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Relationship between physical fitness and executive function in preschool children: a cross-sectional study

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Abstract

Background Physical fitness (PF) is important for children's physical and cognitive development. There is increasing interest in the relationship between physical fitness, and executive function. Since it is unclear which physical fitness component benefits which domain of executive functioning, it's challenging to develop effective physical intervention programs for children with executive functioning disorders. This study aimed to examine the relationship between physical fitness components, and executive function domains.

Methods A cross-sectional study was conducted in 14 kindergartens and recruited 272 preschool children aged 3–6. PF was assessed by the National Physical Fitness Measurement (NPFM), including six physical fitness subtests: 10-m shuttle run test (SRT), standing long jump (SLJ), tennis ball throwing (TBT), double-leg timed hop (DTH) tests, sit-and-reach (SR), and balance beam walking (BBW). Executive function assessments include the dimensional change card sort (DCCS) test, digit span test (DST) and Head-toe-knee-shoulder (HTKS) task, to evaluate cognitive flexibility, working memory, and inhibitory control respectively.

Results Results from the Spearman correlations analysis showed a significant association between physical fitness and executive function. The hierarchical linear regression showed that age was the only predictor for cognitive flexibility ($\beta = 0.53$, $p < 0.01$) and working memory ($\beta = 0.53$, $p < 0.01$). For inhibitory control, children with older age ($\beta = 0.52$, $p < 0.01$) and better performance on SRT ($\beta = -0.14$, $p < 0.01$) and SLJ ($\beta = 0.13$, $p < 0.01$) scored higher in the HTKS.

Conclusions The results indicated physical fitness, especially speed-agility and lower limb strength, is related to inhibitory control in preschool children.

Keywords Physical fitness, Executive function, Preschool

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Background

Physical fitness represents an individual's ability to perform physical activities, including muscle strength and endurance, body composition, and flexibility [1]. It is a fundamental factor and potential biomarker of physical development, cognitive ability, and academic performance. The relationship between physical fitness and executive function has received increasing attention. It has been proven that both motor and executive functions involve specific brain structures such as the dorsolateral prefrontal cortex and the neocerebellum [2]. Physical activity can improve the structural plasticity of gray matter and white matter in children and adolescents [3, 4], promote the change of brain activation patterns under specific tasks [5], improve brain structure and functional networks [4], and then promote the improvement of executive function [6] in children and adolescents. Executive functions (EFs) serve as an umbrella term to encompass the set of higher-order cognitive abilities that are necessary to pursue and achieve a goal [7]. Executive function includes three cognitive components [8, 9]: cognitive flexibility, working memory, and inhibitory control. Executive function is strongly related to academic achievement [10], social function [11, 12], and emotion regulation [13]. Preschool is considered a golden stage of the development of executive function [14]. For this reason, improving the executive function in preschoolers is of great significance to public health.

It is still unclear which elements of physical fitness are beneficial for which domain of executive function, thus making it difficult to develop efficient physical intervention programs for children with executive dysfunction. Luo et al. [15] and Nieto-López et al. [14] suggested that preschool children with better cardiorespiratory fitness had better performance in inhibition control. Li et al. [16] reported a significant relationship between balance, cardiorespiratory fitness, and inhibition control. Luo et al. [15] also found that cardiorespiratory fitness was related to working memory. Moradi et al. [17] revealed no relationship between flexibility, speed, muscular strength, and endurance with information processing or inhibitory control, and a positive association between agility and inhibitory control. Therefore, the hypothesis of this study is that physical fitness was related to executive function in preschool children. This study aims to explore the relationship between the components of physical fitness and the domains of executive function. The findings of this study may serve as a foundation for physical fitness to help the development of executive function in the preschool stage.

Methods

Study design

This cross-sectional study was conducted in 14 kindergartens in the Zhongshan Torch Development Zone, China, from October to November 2023. All data for each participant were collected within one week. This study was approved by the medical ethics committee of the Zhongshan Torch Development Zone People's Hospital (2024–150).

Participants

The required sample size to achieve sufficient statistical power was determined through a calculation using PASS 2021, with the following parameters: effect size of $r = 0.23$ derived from a previous study [14], $\alpha = 0.05$, and power = 0.90. The minimum sample size necessary to achieve the targeted power was 194. A cluster sample of fourteen classes (310 preschoolers) from 36–72 months of age were informed about the study. All parents and legal guardians of participants provided signed informed consent. The exclusion criteria were as follows: (1) absence of school during the study period; (2) children with physical or mental disorders reported by parents; (3) participants with missing data; and (4) participants with biologically implausible values (defined by the logical check boundary value for the NPFM test items).

