EXPLORING THE RELATIONSHIP BETWEEN VISUAL-SPATIAL WORKING MEMORY AND GROSS MOTOR SKILLS IN PRIMARY SCHOOL CHILDREN

ESPLORARE LA RELAZIONE TRA MEMORIA DI LAVORO VISUO-SPAZIALE E ABILITÀ GROSSO MOTORIE NEI BAMBINI DELLA SCUOLA PRIMARIA

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ABSTRACT
Physical activity plays a key role in improving overall health and cognitive functions, especially executive functions, understood as inhibitory control, working memory, and cognitive flexibility. This study explores the link between visuospatial working memory and gross motor skills in primary children, finding a moderate positive correlation. These findings reinforce existing literature promoting the integration of movement-based approaches in educational settings.

L'attività fisica svolge un ruolo chiave nel migliorare la salute generale e le funzioni cognitive, in particolare le funzioni esecutive, intese come controllo inibitorio, memoria di lavoro e flessibilità cognitiva. Questo studio esplora il legame tra memoria di lavoro visuospaziale e abilità motorie grossolane nei bambini della scuola primaria, evidenziando una correlazione positiva moderata. Questi risultati rafforzano la letteratura esistente che promuove l'integrazione di approcci basati sul movimento negli ambienti educativi.

KEYWORDS
Executive functions; gross-motor development; primary school
Funzioni esecutive; sviluppo grosso motorio; scuola primaria

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Introduction

During early childhood, a child's development is marked by rapid changes across biological, psychosocial, and emotional domains, leading to significant acquisitions and progressive refinement of higher cognitive functions. In this context, psychomotor development plays a crucial role, as the dynamic interaction between the organism and the environment is a key factor in the emergence and consolidation of motor skills, thereby also influencing related neurocognitive processes (Seer-Uke et al., 2025)

Cognitive development refers to the complex process through which individuals acquire, organize, and process information, progressively enhancing abilities related to abstract thinking, problem-solving, decision-making, and understanding the surrounding environment (Schacter, 2019; 2019). This development encompasses the maturation of higher-order mental functions and is reflected in the evolution of cognitive structures that enable individuals to ascribe meaning to their experiences. According to Sellers, Machluf, and Bjorklund (2018), cognitive development results from the synergistic interaction between genetic predispositions and experiential learning processes, influencing how individuals perceive, interpret, and engage with the world. Key areas of cognitive competence include information processing, intelligence, logical reasoning, language development, and memory (Seer-Uke et al., 2025)

The relationship between physical activity and cognitive function has been the subject of extensive research, revealing numerous benefits for both children and adults. The positive effects of physical exercise on brain health are multifaceted, influencing various aspects of cognitive performance, including executive functions, memory, and overall academic achievement (Dixon et al., 2025; Mavildi et al., 2023). Executive functions (EFs), encompassing inhibitory control, cognitive flexibility, and working memory (Diamond, 2013), are essential for academic achievement (Ahmed et al., 2019). Diamond (2020) suggests that EFs development is closely associated with neural maturation, particularly within the prefrontal cortex, which interacts with other neural networks involved in motor control.

The specific type, intensity, and duration of physical activity can differentially impact distinct executive functions; for instance, activities requiring greater cognitive engagement, such as team sports or complex motor tasks, may particularly bolster cognitive flexibility and inhibitory control (Gilbert et al., 2023).

Scientific literature highlights that physical activity improves executive functions in children, with a greater impact linked to the duration of the intervention.

Specifically, play-based pedagogical approaches within sports activities are an effective way to promote the development of these functions in young children (Contreras et al., 2021; Sember et al., 2020; Wei et al., 2024). The motor cortex, responsible for the coordination of complex motor sequences, plays a significant role not only in motor control but also in higher-order cognitive processes, such as decision-making. Research indicates that physical activity engages the motor cortex, thereby influencing cognitive processes related to executive control. Gordon, Chauvin, and Van (2023) emphasize the interaction of the motor cortex with neural structures that mediate both cognitive functions and physiological processes, contributing to complex adaptive behaviors crucial for learning.

