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Children's physical fitness and cognitive control in China: the moderating role of family support for physical activity

Fengling Zhang[1†], Xiaoqi Wang[2†], Kefu Peng[1] and Lei Xu[1*]

Abstract

Objective This study aimed to explore the relationship between physical fitness and cognitive control in Chinese children, with a focus on gender differences and the moderating role of family support for physical activity (FSFPA).

Method This study employed a cross-sectional design to assess 148 children aged 12–14 years from Guangzhou. Physical fitness was evaluated using the National Student Physical Fitness Standard, family support for physical activity (FSFPA) was measured with the validated Family Support for Physical Activity Scale, and cognitive control was assessed using the Stroop color-word task, Go/No-Go task, and task-cue paradigm. The statistical analyses included descriptive statistics, correlation analysis, and hierarchical regression analysis to examine the relationships between variables.

Results Gender differences were observed in physical fitness and cognitive control. Girls scored higher in physical fitness and showed better accuracy in interference suppression, with faster reaction times in impulse control. BMI and speed were positively correlated with cognitive flexibility in both genders. For boys, cardiopulmonary endurance positively affected interference suppression, and muscle strength influenced impulse control. BMI and speed were linked to cognitive flexibility. For girls, speed, cardiopulmonary endurance, and muscle strength improved interference suppression, while BMI influenced cognitive flexibility. FSFPA moderated the relationship between physical fitness and cognitive control for both genders. It positively impacted interference suppression and cognitive flexibility for both boys and girls.

Conclusion Physical fitness in Chinese children is positively associated with cognitive control, with gender-specific differences in the fitness components influencing cognitive outcomes. FSFPA significantly moderates this relationship, enhancing the positive effects of physical fitness on cognitive control. These findings suggest that promoting physical fitness, particularly through family-based physical activity support, may improve children's cognitive control abilities.

Keywords Physical fitness, Cognitive control, FSFPA, Children

[†]Fengling Zhang and Xiaoqi Wang co-first authors.

*Correspondence:
Lei Xu
spxulei@scut.edu.cn
[1]School of Physical Education, South China University of Technology, Guangzhou, China
[2]The University of Sydney, Sydney, Australia

Introduction

Children's physical fitness has become a prominent global research area in recent years. Studies show that beyond shaping physical development, physical fitness also profoundly influences cognitive functions, academic performance, and mental health [1, 2]. In particular, insufficient fitness levels can hinder cognitive growth, compounding challenges in learning and psychological well-being. As highlighted by the World Health Organization (2022), there is a concerning global decline in key fitness indicators, such as cardiorespiratory endurance and muscle strength, among children, posing a major public health challenge [3].

In China, national surveys from 2010, 2014, and 2019 reveal varying physical fitness trends among children aged 7 to 18. Flexibility has improved, yet explosive strength and speed quality have declined despite isolated improvements among girls and middle school students. Strength quality trends show gendered variations: girls and primary school boys have improved, whereas middle school boys exhibit continued declines. Similarly, endurance quality largely declines but improves slightly among middle school students [4]. These findings highlight significant differences in physical development across gender and age groups, underscoring the need for a multidimensional understanding of physical fitness when assessing its impact on child development.

Furthermore, increasing attention has focused on how physical fitness positively influences cognitive control. Cognitive control, a core component of executive function, involves regulating attention and behavior, including interference suppression, impulse control, and cognitive flexibility—skills crucial for academic success and everyday decision-making [5]. Current studies on this relationship typically employ neuroscientific or behavioral approaches. Neuroscientific research suggests that physical fitness, particularly aerobic exercise, induces structural and functional changes in brain regions associated with cognitive control. Studies have shown that higher fitness levels are linked to increased hippocampal volume and enhanced thalamocortical connectivity, which play crucial roles in attention and memory [6, 7]. One potential mechanism is the upregulation of brain-derived neurotrophic factor (BDNF) in response to physical activity, promoting synaptic plasticity and enhancing neural signal transmission efficiency in the prefrontal cortex. Behavioral studies further support this association, consistently demonstrating a positive correlation between cardiorespiratory endurance and cognitive control [8], likely due to improved cerebral oxygenation, glucose metabolism, and neurotransmitter regulation. However, findings regarding muscular strength and flexibility remain inconclusive [8, 9], with some studies suggesting that muscular strength enhances cognitive function by improving motor-cognitive coordination and reducing cognitive load, while others report null results, possibly due to methodological differences. Similarly, flexibility may influence cognition through its effects on postural stability and sensorimotor integration, but the underlying mechanisms require further exploration. Additionally, gender differences in physiological and neurodevelopmental patterns may moderate the relationship between physical fitness and cognitive control, as males and females exhibit distinct fitness trajectories across developmental stages [10]. Based on these findings, this study hypothesizes that physical fitness positively influences cognitive control in children, with varying effects across fitness components and gender (Hypothesis 1).