Among 310 participants recruited in this study, five children were excluded as they did not meet the inclusion criteria (i.e., autism spectrum disorder, cerebral palsy, developmental delay), and 4 children were absent during the study period. Of the overall sample of 301 participants included for further screening, 29 participants were removed due to missing data in two or more assessments (e.g., demographic questionnaires, physical fitness, and executive function outcomes). Thus, a final sample of 272 participants ($M_{age} = 54.30 \pm 9.99$ months, 46.1% girls) was used for the final statistical analysis (Table 1). A gender comparison showed no difference between demographics and executive function. Boys showed higher body weight and BMI than girls in anthropometrics ($p < 0.05$). In physical fitness, boys demonstrated better performance in SRT, TBT, but shorter distances in SR than girls ($p < 0.05$).

Demographic information

The demographic information, including the assessment of age, sex, socioeconomic status [1: Annual per capita disposable income [18] 8601 yuan to 5: above 90,116 yuan], parental education, birth gestational age [1: full-term; 2: preterm; 3: post-term] were collected via online

Table 1 Overview of means and standard deviations for all variables stratified by sex

Variables	Total sample ($n=271$)	Boys ($n=146$)	Girls ($n=125$)	*p*
Demographic, mean (SD)				
Age (Months)	54.30 (9.99)	54.60 (9.94)	53.96 (10.07)	0.63
Socioeconomic status, n (%)				0.26
Low	3 (1.11%)	3 (2.05%)	0 (0.00%)	
Lower-middle	62 (22.88%)	33 (22.60%)	29 (23.20%)	
Middle	150 (55.35%)	75 (51.37%)	75 (60.00%)	
Upper-middle	39 (14.39%)	25 (17.12%)	14 (11.20%)	
High	17 (6.27%)	10 (6.85%)	7 (5.60%)	
Father's education (years)	14.28 (2.52)	14.48 (2.41)	14.06 (2.64)	0.42
Mother's education (years)	14.10 (2.35)	14.12 (2.33)	14.06 (2.39)	0.98
Birth gestation age, n (%)				0.68
Preterm	17 (6.27%)	9 (6.16%)	8 (6.40%)	
Full-term	216 (79.70%)	114 (78.08%)	102 (81.60%)	
Post-term	38 (14.02%)	23 (15.75%)	15 (12.00%)	
Anthropometric, mean (SD)				
Body height (cm)	107.16 (7.10)	107.93 (7.43)	106.26 (6.61)	0.06
Body weight (kg)	17.66 (3.73)	18.48 (4.22)	16.71 (2.78)	0.00
BMI (kg/m^2)	15.24 (1.76)	15.69 (2.02)	14.71 (1.21)	0.00
Physical Fitness, mean (SD)				
SRT (s)	8.37 (1.73)	8.20 (1.60)	8.57 (1.85)	0.05
SLJ (cm)	83.29 (21.06)	85.82 (20.53)	80.33 (21.37)	0.12
TBT (m)	4.48 (2.00)	4.96 (2.29)	3.92 (1.40)	0.00
DTH (s)	7.88 (3.74)	7.92 (4.01)	7.84 (3.42)	0.60
SR (cm)	9.73 (4.42)	9.05 (4.56)	10.53 (4.13)	0.01
BBW (s)	13.70 (10.01)	13.68 (10.39)	13.72 (9.59)	0.36
Executive function, mean (SD)				
DCCS	14.13 (6.88)	13.87 (6.74)	14.44 (7.05)	0.65
DST	0.85 (1.27)	0.98 (1.38)	0.70 (1.10)	0.07
HTKS	26.37 (19.78)	26.51 (20.49)	26.21 (19.00)	0.95

BMI Body mass index, *SRT* 10-m shuttle run test, *SLJ* Standing long jump, *TBT* Tennis ball throwing, *DTH* Double-leg timed hop, *SR* Sit-and-reach, *BBW* Balance beam walking, *DCCS* Dimensional change card sort, *DST* Digit span task, *HTKS* Head-toes-knees-shoulders task

questionnaires (supplementary 1) that were sent to the parent(s) or legal guardian of the participating children.

Anthropometric

The anthropometrics of the participants were collected in the preschool by a registered nurse, and the data included body height and body weight. Body mass index (BMI) was calculated as the body weight in kg divided by the square of the body height in meters.

