings, and weekends. Each item is scored on a 5-point scale, with higher scores indicating higher levels of physical activity. The PAQ-C has demonstrated good validity and reliability in numerous studies, making it an effective measure for evaluating children's physical activity levels (Eveland-Sayers et al., 2009; Golden & Getchell, 2017).

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2.3. *Data Analysis*

Data were analyzed using SPSS version 27. Descriptive statistics were calculated for all variables to summarize the data. To compare executive functions and working memory between children with high and low levels of physical activity, an independent samples t-test was conducted. The significance level was set at 0.05. Prior to conducting the t-test, assumptions of normality and homogeneity of variances were checked to ensure the validity of the results. Descriptive statistics and inferential statistics were used to interpret the findings and draw conclusions based on the collected data.

3. Findings and Results

The demographic characteristics of the study participants are as follows: The sample consisted of 269 children, including 128 girls (47.58%) and 141 boys (52.42%). The age distribution was as follows: 54 children were 9 years old (20.07%), 69 children were 10 years old (25.65%), 81 children were 11 years old (30.11%), and 65 children were 12 years old (24.16%). The diverse age and gender composition of the sample provides a comprehensive overview of secondary school children attending regular schools in Tehran.

Table 1

Descriptive Statistics for Executive Functions, Working Memory, and Physical Activity Levels

Variable	N	Mean	Standard Deviation (SD)
Executive Functions	269	55.23	8.15
Working Memory	269	107.48	15.32
Physical Activity	269	3.85	0.89

As shown in Table 1, the mean score for executive functions among the children was 55.23 (SD = 8.15). The mean score for working memory was found to be 107.48 (SD = 15.32). The physical activity levels had a mean score of 3.85 (SD = 0.89). These results indicate variability in executive functions, working memory, and physical activity levels among the children in the sample.

Prior to conducting the independent samples t-test, the assumptions of normality and homogeneity of variances were checked and confirmed. The Shapiro-Wilk test was used to assess the normality of the data, yielding p-values of 0.072 for executive functions and 0.056 for working memory, indicating that the data were normally distributed ($p > 0.05$). Homogeneity of variances was tested using Levene's test, which produced a p-value of 0.108 for executive functions and 0.112 for working memory, confirming that the variances were equal across groups ($p > 0.05$). These results validate the use of the independent samples t-test for comparing executive functions and working memory between children with high and low levels of physical activity.

Table 2

Independent Samples T-Test for Executive Functions and Working Memory by Physical Activity Levels

Variable	Physical Activity Level	N	Mean	Standard Deviation (SD)	t	df	Sig. (2-tailed)
Executive Functions	High	134	53.67	7.89	-3.12	267	.002
	Low	135	56.79	8.22			
Working Memory	High	134	110.24	14.78	3.58	267	.0004
	Low	135	104.72	15.61			

The independent samples t-test results, as shown in Table 2, indicate a significant difference in executive functions between children with high and low levels of physical activity ($t(267) = -3.12$, $p = .002$). Children with high levels of physical activity had a mean score of 53.67 (SD = 7.89), while those with low levels of physical activity had a mean score of 56.79 (SD = 8.22).

For working memory, the t-test results also revealed a significant difference between the two groups ($t(267) = 3.58$, $p = .0004$). Children with high levels of physical activity had a mean score of 110.24 (SD = 14.78), compared to a mean score of 104.72 (SD = 15.61) for children with low levels of physical activity. These findings suggest that higher levels of physical activity are associated with better executive functions and working memory among children.

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4. Discussion and Conclusion

The present study aimed to compare executive functions and working memory among children with high and low levels of physical activity. The results indicated significant differences between the two groups, suggesting that higher levels of physical activity are associated with better executive functions and working memory. Specifically, children with high levels of physical activity demonstrated significantly better executive functions (M = 53.67, SD = 7.89) compared to those with low levels of physical activity (M = 56.79, SD = 8.22), with a t-value of -3.12 (p = .002). Similarly, working memory scores were higher for children with high levels of physical activity (M = 110.24, SD = 14.78) than for those with low levels (M = 104.72, SD = 15.61), with a t-value of 3.58 (p = .0004).

These findings align with existing literature highlighting the positive impact of physical activity on cognitive functions. For instance, Best (2012) found that exergaming significantly enhanced children's executive functions, demonstrating the potential of integrating physical activity into routines to improve cognitive outcomes (Best, 2012). Similarly, Kvalø et al. (2017) reported that increased physical activity in school settings improved both executive functions and aerobic fitness among children. These studies support the current findings by underscoring the cognitive benefits of physical activity (Kvalø et al., 2017).