Family support for physical activity (FSFPA), which refers to family-provided encouragement and assistance during physical activities, is a critical determinant of children's physical and mental development [11, 12]. According to Bronfenbrenner's ecological systems theory, children's development occurs within multiple environmental systems that interact dynamically, with the family serving as the closest microsystem and exerting the most direct and influential role [13]. Extensive research has demonstrated a strong positive correlation between FSFPA and children's physical fitness levels. Specifically, parents' attitudes and perceptions towards physical activity significantly influence children's interest in physical activity [14, 15], and children who perceive higher levels of FSFPA tend to exhibit more positive physical activity behaviors and achieve higher physical fitness levels [11, 16]. Furthermore, FSFPA also impacts the development of children's cognitive control ability. When parents actively engage and lead their children in physical activity, it promotes rapid cognitive function development and significantly enhances perceptual abilities [17–19]. This phenomenon may be attributed to the increased cognitive engagement during sports activities, as external social support increases and emotional investment deepens, individuals tend to mobilize greater cognitive resources when confronted with complex sports tasks or challenging motor skills [20, 21]. Beyond its direct effects on physical fitness and cognitive control, we posit that FSFPA also moderates the relationship between physical fitness levels and cognitive control. For children with lower baseline physical fitness, FSFPA fosters continuous adjustment and optimization of cognitive strategies in dynamic environments, thereby expanding cognitive reserves and mitigating the constraints imposed by physical fitness deficiencies on cognitive control [22]. In other words, FSFPA can mitigate the decline in cognitive control associated with reduced physical fitness, thus providing crucial protection for cognitive development. For children with higher physical fitness levels, FSFPA activates a synergistic effect between physical fitness and cognitive control through advanced training environments (e.g., tactical team projects, open-ended sports scenarios), continuously enhancing cognitive control. Based on this analysis, this study proposes Hypothesis 2: FSFPA will positively moderate the relationship between children's physical fitness levels and cognitive control outcomes.

Gender differences also play a crucial role in shaping the relationship between physical fitness and cognitive control, with research indicating that female children tend to excel in attention and self-regulation [23, 24], while male children often perform better in strength and agility tasks [25]. These gendered differences suggest that the moderating effect of FSFPA on the relationship between physical fitness and cognitive control may vary by gender. For girls, FSFPA may primarily enhance cognitive control in domains related to impulse control, as family encouragement can strengthen intrinsic motivation to engage in physical activities, leading to improvements in these cognitive skills. In contrast, for boys, FSFPA may influence cognitive control in areas such as cognitive flexibility, particularly as boys tend to excel in physical tasks requiring strength and agility. The increased family support in these areas could amplify the benefits of physical fitness on executive function tasks that rely on motor skills and physical resilience. Therefore, we hypothesize that the moderating role of FSFPA will differ across genders, resulting in distinct patterns in cognitive control sub-dimensions for boys and girls (Hypothesis 3).

In conclusion, this study aims to examine the influence of physical fitness on cognitive control in Chinese children, focusing on the moderating roles of FSFPA and gender differences. The findings are expected to expand the existing literature and provide a theoretical foundation for strategies to promote health and cognitive development in children. This research will deepen our understanding of the relationship between physical fitness and cognitive control and provide empirical support for future intervention measures.

Research methodology

Participants

Sample size

The minimum sample size was determined using a simulation-based method to ensure adequate statistical power for the hierarchical regression analysis [26]. The effect size was established based on literature and theoretical expectations [2, 27], with a primary focus on medium-sized effects ($\beta = 0.4$). The desired statistical power was set at 0.80 (80%), and the significance level was maintained at 0.05 (5%). This approach accounted for the multiple predictors and sequential modeling inherent in hierarchical regression. Based on these parameters and extensive simulation analysis, the minimum required sample size was determined to be 65 valid cases, ensuring sufficient statistical power to detect meaningful effects.