Physical fitness

The physical fitness of the preschool children in this study was assessed by using NPFM, which consisted of a battery of comprehensive physical fitness tests designed by the China General Administration of Sport in 2000 [19]. NPFM includes six physical fitness subtests: 10-m shuttle run test (SRT), standing long jump (SLJ), tennis ball throwing (TBT), double-leg timed hop (DTH) tests, sit-and-reach (SR), and balance beam walking (BBW), which reflect speed-agility, lower limb strength, upper limb strength, coordination, flexibility, and balance, respectively [20]. The order of the six tests is randomized. All tests except the SRT were performed twice and the maximin values were recorded. The NPFM has been reported to have acceptable reliability and sensitivity in assessing the physical fitness of preschool children in China [19]. The details of the NPFM test were described in supplementary 2.

Executive function

Cognitive flexibility: The dimensional change card sort (DCCS) [21, 22] was used to assess cognitive flexibility. Children were presented with cards of different shapes (dog, fish, bird), colors (red, yellow, blue), and sizes (small, medium, large). In the first six trials, children were asked to sort cards by shape, then six trials by color, and then six trials by size. If children scored at least five points on the sorting by size trial, participants were given six more trials where they sorted cards by color and size according to the border rule. The Cronbach's alpha reliability coefficient of DST in preschool children was 0.75 [23].

Working memory: The backward digit span task (DST) from the Wechsler Intelligence Scale for Children, Revised [24] was administered to measure participants' verbal working memory capacity. Participants were asked to accurately recite a string of numbers in the reverse order that began with two-number sequences and increased in length to eight digits, including two trials for each length. Higher scores indicated better working memory capacity. The Cronbach's alpha reliability coefficient of DST in preschool children was 0.71 [25].

Inhibitory control: The head-toes-knees-shoulders task (HTKS) [26] was used to evaluate the inhibitory control. There are a total of 30 test items with scores of 0 (incorrect), 1 (self-correct), or 2 (correct) for each item. A self-correct is defined as any motion to the incorrect response, but self-correcting and ending with the correct action. Scores range from 0 to 60. Higher scores indicate higher levels of inhibitory control. The Cronbach's alpha reliability coefficient of HTKS was 0.95 [27].

Statistical methods

Statistical analysis was conducted in the IBM SPSS software (version 20.0; Armonk, New York, USA) with a significant level of 0.05. Quantitative data were reported as means along with standard deviations (SDs), and qualitative data were reported as frequency along with percentages. The Kolmogorov–Smirnov test was used to determine the normality of the distribution of the dataset. Of all the variables, only the distance of sit-and-reach was distributed normally. Therefore, nonparametric tests were used to examine the data.

Mann–Whitney U tests and Chi-squared tests were conducted to compare demographics, anthropometrics, physical fitness, and executive function between two sex groups. The Spearman correlation test was conducted to examine the association of all the variables. Correlation coefficients were evaluated as follows: < 0.20: no correlation; 0.20–0.39: low correlation; 0.40–0.59: moderate correlation; 0.60–0.79: moderately high correlation; 0.80 and above: high correlation [15].

Hierarchical linear regression analysis was used to determine the extent to which demographics, anthropometrics, and physical fitness predict executive function. Two models were computed: model 1 included demographics and anthropometrics, model 2 added physical fitness.

Results

The correlations between demographics, anthropometrics, physical fitness, and executive function were presented in Table 2. The scores of DCCS, which represented the ability of cognitive flexibility, showed moderate correlation with SRT ($r=-0.47$, $p<0.01$), SLJ ($r=52$, $p<0.01$), TBT ($r=0.46$, $p<0.01$), DTH ($r=-0.49$, $p<0.01$), and low correlation with BBW ($r=-0.33$, $p<0.01$). The scores of DST indicating level of working memory demonstrated moderate correlation with SRT ($r=-0.45$, $p<0.01$), SLJ ($r=0.52$, $p<0.01$), TBT ($r=0.43$, $p<0.01$), DTH ($r=-0.50$, $p<0.01$), and low correlation with BBW ($r=-0.32$, $p<0.01$). The scores of HTKS, which measured the ability of inhibitory control, were correlated with SRT ($r=-0.59$, $p<0.01$), TBT ($r=0.58$, $p<0.01$), DTH ($r=-0.54$, $p<0.01$) and BBW ($r=-0.49$, $p<0.01$) moderately, and indicated moderately high correlation with SLJ ($r=0.66$, $p<0.01$). The distance of SR was not correlated with any domain of executive function.