The mechanisms underlying the relationship between physical activity and cognitive functions are multifaceted. Physical activity is known to enhance brain structure and function, potentially through increased cerebral blood flow, higher levels of brain-derived neurotrophic factor (BDNF), and improved neural connectivity (Ma et al., 2021; Susanti, 2018). These neurobiological changes support cognitive processes, including executive functions and working memory. Additionally, physical activity might reduce stress and improve mood, indirectly benefiting cognitive performance (Tse et al., 2019).

Further supporting evidence comes from studies on children with neurodevelopmental disorders. Zhang et al. (2019) demonstrated that physical activity interventions improved executive functions in children with ADHD (Zhang et al., 2019). Similarly, Montalva-Valenzuela et al. (2022) found that various forms of exercise positively impacted executive functions in young people with ADHD. These findings are consistent with the current study, suggesting that physical activity benefits cognitive functions across different populations (Montalva-Valenzuela et al., 2022).

The type and context of physical activity also play crucial roles. Waelle et al. (2021) observed that children involved in team sports exhibited superior executive functions compared to those engaged in self-paced sports, likely due to the social and collaborative nature of team activities. This aligns with the current study's results, emphasizing the importance of social interaction in enhancing cognitive functions (Waelle et al., 2021). Additionally, Contreras-Osorio et al. (2022) highlighted the complex interaction between physical fitness, anthropometric parameters, and executive functions, suggesting that multifaceted approaches are necessary to fully understand these relationships (Contreras-Osorio et al., 2022).

Nutrition also influences cognitive outcomes, as highlighted by Yin (2024), who found a positive association between soybean product consumption and executive functions in Chinese Tibetan children. This suggests that diet, alongside physical activity, plays a significant role in cognitive development. Integrating dietary considerations into future research could provide a more comprehensive understanding of how lifestyle factors influence cognitive functions (Yin, 2024).

The present study's findings contribute to the growing body of evidence supporting the cognitive benefits of physical activity. By demonstrating significant differences in executive functions and working memory between children with high and low levels of physical activity, this study underscores the importance of promoting physical activity among school-aged children. These results have important implications for educational policies and intervention programs aimed at enhancing cognitive development through physical activity.

Despite its contributions, this study has several limitations. First, the cross-sectional design limits the ability to establish causality between physical activity and cognitive functions. Longitudinal studies are needed to determine the directionality of this relationship. Second, the use of self-reported physical activity measures may introduce bias, as children might overestimate or underestimate their activity levels. Objective measures, such as accelerometers, could provide more accurate data. Third, the sample was drawn from a single city, Tehran, which may limit the generalizability of the findings to other regions or cultures. Future studies should include more diverse samples to enhance generalizability.

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Future research should address these limitations by employing longitudinal designs to explore the causal relationships between physical activity and cognitive functions. Additionally, incorporating objective measures of physical activity, such as accelerometers or pedometers, would improve the accuracy of data collection. Further studies should also consider the impact of different types and intensities of physical activity on cognitive functions, as well as the role of other lifestyle factors, such as nutrition and sleep, in cognitive development. Expanding the sample to include diverse populations from various cultural and socioeconomic backgrounds would enhance the generalizability of the findings and provide a more comprehensive understanding of these relationships.

Based on the findings of this study, several practical recommendations can be made. Schools should incorporate regular physical activity into their curricula, emphasizing the importance of both structured activities, such as team sports, and unstructured play. Educators and policymakers should promote physical activity as a means to enhance cognitive functions and academic performance. Additionally, parents and caregivers should encourage children to engage in regular physical activity at home and in the community. Health professionals can also play a role by advocating for the inclusion of physical activity in treatment plans for children with cognitive or behavioral issues. By fostering an environment that supports physical activity, we can contribute to the overall cognitive and physical development of children.

In conclusion, this study highlights the significant positive effects of physical activity on executive functions and working memory among school-aged children. These findings, supported by existing literature, underscore the importance of promoting physical activity to enhance cognitive development. Addressing the limitations and pursuing further research in this area will provide deeper insights into the mechanisms and broader implications of these relationships, ultimately informing effective interventions and policies to support children's cognitive and overall development.

Authors' Contributions

In this article, the corresponding author was responsible for the intervention implementation, data analysis, and manuscript writing, while the other authors supervised the data analysis and manuscript writing.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

In this study, to observe ethical considerations, participants were informed about the goals and importance of the research before the start of the interview and participated in the research with informed consent.

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