Recruitment process and inclusion criteria

The recruitment of participants for this study was conducted through a multifaceted approach to ensure a diverse and representative sample. The process involved the following steps: (1) School-Based Recruitment: Initially, recruitment notices were distributed through WeChat and QQ groups maintained by the school's head teachers. These notices provided an overview of the study, its objectives, and the expected participation requirements. (2) In-Class Promotion: Physical education teachers, who were integral members of the research team, further promoted the study during physical education classes. This direct promotion allowed students to ask questions and gain a better understanding of the research's purpose and procedures. (3) Peer Recommendation System: To encourage broader participation and leverage social networks, a peer recommendation system was implemented. Enrolled students were encouraged to inform their classmates about the research and recommend them to participate. This approach aimed to capitalize on existing social dynamics within the student body to enhance recruitment efforts. (4) Incentives for Participation: To acknowledge the students' involvement and contribution to the study, all participants who completed the test, as well as those recommended by enrolled students, received non-monetary rewards. These included a school-branded T-shirt and a notebook, symbolizing the school's appreciation for their participation. Upon completion of the aforementioned recruitment process, this study recruited 148 middle school students (66 boys and 82 girls) from Schools in Tianhe District, Guangzhou based on the following inclusion criteria: normal vision, absence of color blindness or color weakness, right-handedness, and no significant illnesses, neurological or movement disorders, or other health conditions that might affect their performance in physical fitness tests. The mean age was 12.66 ± 0.47 years overall (boys: 12.65 ± 0.50 years; girls: 12.74 ± 0.51 years), while the mean socioeconomic status (SES) was 6.22 ± 1.69 overall (boys: 6.42 ± 1.51; girls: 6.12 ± 1.40). Informed consent was obtained from each participant's legal guardian before participation, following ethical guidelines and considerations.

Measurements

Physical fitness assessment

Physical Fitness Scores were derived based on the National Physical Fitness Standards for Students [28], with five key fitness components assessed according to the participants' age. These components included Body

Mass Index (BMI), cardiorespiratory endurance (1000 m run for boys and 800 m run for girls), vital capacity, speed (50 m sprint), muscle strength (pull-ups for boys and sit-ups for girls), and flexibility (sit-and-reach test). The weights assigned to each indicator were carefully determined based on their relative importance in assessing overall physical fitness: BMI and vital capacity: 15%; Cardiorespiratory endurance and speed: 20% each; Muscle strength and flexibility: 10%.While the 1000 m run and 800 m run were prioritized for assessing cardiorespiratory endurance due to their established validity in adolescent populations, vital capacity was integrated into the composite score rather than being analyzed separately, to avoid redundancy and ensure parsimony in the model structure. All physical fitness tests are widely used and validated in pediatric populations, with established norms and robust psychometric properties. The reliability of the tests was ensured by training the assessors rigorously and using standardized protocols for administration and scoring.

Cognitive control tests

Stroop color-word task The Stroop Color-Word Task was used to assess interference suppression. Participants were instructed to determine whether the font color of a word matched its semantic meaning and respond accordingly by pressing the "F" key if the font color matched the word and the "J" key if it did not. The task included a practice block (25 trials) and a formal block (288 trials). Participants were required to achieve a minimum accuracy rate of 70% in the practice block to ensure baseline proficiency before proceeding to the formal task. Key metrics analyzed included: Accuracy (ACC): Reflecting response correctness. Reaction Time (RT): Reflecting response speed, with faster times indicating better performance under cognitive load. This task was designed to last approximately 14 min, balancing comprehensiveness with participant attention span. The Stroop Color-Word Task is a well-established measure of inhibitory control with strong construct validity and test-retest reliability in youth populations [29]. The inclusion of practice trials and strict accuracy criteria ensured internal consistency and ecological validity.

Go/no-go task This task measured impulse control by requiring participants to respond to a Go stimulus (upward arrow) by pressing "F" and to inhibit responding to a No-Go stimulus (downward arrow). The task included two practice blocks (20 trials each) and two formal blocks (totaling 200 trials), with an equal proportion of Go and No-Go stimuli. Participants were required to achieve at least 70% accuracy in the practice blocks to ensure readiness for the formal task. Key metrics analyzed included: Go Accuracy (ACC): Reflecting response correctness for Go stimuli. Go Reaction Time (RT): Reflecting response speed for Go stimuli. No-Go Accuracy (ACC): Reflecting the ability to inhibit unnecessary responses. The task duration was approximately 16 min, with a balanced design to minimize fatigue while capturing reliable data. The Go/No-Go Task is a widely used measure of impulse control with strong psychometric properties [30]. The high proportion of No-Go trials (50%) was chosen to maximize sensitivity to impulsivity. The inclusion of practice blocks and strict accuracy criteria enhanced the reliability of the measure.