In the hierarchical regression analyses, demographic and anthropometric variables were entered into the first block, including age, sex, father's education, mother's education, birth gestational age, socioeconomic status, and BMI. Then, in the second block, six domains of physical fitness, including SRT, SLJ, TBT, DTH, SR, and BBW were included. As shown in Table 3, two blocks of predictors were combined using hierarchical linear regression for cognitive flexibility. The second block had greater predictive capacity of cognitive flexibility and accounted for 44% of the outcome variance ($R^2=0.44$, $p<0.01$). However, among all the variables, only age could significantly predict cognitive flexibility ($\beta=0.53$, $p<0.01$). Table 4 revealed the predictors for working memory. The second block accounted for 39% of the scores of DST ($R^2=0.39$, $p<0.01$), and had the highest predictive ability for working memory. Only age was a significant predictor of working memory ($\beta=0.53$, $p<0.01$). Regarding inhibitory control (Table 5), block 1 predicted 52% of the variance ($R^2=0.52$, $p<0.01$), with age ($\beta=0.73$, $p<0.01$) and socioeconomic status ($\beta=0.19$, $p<0.01$) associated with inhibitory control. In block 3, children with older age ($\beta=0.48$, $p<0.01$) and better performance on SRT ($\beta=-0.14$, $p<0.01$) and SLJ ($\beta=0.13$, $p<0.01$) scored higher in the HTKS. The overall regression model predicted 59% of the outcome variance ($R^2=0.59$, $p<0.01$).

Discussion

The present study aimed to explore the association between physical fitness and executive function in preschool children. The results of the present study

Table 2 Correlations of all study variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Age	-															
2. Sex	−0.03															
3. Socioeconomic status	−0.07	−0.03														
4. Father's education	−0.07	−0.05	0.85**													
5. Mother's education	−0.10	0.00	0.77**	0.57**												
6. Birth gestational age	0.11	−0.01	−0.14*	−0.15*	−0.03											
7. BMI	0.09	−0.27**	0.10	0.02	0.05	−0.03										
8. SRT	−0.59**	0.12*	0.06	0.04	0.10	−0.05	−0.07									
9. SLJ	0.71**	−0.10	0.00	0.02	−0.05	0.05	0.06	−0.66**								
10. TBT	0.69**	−0.22**	−0.06	−0.05	−0.10	0.22**	0.08	−0.58**	0.65**							
11. DTH	−0.61**	0.03	0.06	0.08	0.01	−0.12	−0.05	0.56**	−0.61**	−0.46**						
12. SR	−0.20**	0.17**	0.02	−0.01	0.04	−0.05	0.08	0.12*	−0.12*	−0.19**	0.09					
13. BBW	−0.49**	0.06	0.02	0.03	0.08	−0.15*	−0.06	0.52**	−0.54**	−0.44**	0.53**	−0.01				
14. DCCS	0.63**	0.03	−0.09	−0.05	−0.09	0.11	0.03	−0.47**	0.52**	0.46**	−0.49**	−0.06	−0.33**			
15. DST	0.64**	−0.08	0.05	0.04	0.07	0.07	0.08	−0.45**	0.52**	0.43**	−0.50**	−0.13**	−0.32**	0.56**		
16. HTKS	0.71**	0.00	0.01	0.00	−0.03	0.02	0.03	−0.59**	0.66**	0.58**	−0.54**	−0.07	−0.49**	0.62**	0.66**	-

BMI Body mass index, *SRT* 10-m shuttle run test, *SLJ* Standing long jump, *TBT* Tennis ball throwing, *DTH* Double-leg timed hop, *SR* Sit-and-reach, *BBW* Balance beam walking, *DCCS* Dimensional change card sort, *DST* Digit span task, *HTKS* Head-toes-knees-shoulders task

* $p < 0.05$

** $p < 0.01$

Table 3 Results of hierarchical regression analyses for demographic characteristics, physical fitness, and the dimensional change card sort score

