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The Predictive Role of Working Memory on Fundamental Movement Skills in Preschool Children: A Stratified Regression-Based Analysis

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Abstract. The aim of this study was to investigate the relationship between working memory (WM) and fundamental movement skills (FMS) in preschool children and to examine the roles of age and gender in this context. A total of 131 preschool children were recruited, and their WM abilities and FMS levels were assessed using standardized WM tasks and the TGMD-3. The results revealed no significant gender differences in WM tasks and total FMS scores, with the exception of the backward digit span task. Weak to moderate significant positive correlations were found between total WM score and total locomotor skills score ($r \approx 0.265$) as well as total FMS score ($r \approx 0.245$). Furthermore, age significantly predicted the total score of object control skills (OCS), while the total WM score was a significant positive predictor of the total FMS score. These findings suggest an association between WM and FMS in preschoolers, with age being a significant influencing factor. The results have important implications for preschool educational practices and related intervention studies.

Keywords: Working Memory, Fundamental Movement Skills, Preschool education

1. Introduction

The ages of 3–6 years constitute a critical period for both cognitive and motor development. Working memory (WM), a core component of the cognitive system [1],refers to a limited-capacity system for short-term information storage and processing. Deficits in WM during the preschool years are associated with significant developmental risks. These deficits can impede skill learning and coordination, particularly in children with developmental coordination disorder (DCD) [2,3], and may increase the risk of poor eating habits, physical inactivity, and obesity [4,5]. Moreover, WM deficits are commonly observed in neurodevelopmental disorders like ADHD and autism, affecting early learning and academic potential [6,7]. Thus, promoting effective WM activities for preschoolers holds significant educational and clinical value.

Motor development, particularly proficiency in Fundamental Movement Skills (FMS)—the 'building blocks' for more complex motor tasks—is a crucial developmental task in childhood [8]. Mastering FMS is critical as it significantly enhances children's physical activity participation, which in turn promotes physical fitness and helps prevent childhood obesity [9]. Beyond physical

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benefits, FMS proficiency is positively associated with children's cognitive development and socio-emotional well-being, [10]. Conversely, children with FMS deficits may face a 'motor ability barrier' that can lead to a sedentary lifestyle and affect lifelong physical activity participation. Therefore, actively promoting FMS is essential for a child's overall healthy development.

The relationship between FMS and WM is a central theme in understanding the synergistic development of cognition and movement. Early theories proposed that motor development provides a necessary prerequisite for the acquisition of cognitive abilities [11,12]. Neurophysiological studies have since provided a basis for this link, demonstrating the co-activation of key brain regions—such as the prefrontal cortex and cerebellum—in complex tasks requiring both WM and motor skills [13]. The association between WM and FMS has been widely demonstrated. Children with Developmental Coordination Disorder (DCD) and Attention-Deficit/Hyperactivity Disorder (ADHD) often exhibit coexisting deficits in both motor skills and WM [14]. Similarly, studies on typically developing children have consistently revealed a positive association between WM and FMS [15]. However, findings on the strength and generalizability of this association are not entirely consistent [16], suggesting the relationship may be influenced by task type, age, and other factors. Therefore, in the critical preschool period when both FMS and WM are undergoing rapid development, the precise pattern and strength of their relationship warrant further investigation.

This study aimed to examine the relationship between working memory (WM) and fundamental movement skills (FMS) in healthy preschoolers aged 5-6 years. Specifically, we investigated the association between various WM subtasks (e.g., Dot Short-Term Memory, Word Span, Backward Digit Span) and different FMS components (Locomotor Skills and Object Control Skills). We also sought to clarify the roles of age and gender in this relationship. Through correlation and hierarchical regression analyses, we aimed to determine the independent predictive value of WM on FMS performance after controlling for demographic variables. We hypothesized that WM would significantly predict FMS and its sub-components.