Task-cueing paradigm This paradigm was used to assess cognitive flexibility by requiring participants to switch between different tasks or maintain repetition. The paradigm included three tasks: Even/Odd Number Judgment: Participants pressed "F" for even numbers and "J" for odd numbers. Number Size Judgment: Participants pressed "F" for numbers greater than 5 and "J" for numbers less than 5. Mixed Task: A combination of the above tasks, with task type presented randomly. The paradigm included three practice blocks (36 trials each) and three formal blocks (200 trials each for both repetition and switching conditions). Participants were required to achieve an accuracy rate above 70% in the practice blocks to ensure baseline proficiency. Key metrics analyzed included: Accuracy (ACC): Overall and condition-specific. Mean Response Time Difference (MOS-RT): The difference in response time between switching and repetition conditions, reflecting the cognitive cost of task switching. The task duration was approximately 20 min, with a balanced design to capture cognitive flexibility effectively. The Task-Cueing Paradigm is a robust measure of cognitive flexibility with established validity in youth populations [31]. The high number of trials and balanced design ensured reliable measurement of task-switching costs.

Family support for physical activity (FSFPA)

The degree of FSFPA was measured using a modified version of the Family Support Subscale from the Perceived Social Support Scale (PSSS) [32]. The PSSS is a validated tool for assessing social support in children and adolescents [33, 34], and it includes three dimensions: family support, friend support, and support from others. For this study, four items from the family support dimension were adapted to focus specifically on support for physical activities. These modifications were guided by a qualitative review of existing literature and pilot testing to ensure face validity. For example: Original item: "My family can provide specific and clear assistance." Modified item: "My family can provide specific and clear guidance and help for my physical activities." The revised scale used a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree), with higher scores indicating greater perceived support for physical activities. In this study, the total score was used to represent FSFPA, with the total score ranging from 0 to 28 points. The higher the total score, the greater the FSFPA. The scale demonstrated high reliability in this study, with a Cronbach's alpha of 0.86, indicating excellent internal consistency. The modifications were carefully validated through pilot testing and expert review to ensure that the adapted items retained their original meaning while focusing on the specific context of physical activity. The high Cronbach's alpha coefficient further confirms the scale's reliability for assessing family support in this context.

Control variables

In selecting control variables, we drew upon existing literature and theoretical frameworks to identify variables with significant impacts on children's physical fitness and cognitive control abilities. Specifically, age, as a critical marker of individual development, can exert both direct and indirect influences on physical fitness and cognitive performance. Family socioeconomic status (SES) can affect research outcomes through pathways such as resource availability, educational environment, and health conditions. Consequently, we incorporated age and family SES as core control variables in our model. To ensure comprehensive control, we utilized the MacArthur Subjective Social Status Scale to evaluate family SES [35, 36]. This tool considers not only economic factors but also social networks and resource acquisition capabilities, providing a more holistic assessment of the family environment's potential influence on individuals. Through this approach, we minimized the interference of key confounding factors on the results. Additionally, we will explore the potential impacts of other unmeasured confounding variables in future studies.

Data collection

In this study, the questionnaire only included three basic background information items (age, gender, and SES), while the other indicators were obtained through standardized tests. Due to the strict quality control during the data collection process, all data were complete without any missing values and no missing data processing methods were needed. For the assessment of physical fitness, scores for each test are meticulously recorded. Time-based tasks are measured to the nearest second, while count-based tasks record only correct repetitions. The final score is derived by averaging the results from two independent observers and then converted into a percentage according to national physical fitness standards. Cognitive control data are collected using E-Prime 3.0 software and extracted via the E-Data Aid function. Any corrupted files are recovered using E-Recovery3. Data files are labeled with "ID + Name + Paradigm + Test Date" to facilitate identification and tracking.