Research has shown that higher levels of physical fitness in children are associated with structural changes in the brain, particularly in regions such as the hippocampus and basal ganglia, both of which play critical roles in memory, learning, and motor control (Di Liegro, 2019; Donnelly, 2016). Erickson et al. (2015; 2019) demonstrated that increased physical fitness is linked to larger brain volumes in these areas, as well as enhanced white matter integrity, which supports more efficient brain function. These changes in brain structure are thought to underlie improvements in cognitive performance, leading to enhanced academic outcomes. One of the most significant benefits of regular physical activity is its role in promoting neuroplasticity—the brain's ability to reorganise itself by forming new neural connections. Neuroplasticity is crucial for learning and memory processes, and it is particularly influenced by physical exercise. Exercise has been shown to stimulate the production of brain-derived neurotrophic factor (BDNF), which facilitates the growth of new neurons and strengthens synaptic connections. This neuroplastic effect is vital for maintaining cognitive function, particularly as individuals age (Barenberg et al., 2011).

Furthermore, physical activities that incorporate coordination and strategy, such as those found in team sports, have been shown to enhance cognitive flexibility—the ability to shift thinking between different concepts or adapt to new situations (Ángel Latorre-Román, 2021). Similarly, tasks that require fine motor control or attention to detail can improve inhibitory control, which is essential for suppressing automatic responses and focusing attention on relevant tasks (Biino et al., 2023). Several studies suggest that motor activities requiring strategy and coordination may help to strengthen executive functions such as working memory, which are crucial for academic success (Diamond, 2012; 2013; Mavilidi et al., 2023; McClelland & Cameron, 2019; Tomporowski & Pesce, 2019; Pesce, 2021; Kolovelonis, 2022).

Numerous scientific studies have shown that physical activity—particularly that which involves coordinative and strategic components—can significantly enhance executive functions in children and adolescents (Ángel Latorre-Román, 2021; Diamond, 2012; Pesce, 2021). Specifically, exercises requiring bilateral coordination and fine motor control are associated with improvements in working memory, selective attention, and visuospatial perception (Lin et al., 2023; Tomporowski et al., 2011). These activities stimulate brain structures such as the cerebellum, which plays a central role in attentional and memory processes (Guillamón et al., 2020), thereby promoting more efficient information processing and reducing cognitive processing time.

Working memory, understood as the capacity to temporarily hold and consciously manipulate information (Baddeley, 2007), is considered a key component in cognitive development and is particularly sensitive during childhood (Diamon, 2000). Moreover, it appears to be especially responsive to environmental stimuli and to structured coordinative exercise protocols (Chang et al., 2013; Padilla et al., 2014), highlighting the relevance of such activities as effective tools for cognitive enhancement.

In light of the extensive empirical evidence highlighting the interaction between motor development and cognitive functions, the present study aims to further investigate the relationship between visuospatial working memory and gross motor skills in primary school children, hypothesizing that higher levels of motor competence are significantly associated with better performance in visuospatial working memory tasks. This investigation particular relevance within the educational context, as a deeper understanding of these connections could facilitate the implementation of targeted instructional strategies and intervention programs designed to enhance both motor skills and cognitive skills essential for learning and academic success.

1. Materials and Methods

1.1. Design

Data collection began following the formal authorization from the host school, which approved the implementation of the research project. A preliminary meeting was held with the teaching staff to present the study’s objectives, methods, and procedures, ensuring full understanding and cooperation. After obtaining informed consent from the families, the activities were introduced to the children to promote engagement and prepare them for participation.

All procedures were conducted in the school gym during morning hours on weekdays, ensuring consistent testing conditions for all participants. Before each task, clear instructions and demonstrations were provided, allowing students to become familiar with the procedures. Participants performed the activities wearing appropriate sportswear in a well-prepared and comfortable setting, supporting accurate and efficient data collection.

Additionally, information regarding each child's physical characteristics and extracurricular habits was obtained through a parent-completed questionnaire during the informed consent process. Parents reported data on height, weight (for BMI calculation), weekly sport participation (type and duration), and other non-sport activities such as music, dance, or drama.

The ethical committee of the Pegaso University approved this study (001221).

1.2. Partecipants

This descriptive study involves 107 children aged 8-10 years old (mean age = 9.39 years, SD = 0.54 years), 46,7% of girls and 53,3% of boys. Participants were recruited from primary school (Grades 4 and 5) within a city in Southern Italy.

All children were included in the study except those whose parents children whose parents have explicitly refused to participate in the research.

1.3. Tools

1.3.1. Test of Gross Motor Development—3rd edition (TGMD-3)

Gross motor skills were assessed using the *Test of Gross Motor Development–Third Edition (TGMD-3)*, Italian version (Ulrich & D'Anna, 2023), a standardized instrument designed for children aged 3 to 11 years.The TGMD-3 consists of two sub-tests locomotor skills (it provides for six items such as: run, gallop, hop, skip, horizontal jump, and slide), and ball skills (it provides for seven items such as: two-hand strike, one-hand strike, dribble, catch, kick, overhand throw, and underhand throw.