2. Methodology

2.1. Participants

This study included 131 preschool children (64 boys, 67 girls) aged 5-6 years from Xi'an. Parental and child consent was obtained after explaining the study. Inclusion criteria were: (1) 5–6 years old; (2) physically and mentally healthy; and (3) consent from guardians. Research instruments and measurement procedures.

2.2. Research instruments and measurement procedures

A trained evaluator and assistant completed all tests in a fixed order to minimize errors. Demographic information was collected by classroom teachers. Body Mass Index (BMI) was assessed following the National Standard for Physical Fitness Measurement (Revised 2023).

2.2.1. Working memory assessment

All participants were guided by a professional tester to complete all tests individually in an environmentally quiet place, with the next participant starting the test only when the previous participant had finished, and with participants taking a 2-minute break after completing a task before starting the next one. WM was measured using four standardized subtasks, completed individually in a quiet setting. Dot Short-Term Memory Task: Assessed visuospatial working memory,

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specifically the capacity to retain information. Scored out of 15 points. Find the Difference/N-back Task: Examined non-verbal central executive function, including information updating and dynamic tracking. Scored out of 9 points. Verbal Span/Word Span Forward: Probed phonological short-term memory capacity [17]. Scored out of 18 points. Backward Digit Span: Measured phonological WM, requiring mental manipulation and greater central executive involvement. Scored out of 16 points. All four subtasks demonstrated good internal consistency (Cronbach's alpha coefficients: 0.712, 0.714, 0.710, and 0.702 respectively).

2.2.2. Assessment of motor development

Fundamental Movement Skills (FMS) were assessed using the US Test of Gross Motor Development, Third Edition (TGMD-3). TGMD-3 is a standardized tool for children aged 3–10 years, widely accepted globally and validated for Chinese children aged 3–12 years [18]. The study's TGMD-3 internal consistency and test-retest reliability were 0.711 and 0.826, respectively. The TGMD-3 comprises Locomotor Skills (LS) (6 items) and Object Control Skills (OCS) (7 items). Trained evaluators conducted testing, involving demonstration, one practice, and two formal trials, with scores summed for total LS, OCS, and FMS scores.

2.3. Data processing and analysis

The total WM score was calculated as the sum of standardized subtask scores. Normality was tested using Kolmogorov-Smirnov and Shapiro-Wilk tests. Gender differences were analyzed with independent samples t-tests or Mann-Whitney U tests. Pearson or Spearman correlations were used for relationships between age and key variables. A Hierarchical Multiple Linear Regression (HMLR) model examined WM's predictive role on FMS, controlling for BMI, age, and gender. A bootstrap method (2000 replications) was used for robustness. All analyses were performed in SPSS and R at p<0.05.

3. Description of studies

Table 1. Working Memory (WM), Object Control Skills (OCS) and Body Mass Index (BMI) and gender and age differences in 5-6 year olds mean±SD

Age	Gender	n	BMI	WM Score (Z-score)	OCS
5	boy	38	±15.61 0.90	±-1.05 3.39	±15.59 3.06
	girl	43	±16.27 2.13	±-0.42 2.30	±15.98 3.24
6	boy	26	±16.40 2.27	±1.54 2.16***	±18.31 3.37**
	girl	24	±16.09 2.48	±0.76 2.58	±16.58 3.50
Total	boy	64	±15.93 1.63	±0.00 3.20	±16.70 3.44
	girl	67	±16.21 2.24	±0.00 2.45	±16.19 3.32

Note: Mean±SD: mean Standard deviation. *p<0.05, **p<0.01, ***p<0.001 (5 vs 6 years within the same sex).