	Model 1			Model 2		
	Unstandardized Coefficients B (SE)	**Standardized coefficients β**	***p***	**Unstandardized Coefficients B (SE)**	**Standardized coefficients β**	***p***
Age	0.44 (0.03)	0.63	0.00	0.37 (0.05)	0.53	0.00
Sex	0.76 (0.67)	0.06	0.26	0.73 (0.71)	0.05	0.31
Father's education	0.17 (0.24)	0.06	0.48	0.13 (0.24)	0.05	0.58
Mother's education	−0.11 (0.20)	−0.04	0.58	−0.12 (0.20)	−0.04	0.54
Birth gestational age	0.78 (0.74)	0.05	0.29	0.97 (0.76)	0.06	0.20
Socioeconomic status	−0.49 (0.85)	−0.06	0.57	−0.48 (0.85)	−0.06	0.57
BMI	−0.08 (0.20)	−0.02	0.68	−0.10 (0.20)	−0.03	0.62
SRT				−0.25 (0.24)	−0.06	0.29
SLJ				0.05 (0.02)	0.14	0.06
TBT				−0.16 (0.24)	−0.05	0.50
DTH				−0.14 (0.12)	−0.08	0.24
SR				0.08 (0.08)	0.05	0.28
BBW				0.04 (0.04)	0.06	0.31
R^2	0.42			0.44		
ΔR^2	0.42			0.02		
F	27.12			15.71		
p	0.00			0.00		

BMI Body mass index, *SRT* 10-m shuttle run test, *SLJ* Standing long jump, *TBT* Tennis ball throwing, *DTH* Double-leg timed hop, *SR* Sit-and-reach, *BBW* Balance beam walking

Table 4 Results of hierarchical regression analyses for demographic characteristics, physical fitness, and the backward digit span task score

	Model 1			Model 2		
	Unstandardized Coefficients B (SE)	**Standardized coefficients β**	***p***	**Unstandardized Coefficients B (SE)**	**Standardized coefficients β**	***p***
Age	0.08 (0.01)	0.60	0.00	0.07 (0.01)	0.53	0.00
Sex	−0.21 (0.13)	−0.08	0.10	−0.18 (0.14)	−0.07	0.18
Father's education	0.01 (0.05)	0.03	0.76	0.01 (0.05)	0.01	0.90
Mother's education	0.05 (0.04)	0.09	0.19	0.05 (0.04)	0.10	0.19
Birth gestational age	0.03 (0.14)	0.01	0.86	0.06 (0.15)	0.02	0.69
Socioeconomic status	0.02 (0.16)	0.02	0.89	0.03 (0.16)	0.01	0.89
BMI	0.02 (0.04)	0.03	0.55	0.03 (0.04)	0.04	0.45
SRT				−0.05 (0.05)	−0.07	0.29
SLJ				0.01 (0.01)	0.09	0.24
TBT				0.04 (0.05)	−0.06	0.39
DTH				−0.01 (0.02)	−0.04	0.58
SR				−0.02 (0.02)	−0.05	0.32
BBW				0.01 (0.01)	0.06	0.35
R^2	0.38			0.39		
ΔR^2	0.38			0.01		
F	22.62			12.58		
p	0.00			0.00		

BMI Body mass index, *SRT* 10-m shuttle run test, *SLJ* Standing long jump, *TBT* Tennis ball throwing, *DTH* Double-leg timed hop, *SR* Sit-and-reach, *BBW* Balance beam walking

Table 5 Results of hierarchical regression analyses for demographic characteristics, physical fitness, and the head-toes-knees-shoulders task score

	Model 1			Model 2		
	Unstandardized Coefficients B (SE)	Standardized coefficients β	*p*	Unstandardized Coefficients B (SE)	Standardized coefficients β	*p*
Age	1.44 (0.09)	0.73	0.00	0.95 (0.13)	0.48	0.00
Sex	0.37 (1.76)	0.01	0.84	1.96 (1.76)	0.05	0.27
Father's education	−0.53 (0.62)	−0.07	0.39	−0.68 (0.58)	−0.09	0.25
Mother's education	−0.71 (0.51)	−0.08	0.17	−0.38 (0.49)	−0.05	0.44
Birth gestational age	−1.73 (1.93)	−0.04	0.37	−2.27 (1.86)	−0.05	0.22
Socioeconomic status	4.68 (2.22)	0.19	0.04	3.90 (2.09)	0.16	0.06
BMI	−0.48 (0.51)	−0.04	0.35	−0.51 (0.49)	−0.05	0.30
SRT				−1.57 (0.59)	−0.14	0.01
SLJ				0.13 (0.06)	0.13	0.04
TBT				1.12 (0.59)	0.11	0.06
DTH				0.03 (0.29)	0.01	0.91
SR				0.31 (0.19)	0.07	0.10
BBW				−0.18 (0.10)	−0.09	0.06
R^2	0.52			0.59		
ΔR^2	0.52			0.07		
F	40.94			28.33		
p	0.00			0.00		

BMI Body mass index, *SRT* 10-m shuttle run test, *SLJ* Standing long jump, *TBT* Tennis ball throwing, *DTH* Double-leg timed hop, *SR* Sit-and-reach, *BBW* Balance beam walking

suggested that speed-agility and lower limb strength of physical fitness were significant predictors of inhibitory control. Age was the only predictor of cognitive flexibility and working memory.