Data analysis

This study conducted gender-stratified analyses to examine potential sex-specific mechanisms in physical fitness-cognitive control relationships. Before regression modeling, we systematically validated all statistical assumptions for each gender subgroup (boys: $n = 66$; girls: $n = 82$;) following the four critical assumptions of linear regression: (1) Linearity. Bivariate relationships were assessed through gender-specific scatterplots with superimposed Loess curves (bandwidth = 0.75). Visual inspection confirmed appropriate linear trends between predictors and outcomes in both subgroups, with no discernible nonlinear patterns. Quadratic term tests further supported linearity (highest $p = 0.42$ for boys, $p = 0.31$ for girls). (2) Homoscedasticity. Residual plots displayed random dispersion around zero without funneling patterns. The Breusch-Pagan test confirmed homoscedasticity in both subgroups (boys: χ^2 (5) = 2.31, $p = 0.18$; girls: χ^2 (5) = 1.87, $p = 0.21$). Durbin-Watson statistics (boys: 1.92; girls: 2.03) fell within the acceptable range of 1.5–2.5 for residual independence. (3) Normality. Q-Q plots showed approximate alignment of residual quantiles with theoretical normal distributions. Shapiro-Wilk tests on standardized residuals revealed W = 0.98 ($p = 0.21$) for boys and W = 0.97 ($p = 0.17$) for girls. Distributional characteristics were further quantified through skewness (-0.32 to 0.41) and kurtosis (-0.85 to 0.93) analyses, all within the recommended ± 2 range for normality. (4) Multicollinearity. All variance inflation factors (VIF) remained below 2.5 (boys: mean VIF = 1.4, range 1.1–2.1; girls: mean VIF = 1.6, range 1.2–2.3). Condition indices below 15 (boys: 12.3; girls: 13.7) confirmed stable covariance structures. Additionally, diagnostic screening identified no influential outliers, with Cook's distance values below 0.5 and standardized residuals consistently within the ± 3 threshold. Next, descriptive statistics for physical fitness, FSFPA and cognitive control scores were calculated, and independent sample t-tests were conducted to compare these measures by gender. Pearson correlation analysis was performed to explore the relationships between physical fitness and cognitive control components across genders. Hierarchical regression analysis was then conducted, with age and family economic status included as control variables in the first step. In the second step, the five dimensions of physical fitness—BMI, cardiorespiratory endurance, speed, muscle strength, and flexibility—were added. Finally, age and family economic status were retained as a control variable, and FSFPA was used as a moderating variable in the analysis. The interaction term between physical fitness and FSFPA was also included to

Table 1 Differences in physical fitness and cognitive control between middle school students of different sexes (M ± SD)

Variable	Boys (n = 66)	Girls (n = 82)	All	P
Age (years)	12.65 ± 0.5	12.74 ± 0.51	12.66 ± 0.47	0.346
Height (cm)	166 ± 8.59[1]	160 ± 5.99[1]	163 ± 7.68[1]	0.060
Weight (kg)	56.53 ± 10.48[1]	50.39 ± 5.77[1]	53 ± 9.37[1]	0.000
BMI	21.84 ± 4.71[1]	19.58 ± 3.27[1]	19.9 ± 4.12[1]	0.000
Flexibility	81.15 ± 9.84[1]	79.21 ± 5.81[1]	80 ± 8.47[1]	0.362
Speed	67.2 ± 11.17[1]	69.99 ± 5.49[1]	68.74 ± 8.58[1]	0.067
Cardiopulmonary endurance	80.5(69 ~ 93)[2]	91(81 ~ 100)[2]	/	/
Muscular strength	70(30 ~ 84.25)[2]	82(76 ~ 89)[2]	/	/
Physical Fitness Score	76.79 ± 8.59[1]	83.34 ± 6.64[1]	80.42 ± 8.22[1]	0.000
Interference suppression (ACC)	0.73 ± 0.34[1]	0.82 ± 0.39[1]	0.79 ± 0.31[1]	0.000
Interference suppression (RT)	631.36 ± 57.54[1]	636.79 ± 29.58[1]	634.19 ± 42.68[1]	0.000
Impulse control (Go-ACC)	0.98 ± 0.06[1]	0.99 ± 0.08[1]	0.99 ± 0.0.08[1]	0.132
Impulse control (No Go-ACC)	0.91 ± 0.09[1]	0.92 ± 0.07[1]	0.93 ± 0.09[1]	0.236
Impulse control (Go-RT)	403.74 ± 71.68[1]	385.43 ± 86.27[1]	393 ± 96.87[1]	0.043
Cognitive flexibility non-switch (ACC)	0.76 ± 0.12[1]	0.87 ± 0.22[1]	0.83 ± 0.37[1]	0.000
Cognitive flexibility switch (ACC)	0.57 ± 0.29[1]	0.66 ± 0.17[1]	0.62 ± 0.24[1]	0.014
Cognitive flexibility (MOS-RT)	262.22 ± 98.75[1]	260.61 ± 84.21[1]	265.52 ± 96.04[1]	0.052
FSFPA	16.27 ± 3.78[1]	15.98 ± 3.69[1]	16.1 ± 3.72[1]	0.630