Independent samples t-tests compared WM, OCS, and BMI across age and gender groups (Table 1). Six-year-old boys had significantly higher total WM scores than 5-year-old boys [M=1.54, SD=2.16vs. M=-1.05, SD=3.39, t (61.765) =-3.735, p<.001]. No significant age differences in WM were found for girls, nor overall gender differences in WM total scores. Six-year-old boys also

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showed significantly higher total OCS scores than 5-year-old boys [M=18.31, SD=3.37vs. M=15.59, SD=3.06, t (62) =-3.347, p=.001]. No significant age differences in OCS were observed for girls, nor overall gender differences in OCS total scores. Lastly, BMI showed no significant differences between boys and girls across age groups.

Table 2. Total scores and gender and age differences in Working Memory (WM) subtasks, Locomotor Skills (LS) and Fundamental Movement Skills (FMS) m (P25, P75)

Age	Gender	n	DSTM Task	N-back	WSF	BDS	LS	FMS
5	boy	38	8 (7,10)	7 (5,8)	16 (13,17)	3 (2,4)	17.75 (13.125, 19.875)	33.75 (28.75, 35.5)
	girl	43	8 (7,9)	7 (7,8)	16 (14,17)	3 (2,4)	19 (16.25, 20)	34.5 (30.75, 37.25)
6	boy	26	10 (9,12) *	8 (8,9) *	16 (14.25, 17)	4.5 (4,5) ***	19.75 (18.125,21) *	37.25 (35,41) ***
	girl	24	9 (8, 10.25)	8 (7,9)	16 (13.75,17)	3.5 (2,4)	19.25 (15, 21)	35.25 (31.875, 38.625)
Total	boy	64	9 (7,11)	8(6,9)	16 (13,17)	4 (2,5)	18.5 (16, 20)	35 (31.875, 37.5)
	girl	67	9 (7,10)	8(7,8.5)	16 (14,17)	3 (2,4)	19 (16, 20.5)	34.5 (30.75, 37.75)

Note: M (P25, P75): median (1st quartile, 3rd quartile). *p < 0.05, **p < 0.01, ***p< 0.001 (5 vs 6 years within the same sex).

The Mann-Whitney U Test compared performance across age and gender groups (Table 2). Six-year-old boys significantly outperformed 5-year-old boys on the Backward Digit Span task (Mdn = 4.5, IQR = [4,5] vs. Mdn = 3.0, IQR = [2,4]; U = 770.0, Z = -5.02, p< .001). They also showed significantly higher total FMS scores (Mdn=37.25, IQR= [35,41]) compared to 5-year-old boys (Mdn=33.75, IQR = [28.75,35.5]; U = 754.5, Z = -3.88, p < .001), a 10.4% improvement. Girls in the same age group showed less than 3% improvement in total FMS scores and no statistically significant difference. Regarding gender differences, 6-year-old boys performed significantly better than girls on the Dot Short-Term Memory Task (Mdn = 10, IQR = [9,12] vs. Mdn = 9, IQR = [8,10.25]), Find the Difference/N-back Task (Mdn = 8, IQR = [8,9] vs. Mdn = 8, IQR = [7,9]), Backward Digit Span Task (Mdn = 4.5, IQR = [4,5]vs. Mdn = 3.5, IQR = [2,4]), and total locomotor skills (Mdn = 19.75, IQR = [18.125,21]vs. Mdn = 19.25, IQR = [15,21]). Girls showed no significant age-related changes across any indices (all p>.05).

Table 3. Correlation analysis between Fundamental Movement Skills (FMS) and Working Memory (WM) of 5–6-year-olds

Methods	FMS	WM Score (Z-score)	DSTM Task	N-back	WSF	BDS
Pearson (parameters)	LS	.265**	.191*	.202*	.121	.238**
	OCS	.190*	.100	.212*	.103	.206*
	FMS	.269**	.172*	.245**	.132	.263**
Spielmann (non-parametric)	LS	.261**	.220*	.172*	.109	.261**
	OCS	.155	.110	.179*	.078	.198*
	FMS	.251**	.195*	.219*	.123	.262**

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Note: *p < 0.05, **p < 0.01, ***p < 0.001 (two-tailed test). WM Score (Z-score): Working Memory (Z-score).