Each item is evaluated using checklists that specify performance criteria. Each criterion is rated as 1 if met and 0 if not met. Two trials are administered for each task, and the total score for each item is calculated by summing the performance criteria scores from both trials. The aggregate scores from the locomotor and ball skills subtests contribute to the overall TGMD-3 score, which provides a comprehensive measure of a child's gross motor development (Gross Motor Index – GMI).

The complete administration of the TGMD-3 requires approximately 20 minutes per child. The time required for testing can vary depending on the age of the child and the experience of the administrator.

1.3.2. BVS-Corsi-2 Battery for the Assessment of Visuospatial Working Memory (ages 8–12)

The *Corsi Block-Tapping Task*, specifically the version included in the *BVS-Corsi 2* (Mammarella et., 2023), was administered. This task is a well-established tool for evaluating short-term memory, visuospatial working memory, and attention (Kessels, 2000). Research by Mammarella et al. (2023) has expanded on the use of this test, considering how it relates to working memory, executive functions, and spatial processing abilities in various populations, including children, elderly individuals, and those with cognitive impairments.

The task involves a board with 9 cubes numbered from 1 to 9, arranged irregularly in front of the examiner. The examiner touches the cubes in ascending order of length, following a predefined checklist. The test begins with two cubes, and after each sequence touched, the participant must attempt to reproduce the sequence just touched by the examiner. The examiner presents three sequences for each set. If the participant correctly reproduces at least two of the three sequences, a new sequence with increasing length is presented. The test involves recalling the touched cubes in the same order in the Corsi Block-Tapping Test Forward. Furthermore, the test also includes a backward sequence, where the participant must reproduce the sequence in reverse order (Corsi's Block-Tapping Test Backward), making the task more difficult and activating additional cognitive processes, such as inhibition and flexibility. The test ends when the participant makes three consecutive errors in the same set, both for the Corsi Forward and the Corsi Backward. Figure 1 shows the Corsi Block-Tapping used in this study. The total test time for each participant is approximately 15 minutes, including the instruction and practice phase.

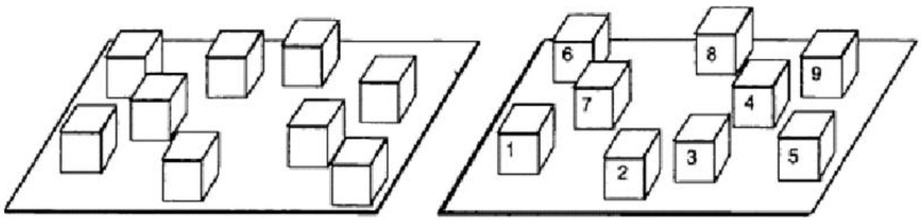

Figure 1. The Corsi Block-Tapping task (Mammarella et al., 2023)

1.4. Statistical Analysis

All statistical analyses were conducted using Jamovi statistical software. Descriptive statistics—including means, standard deviations, medians, ranges, and frequency distributions—were computed to summarize the demographic characteristics of the sample and performance scores on the Span Forward, Span Backward, and Gross Motor Index (GMI).

Prior to interpreting the regression results, diagnostic procedures were conducted to verify that the necessary assumptions of the linear model were met. The normality of the residuals was tested using the Shapiro–Wilk test. Multicollinearity among predictors was assessed via the Variance Inflation Factor (VIF) and tolerance statistics, and the independence of residuals was evaluated using the Durbin–Watson statistic. These checks ensured the robustness and validity of the model estimates.

To examine the associations among the variables of interest, Pearson’s correlation coefficients were calculated, to assess the relationships between gross motor skills and the two measures of visuospatial working memory (Span Forward and Span Backward).

2. Results

The descriptive statistics provide a foundational understanding of the sample's composition and the distribution of key variables.

Specifically, the mean score for Span Forward is 4.55 (SD = 0.743), for Span Backward it is 4.20 (SD = 0.770), and for the GMI it is 103.91 (SD = 8.286). The test results are presented in Table 1.

Variable	N	Media	SD	Min	Max
Span_Forward	107	4.55	0.743	3	6
Span_Backward	107	4.20	0.770	3	6
Gross Motor Index	107	103.91	8.286	88	119

Table 1. Descriptive statistics for the study variables

To ensure the validity of the linear regression model employed, several fundamental statistical assumptions were verified.