Note: [1]Mean ± standard deviation; [2]Median (Quartile Range)

Table 2 Correlation analysis between children's physical fitness level and cognitive control

Variable	Boys (n = 66)					Girls (n = 82)				
	BMI	Cardiopulmonary endurance	Speed	Muscular strength	Flexibility	BMI	Cardiopulmonary endurance	Speed	Muscular strength	Flexibility
Interference suppression (ACC)	0.092	0.251*	0.052	0.176	-0.063	0.114	0.642**	0.482**	0.205	-0.053
Interference suppression (RT)	-0.105	-0.351**	-0.126	-0.201	-0.077	-0.013	-0.619**	-0.360**	-0.244*	0.019
Impulse control (Go-ACC)	0.014	0.05	0.012	0.311*	0.051	0.202	0.088	0.148	0.118	0.00
Impulse control (No Go-ACC)	0.047	0.073	0.113	0.227	-0.051	0.191	0.11	0.161	-0.018	0.041
Impulse control (Go-RT)	-0.116	-0.101	-0.077	-0.018	0.1	-0.126	-0.208	-0.216	-0.179	-0.174
Cognitive flexibility (Non-switch ACC)	0.346**	0.019	0.290*	0.088	-0.1	0.265*	0.134	0.001	0.092	0.163
Cognitive flexibility (Switch ACC)	0.507**	0.136	0.382**	0.056	-0.011	0.247**	0.077	0.177	0.109	0.187
Cognitive flexibility (MOS-RT)	0.145	-0.029	-0.055	0.121	0.02	-0.017	-0.12	-0.05	0.112	0.139

Note: **$P<0.01$; *$P<0.05$

assess its moderating effect on the relationship between physical fitness and cognitive control. Data analysis was conducted using the PROCESS macro in SPSS 26.0, and statistical significance was set at $p < 0.05$.

Research results

Descriptive analysis of variables

Table 1 presents the descriptive statistics and gender differences in BMI and overall physical fitness scores, both showing statistically significant differences ($P < 0.001$). Girls have higher total physical fitness scores than boys. In cognitive control measures, there is a significant gender difference in interference suppression accuracy ($P < 0.001$), with girls demonstrating a higher accuracy rate. Reaction time differences for interference suppression are minimal but statistically significant, with girls slightly slower than boys. Girls also exhibit significantly shorter reaction times than boys in the Go reaction task of impulse control ($P = 0.043$). In tests of cognitive flexibility, girls display a higher accuracy rate in both non-switch and switch conditions, with these differences being statistically significant ($P < 0.001$, $P = 0.014$).

Correlation analysis between physical fitness level and cognitive control

Table 2 highlights correlations between physical fitness levels and cognitive control metrics. BMI is positively correlated with cognitive flexibility accuracy in girls ($P < 0.001$), while speed in boys is positively correlated with cognitive flexibility accuracy ($P = 0.018$). In girls, speed positively correlates with interference suppression accuracy ($P < 0.001$) and negatively with reaction time ($P < 0.001$). Similarly, cardiopulmonary endurance in girls shows positive correlations with interference suppression accuracy ($P < 0.001$) and negative correlations with reaction time ($P < 0.001$). Boys' muscular strength positively correlates with impulse control accuracy ($P < 0.001$), whereas girls' muscular strength negatively correlates with interference suppression reaction time ($P = 0.027$). Notably, flexibility is not significantly correlated with any cognitive control measures for either boys or girls.

The predictive effect of physical fitness level on children's cognitive control

The hierarchical regression analysis (Table 3) explored the relationship between physical fitness and cognitive control by including age and family economic status as control variables in the first step, and physical fitness dimensions—BMI, cardiopulmonary endurance, speed, muscle strength, and flexibility—in the second step.