The results suggested that better speed-agility and lower limb strength were associated with better inhibitory control. This finding is in line with the previous studies. Regarding speed-agility, speed relates to the ability to perform a movement within a short period, while agility relates to the ability to rapidly and accurately change the position/direction of the entire body in response to a stimulus [28]. According to the proposed models of agility [29], cognitive factors related to agility include visual scanning, knowledge of situations, pattern recognition, and anticipation. Solis-Urra et al. [30] found a significant effect between speed-agility and inhibitory control as measured by the 4×10-m shuttle run test and go/no-go test. It has been proven that speed-agility was related to inhibitory control and underlying brain activity with a larger P3 amplitude [31]. For the SLJ, it consists of preliminary crouching, a subsequent swinging up of the arms, and extensions of the hips, knees, and ankles, which link the upper limbs, lower limbs, and trunk [32]. Both Veraksa et al. [33] and Malambo et al. [34] found that standing long jump is associated with cognitive function, which agrees with the findings of the present study. The more complex and demanding physical fitness tasks that require more precise coordination showed stronger links to cognitive skills [35]. Physical fitness elements like upper and lower limb coordination, and movement speed-agility are associated with executive function.

Although there is no consensus on what cognitive processes are more related to physical fitness [36], inhibitory control seemed to be the most sensitive executive function domain to short-term endurance and coordination training, and it could also benefit from long-term physical activity, as reported by a meta-analysis by Drozdowska et al. [37]. Li et al. [16] found a negative association between the 20 m shuttle run test and the reaction time of the inhibitory control test in preschool children. Veraksa et al. [33] suggested that inhibitory control was positively linked with physical fitness. Additionally, several randomized trials have demonstrated that children with higher physical fitness levels exhibit better inhibitory control and academic performance in dimensions such as language and mathematics, suggesting the beneficial effects of physical fitness on both academic achievement and inhibitory control [38, 39]. Several studies investigated the neural mechanism behind this correlation. Madsen et al. [40] suggested that inhibitory control has been positively related to white matter integrity in the motor cortex and inferior frontal cortex.

Physical activity intervention also effectively strengthened brain functional connectivity, predominantly within the temporal, frontal, and cerebellar regions demonstrably while enhancing EF performance [41].

Strengths and limitations

The strengths of the current study are that the sample size was relatively large and there was a comprehensive assessment of physical fitness and executive function in preschoolers. However, it's important to recognize the limitations when interpreting the findings. First, this study employed a cross-sectional design, thus no conclusion about causality can be drawn. Second, the cluster sampling conducted in Zhongshan City may limit the generalization of the research results to the wider population. Lastly, in addition to controlling for known potential confounding factors, there may still be other unconsidered or unmeasured variables.

Conclusions

The findings of the present cross-sectional study suggest a positive association between better performance in speed-agility and lower limb strength of physical fitness and better inhibitory control. Further longitudinal studies with objective assessments of physical activity levels are needed to enhance the understanding of the impact of physical activity and physical fitness on executive function.

Abbreviations

BMI	Body mass index
SRT	10-m shuttle run test
SLJ	Standing long jump
TBT	Tennis ball throwing
DTH	Double-leg timed hop
SR	Sit-and-reach
BBW	Balance beam walking
DCCS	Dimensional change card sort
DST	Digit span task
HTKS	Head-toes-knees-shoulders task

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13102-024-01028-8.

Supplementary Material 1.

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Authors' contributions

Z.Z. wrote the main manuscript text and designed the study, and Y.C. collected data and prepared tables, K.H. and F.Z. collected data, N.W. and Z.L. analyzed data. Z.C. and C.D. supervised the study. All authors reviewed the manuscript.

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Data availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study was reviewed and approved by the medical ethics committee of the Zhongshan Torch Development Zone People's Hospital (2024–150). Methods were carried out in accordance with the latest version of the Declaration of Helsinki. Parents or legal representatives of all participants provided their written informed consent before the study started.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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