Assumptions underlying the regression analysis were verified. Residuals were normally distributed as indicated by the Shapiro-Wilk test ($W = 0.98$, $p = 0.098$). Multicollinearity diagnostics showed Variance Inflation Factors (VIF) of 1.12 and 1.21 for Span Forward and Span Backward, respectively, well below critical thresholds, confirming predictor independence. The Durbin-Watson statistic of 1.78 ($p = 0.240$) indicated no significant autocorrelation in residuals, supporting the independence assumption.

Pearson's correlation analyses revealed moderate positive relationships between the Gross Motor Index and Span Forward ($r(105) = 0.46$, $p < 0.001$), as well as Span Backward ($r(105) = 0.40$, $p < 0.001$) (see Table 2). These findings suggest that higher visuospatial working memory capacity is associated with better gross motor competence.

		Gross Motor Index
Span_Forward	**r di Pearson**	0.46
	gdl	105
	valore p	<.001
Span_Backward	**r di Pearson**	0.40
	gdl	105
	valore p	<.001

Table 2. Pearson correlation coefficients between working memory measures and Gross Motor Index

A multiple linear regression was conducted to assess the predictive value of Span Forward and Span Backward on Gross Motor Index scores. The model was statistically significant, explaining 26.4% of the variance ($F(2, 104) = 18.7$, $p < 0.001$, $R^2 = 0.264$) (Table 3). Both predictors contributed significantly: each one-unit increase in Span Forward corresponded to a 4.03-unit increase in GMI ($\beta = 4.03$, $SE = 1.03$, $t = 3.90$, $p < 0.001$), while each one-unit increase in Span Backward predicted a 2.63-unit increase in GMI ($\beta = 2.63$, $SE = 1.00$, $t = 2.64$, $p = 0.010$) (Table 4).

			Global Model Test			
Model	**R**	**R²**	**F**	**gdl1**	**gdl2**	**p**
1	0.514	0.264	18.7	2	104	<.001

Nota. Models estimated using sample size of N=107

Table 3. Model Fit Measures

Predictor	**β**	**SE**	**t**	**p**
Intercept	74.52	4.858	15.34	<.001
Span_Forward	4.03	1.033	3.90	<.001
Span_Backward	2.63	0.997	2.64	0.010

Table 4. Linear Regression Table

3. Discussion

The present study examined the relationship between visuospatial working memory—a specific component of executive functions (EF) involved in the maintenance and manipulation of visual and spatial information, assessed using the Corsi Block-Tapping Test (Forward and Backward Span)—and gross motor skills, evaluated through the Test of Gross Motor Development–Third Edition (TGMD-3), in a sample of primary school children.

The relation between working memory and gross motor competence in primary school-aged children constitutes a significant area of research, as both are foundational to cognitive development and academic achievemen. Working memory is crucial for performing tasks such as following instructions, solving problems, and actively participating in classroom learning (Russo, 2021; Kang, 2024), while global motor skills form the basis for physical coordination and general development (Magistro et al., 2020; D'Anna et al., 2024; D'Anna et al., 2025). The interest in this age group lies in the critical period of development in which EF and motor skills undergo a rapid evolution, making it particularly relevant to identify any correlations useful for the design of increasingly effective learning environments and teaching strategies (Ambretti et al., 2025; Forte et al., 2023; Forte et al., 2024; Gomez Paloma, 2020).

The application of the two tests, in an educational context such as school, is also linked to the investigation of how physical activities, such as motor skills or coordination exercises, affect working memory performance (Latino et al., 2021). Cortes Pascual et al. (2019) find that children who regularly participate in physical activities show improvements in their cognitive abilities. Similarly, Trevillion et al. (2022) observe that children who perform moderate to vigorous physical activity have better performance in working memory than those who are less active. Sibley and Etnier (2003) conducted a meta-analysis on the impact of physical activity on children's cognitive abilities. They found that physical activity, especially that involving gross motor skills, significantly improved working memory, particularly when children were engaged in activities that required coordination and multitasking.

The descriptive statistics of the present sample — mean age of 9.39 years, low standard deviation and balanced gender distribution — indicate a homogeneous group, free of significant confounding factors related to age or sex.

The results of the Corsi Test showed a higher average score for the Span Forward than for the Span Backward, in line with the literature showing greater difficulty in remembering information in reverse order (Donolato et al., 2017). Similarly, the average scores of the GMI suggest a good level of motor development, with no significant differences between males and females, confirming what has been reported in previous research (Spessato, 2013; Robinson, 2015; Ulrich, 2019).