Bivariate correlation analysis was conducted to examine the relationship between WM and FMS, using Pearson's for normally distributed variables (WM and OCS) and Spearman's for others. Results are presented in Table 3. Pearson correlation analysis showed that the total WM score was significantly positively correlated with total LS score (r = .265, p = .003), total OCS score (r = .190, p = .030), and total FMS score (r = .245, p = .004, N = 131), indicating higher overall FMS development in children with stronger WM skills. The Backward Digit Span task demonstrated significant positive correlations with total LS scores (Pearson: r = .238, p = .007; Spearman: r_s= .261, p = .003) and total FMS scores (Pearson: r = .263, p = .002; Spearman: r_s = .262, p = .002). These results suggest a stable relationship between the Backward Digit Span Task and children's overall motor skills, particularly mobile skills. The Dot Short-Term Memory Task significantly correlated with total LS (Pearson: r = .191, p = .030; Spearman: r_s= .220, p = .012) and total FMS score (Spearman: r_s= .195, p = .025). The Find the Difference/N-back Task showed a significant positive correlation with OCS total score (Pearson: r = .242, p = .005; Spearman: r_s= .179, p = .040) and a borderline significant relationship with total FMS score (Spearman: r_s= .219, p = .012). Conversely, word span forward showed no statistically significant correlation with any movement skill indicators in both Pearson's and Spearman's analyses.

Table 4. Results of stratified regression analyses of Working Memory (WM) on three categories of fundamental movement skills (N = 131)

Dependent variable	Model	Predictor	B	SE	β	t	P	R^2	Adj R^2	ΔR^2
LS	Model 1	(Constant)	10.360	4.013		2.582	.011*	.035	0.012	
		BMI	0.065	0.150	0.038	0.430	.668			
		Age	1.026	0.605	0.149	1.697	.092			
		Gender	0.711	0.588	0.106	1.210	.229			
	Model 2	(Constant)	13.406	4.080		3.286	.001**	.087	.058	.052**
		BMI	0.058	0.147	0.034	0.398	.692			
		Age	0.486	0.624	0.070	0.787	.438			
		Gender	0.687	0.574	0.102	1.197	.234			
		WM Score (Z-score)	0.287	0.107	0.241	2.680	.008**			
OCS	Model 1	(Constant)	7.946	3.959		2.007	.047*	.063	.041	
		BMI	0.013	0.148	0.008	0.089	.929			
		Age	1.658	0.597	0.240	2.779	.006**			
		Gender	-0.425	0.580	-0.063	-0.733	.465			
	Model 2	(Constant)	9.523	4.107		2.319	.022*	.077	.048	.014
		BMI	0.010	0.148	0.006	0.067	.947			
		Age	1.378	0.628	0.199	2.194	.030*			
		Gender	-0.438	0.578	-0.065	-0.758	.450			
		WM Score (Z-score)	0.149	0.108	0.125	1.378	.171			

Table 4. (continued)

FMS	Model 1	(Constant)	18.306	6.723		2.723	.007**	.054	.032	
		BMI	0.078	0.252	0.027	0.309	.758			
		Age	2.685	1.013	0.230	2.649	.009**			
		Gender	0.286	0.985	0.025	0.290	.772			
	Model 2	(Constant)	22.929	6.871		3.337	.001**	.096	.068	.042*
		BMI	0.068	0.247	0.024	0.276	.783			
		Age	1.864	1.051	0.159	1.774	.079			
		Gender	0.249	0.967	0.022	0.258	.797			
		WM Score (Z-score)	0.436	0.181	0.216	2.415	.017*			

Note: N=131. * Denotes p < 0.05, ** denotes p < 0.01, *** denotes p < 0.001. ΔR^2 denotes the increment in R^2 after the introduction of the total WM score in the second model step. Model 1 contains predictor variables: bmi, age, gender. Model 2 contains predictor variables: BMI, age, gender, and total WM score. LS Total Score Model 1: F (3, 127) = 1.514, p = .214; LS Total Score Model 2: F (4, 126) = 2.987, p = .021. LS Total Score Model 1: F (3, 127) = 2.856, p = .040; LS Total Score Model 2: F (4, 126) = 2.632, p =. 037. FMS Total Score Model 1: F (3, 127) = 2.437, p = .068; FMS Total Score Model 2: F (4, 126) = 3.356, p = .012.