Correlation analyses showed positive and statistically significant relationships between the GMI and working memory scores (Span Forward and Backward), suggesting that children with more developed visuospatial working memory also tend to display better motor skills (Capio et al., 2023; Van der Fels et al., 2022). However, these correlations are of moderate strength, indicating that while working memory contributes to motor performance, it does not fully account for individual differences. This suggests the involvement of additional cognitive, environmental, or biological factors, and highlights the complex interplay between cognitive and motor domains (Abrams et al., 2024; Pesce et al., 2019). Working memory, therefore, represents only one piece of a broader and multifaceted picture.

Regression analysis confirmed that visuospatial working memory is a significant predictor of gross motor skills. In particular, Span Forward and Backward explain a relevant portion of the variance in the GMI, offering a solid basis for the development of integrated educational programs that simultaneously target cognitive and motor development.

It is also relevant to note that most of the participants regularly practiced sports activities, with an average of 3.6 hours per week. This data, combined with the variety of sports practised (individual and team), suggests a favourable context for motor and cognitive development. The presence of non-sport extracurricular activities (music, dance) suggests a variety of environmental stimuli in the participants' daily lives, with potential benefits especially in terms of creativity, memory and self-regulation. The fact that the parents provided the lifestyle information during informed consent ensures good reliability, although the limitation of possible subjectivity or approximation of self-reported data remains.

In conclusion, this study provides evidence for a significant relationship between visuospatial working memory and gross-motor skills in children. Specifically, it seeks to understand whether the ability to retain and manipulate visual information in the mind is related to the co-ordination and control of body movements. The results suggest that children with a better ability to retain and manipulate visual information also tend to have better motor skills. This link suggests that interventions aimed at motor development could, indirectly, also benefit cognitive function.

The use of validated and standardised instruments, such as the TGMD-3 and the BVS-Corsi-2 in their Italian version, guarantees the reliability of the results obtained.

The moderate positive correlation found between gross motor index and visual-spatial working memory suggests a significant link that merits further investigation. Although a descriptive study, these preliminary results provide a solid basis for future research that could explore the causality and effectiveness of specific interventions.

Although the results are statistically significant and in line with the scientific literature, several limitations must be considered.

This study identifies a correlation between gross motor skills and visual-spatial working memory, but it is crucial to emphasise that it does not establish causality. This means that, based solely on this research, we cannot state that improvement in motor skills leads directly to an improvement in visual-spatial working memory; other factors not considered could influence both.

Furthermore, the research was conducted on a relatively small sample from a single primary school. This specificity and the limited sample size reduce the validity of the results to a larger population of children, different age groups or different educational contexts.

Being a descriptive study, it merely observes and describes existing relationships without including any intervention (e.g. a physical activity programme) aimed at improving motor skills and measuring their impact on cognitive functions. Consequently, it provides no indication of the effectiveness of specific programmes.

Finally, the study is cross-sectional, i.e. the data were collected at a single point in time. This precludes observing changes or developments in the relationship between motor skills and visual-spatial working memory over time.

Future studies could expand the sample to include children of different ages, geographic areas and school contexts. Furthermore, it would be useful to design intervention studies to evaluate the impact of structured motor programmes on executive functions. Further investigation could focus on the other components of FE, such as inhibitory control and cognitive flexibility. Finally, exploring the link between motor skills, executive functions and school performance in disciplines such as mathematics and science could reinforce the idea of integrated, cross-curricular Physical Education (PE).

Conclusions

The present study revealed a significant link between visual-spatial working memory and motor skills in children. These findings reinforce the existing literature that promotes the integration of movement-based approaches in educational settings in order to foster holistic well-being and improve learning abilities.

Despite the limited sample of a single primary school and the descriptive nature of the study, which prevents causal relationships from being established, the observed correlation suggests that educational institutions and schools should consider implementing systematic protocols to monitor and promote overall motor development. Understanding and encouraging motor skills can serve as a valuable indicator and facilitator for the development of broader cognitive domains, including working memory, thus contributing to improving not only academic performance but also the overall well-being of children. Further research is needed to explore additional factors and further clarify the complex nature of this relationship.

Author contributions

All authors collaborated in the design and regular review of the manuscript.
Pasqualina Forte contributed to literature research, designed the methodology, data collection, wrote the results, discussion and conclusions.
Elisa Pugliese wrote the abstract and edited the translation.
Carmela Matrisciano wrote the abstract and introduction.
Cristiana D'Anna supervised the study and reviewed the manuscript.
All authors have read and agreed to the published version of the manuscript.

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