Regression analyses revealed total WM score significantly predicted children's LS and FMS total scores, controlling for BMI, age, and gender. Specifically, a one-standard-deviation increase in WM corresponded to a 0.241 standard deviation increase in LS (β = 0.241, p = .008) and a 0.216 standard deviation increase in FMS (β = 0.216, p = .017). Age also showed a trend-significant positive predictive effect on FMS total score (β = 0.159, p = .079). However, total WM did not independently predict total OCS after controlling for demographic variables (ΔR^2 = 0.014, p = .171), with age consistently being the sole significant predictor for OCS in both models (β = 0.240, p = .006 in Model 1; β = 0.199, p = .030 in Model 2). Neither BMI nor gender significantly predicted LS, OCS, or FMS scores across models. All regression models had VIF values below 2 (maximum 1.126), indicating no serious covariance issues.

Table 5. Bootstrap analyses of correlations between total Working Memory (WM) scores and total scores for each fundamental movement skills

Variable	Correlation (r)	Bias	Std. Error	95% Confidence interval
WM Score (Z-score) and LS	0.265	0.0001	0.079	[0.1156, 0.4231]
WM Score (Z-score) and OCS	0.190	-0.0005	0.087	[0.0189, 0.3616]
WM Score (Z-score) and FMS	0.269	-0.0005	0.0824	[0.0963, 0.4208]

Note: Bootstrap repetitions R = 2000.

To validate the robustness of the relationships, 95% BCa confidence intervals were calculated using a non-parametric Bootstrap method with 2,000 repetitions. Table 5 displays these results. The total WM score showed a robust, statistically significant positive correlation with total FMS score (r=0.269, 95% BCa CI [0.0963, 0.4208]), total OCS score (r=0.190, 95% BCa CI [0.0189, 0.3616]), and total LS score (r=0.265, 95% BCa CI [0.1156, 0.4231]). The absence of zero within these intervals confirmed the robustness of these positive correlations.

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4. Discussion

This study investigated the complex relationship between Working Memory (WM) and Fundamental Movement Skills (FMS), including Locomotor Skills (LS), Object Control Skills (OCS), and total FMS scores, in preschool children, also elucidating the critical roles of age and gender.

Findings revealed that 5–6-year-old boys showed a significant age-related increase in both Total WM and OCS scores. This is consistent with the general developmental trend of continued cognitive functioning and motor skills in children in the late preschool years. WM tasks such as Backward Digit Span require children to have the ability to retain and manipulate information, and their increased competence underpins more complex learning activities in the school years. Boys also showed significant age progression in total motor development scores, further confirming that late preschool is a critical period for FMS development [19].

The present study found 6-year-old boys significantly outperformed same-aged girls on multiple memory tasks (e.g., Dot Short-Term Memory, Find the Difference/N-back, Backward Digit Span) and total displacement skills scores. This contrasts with some previous research suggesting girls perform better in displacement skills [20]and WM/inhibition tasks [21]. However, other studies suggest boys may start to outperform girls in executive and inhibitory function after 5-6 years [18]. Observed motor skill gender differences are often attributed to family, environmental, and socio-cultural influences rather than solely biological factors [22]. This study's focus on various WM components (visual WM, information updating, verbal/digit span) may also explain divergence from prior findings. Additionally, the non-significant gender differences in total motor skills scores and OCS align with Barnett's findings [23].

Multiple regression analyses showed that WM significantly predicted children's LS and FMS after controlling for BMI, age, and gender. This finding is highly consistent with the Cognitive-Motor Interconnection Hypothesis, which suggests that higher-level cognitive functions, such as WM, are closely related to the development of motor skills in large muscle groups, and play an important role in guiding complex motor behaviors. This study's results further support the foundational role of WM for overall FMS development, which is an important guide for integrating cognitive and motor training in preschool.

However, while Bootstrap correlation analyses revealed a statistically significant positive relationship between total WM score and total OCS score, total WM score failed to independently and significantly predict total OCS score when demographic variables, such as age, were controlled for in stratified regression analyses. Instead, age was consistently the most significant predictor of total OCS score. This difference may reflect that age plays a key confounding or mediating role in the development of OCS [24]. The development of OCS is a visual representation of children's neurophysiological maturation and motor experience accumulation; both strongly associated with aging. WM capacity itself also develops with age. Thus, the effect of WM on OCS may be realized in part through the common developmental variable of age [25]. When age was included in the regression model, it may have explained much of the variance shared between WM and OCS, making WM's independent predictive role less significant. This suggests the association between WM and OCS may not be simple direct causality but rather moderated or mediated by the more fundamental developmental process of age. In addition, there are differences in the need for cognitive resources between OCS and LS. Research points to OCS as an important predictor of inhibitory control, and displacement skills have been linked to both inhibitory control and WM [26]. LS may be more reliant on real-time, flexible cognitive planning and adaptation, which are core components of WM and executive function [27]. This explains why WM remains independently predictive of LS but not OCS after controlling for age. Studies have also found that WM deficits and

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impaired motor skills co-exist in children with Attention-Deficit/Hyperactivity Disorder (ADHD), but the relationship is complex and involves multiple neurocognitive pathways. Such evidence suggests that certain core developmental factors (e.g., age) have a more macroscopic impact on these abilities in generally developing children.

This study found that neither BMI nor gender had a statistically significant predictive effect on the three FMS total scores after controlling for other variables. This aligns with findings from several studies indicating that the direct effects of BMI and gender on FMS are not as substantial as those of age and cognitive factors at the preschool level, or that their influences may be expressed through other complex pathways.

5. Contributions and limitations

This study significantly contributes by systematically examining the predictive role of cognitive and physical fitness indicators on preschool Fundamental Movement Skills (FMS). Robustness tests, including hierarchical regression and bootstrap, enhanced result reliability. The work also offered a nuanced perspective on the relationship between Working Memory (WM) and Object Control Skills (OCS) by highlighting differences under various analytical methods. These findings provide empirical evidence for educators, implying attention to cognitive skill development (especially WM) alongside motor development, and suggesting differentiated intervention strategies based on motor skill type.

However, limitations exist. The cross-sectional design prevents causal inference; longitudinal studies are needed for clearer WM-FMS interplay. A relatively limited, regional sample restricts generalizability; future research should expand sample size and socioeconomic contexts. The WM assessment, though using four subtasks, lacked comprehensive evaluation of specific WM subcomponent effects on motor skills, suggesting a need for more nuanced tools. Finally, potential confounding/mediating variables like family environment and physical activity levels were not included, warranting future exploration.

6. Conclusion

This study investigated the complex association between Working Memory (WM) and Fundamental Movement Skills (FMS) in preschool children. WM significantly predicted Locomotor Skills (LS) and total FMS after controlling for demographics. This supports the Cognitive-Motor Interconnection Hypothesis, highlighting WM's role in guiding gross motor behaviors. However, WM did not independently predict Object Control Skills (OCS); age was the consistent predictor, possibly due to its mediating role. LS's higher cognitive demands might explain WM's distinct predictive effect. The study systematically examined cognitive and physical indicators on FMS, using robustness tests. Findings offer important implications for preschool practice and intervention.

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