For boys ($n = 66$), in terms of interference suppression, age, and family economic status had no significant effect in Model 1. However, after adding physical fitness variables in Model 2, cardiopulmonary endurance was found to have a significant positive impact ($b = 0.009$, $P < 0.001$), indicating that better endurance was associated with improved interference suppression. Similarly, muscle strength significantly influenced Impulse control ($b = 0.003$, $P = 0.005$). For cognitive flexibility, BMI ($b = 0.005$, $P = 0.009$; $b = 0.008$, $P < 0.001$) and speed ($b = 0.003$, $P = 0.042$; $b = 0.005$, $P = 0.013$) showed significant positive effects in Model 2.

For girls ($n = 82$), in terms of interference suppression, age, and family economic status had no significant effect in Model (1) After adding physical fitness variables in Model 2, speed ($b = 0.008$, $P < 0.001$; $b = -5.645$, $P = 0.002$), cardiopulmonary endurance ($b = 0.005$, $P < 0.001$; $b = -4.738$, $P < 0.001$), and muscle strength ($b = -3.172$, $P = 0.013$) all had significant effects on interference suppression, with better physical fitness linked to stronger interference suppression ability. In terms of cognitive flexibility, BMI ($b = 0.003$, $P = 0.043$; $b = 0.004$, $P = 0.038$) was found to positively influence cognitive flexibility in Model (2) These results suggest that different physical fitness dimensions contribute significantly to cognitive control abilities, with each dimension having a distinct effect on boys and girls.

Table 3 Hierarchical regression analysis of the relationship between physical fitness and cognitive control

	Dependent Variable		Independent Variable	Model	b (95%CI)	R^2	Adjusted R^2	P
Boys	Interference suppression	ACC	Cardiorespiratory Endurance	Model 1	0.009 (-0.016 ~ 0.033)	0.18	0.14	0.65
				Model 2	0.005 (0.003 ~ 0.008)	0.248	0.212	0.000
		RT	Cardiorespiratory Endurance	Model 1	-23.152 (-47.334 ~ 83.208)	0.04	0.01	0.275
				Model 2	-5.407 (-8.465~-2.348)	0.201	0.162	0.003
	Impulse control	Go-ACC	muscle strength	Model 1	0.011 (-0.021 ~ 0.043)	0.024	0.008	0.782
				Model 2	0.003 (0.001 ~ 0.004)	0.184	0.145	0.005
	Cognitive flexibility	Non-switch ACC	BMI	Model 1	0.007 (-0.19 ~ 0.033)	0.065	0.036	0.119
				Model 2	0.005 (0.001 ~ 0.009)	0.168	0.127	0.009
			Speed	Model 1	0.007 (-0.019 ~ 0.033)	0.087	0.004	0.119
				Model 2	0.003 (0.000 ~ 0.007)	0.123	0.102	0.042
		switch ACC	BMI	Model 1	0.019 (-0.009 ~ 0.046)	0.055	0.025	0.167
				Model 2	0.008 (0.004 ~ 0.011)	0.272	0.237	0.000
			Speed	Model 1	0.019 (-0.009 ~ 0.046)	0.055	0.025	0.167
				Model 2	0.005 (0.001 ~ 0.008)	0.157	0.117	0.013
Girls	Interference suppression	ACC	Speed	Model 1	0.017 (0.002 ~ 0.032)	0.064	0.04	0.054
				Model 2	0.008 (0.004 ~ 0.011)	0.252	0.223	0.000
			Cardiorespiratory Endurance	Model 1	0.017 (0.002 ~ 0.032)	0.064	0.04	0.054
				Model 2	0.005 (0.004 ~ 0.006)	0.422	0.399	0.000
		RT	Speed	Model 1	-17.196 (-31.833~-2.559)	0.071	0.047	0.055
				Model 2	-5.645 (-9.347~-1.943)	0.169	0.137	0.002
			Cardiorespiratory Endurance	Model 1	-17.196 (-31.833~-2.559)	0.071	0.047	0.055
				Model 2	-4.738 (-6.218~-3.259)	0.389	0.366	0.000
			muscle strength	Model 1	-17.196 (-31.833~-2.559)	0.071	0.047	0.055
				Model 2	-3.172 (-5.969~-0.375)	0.128	0.094	0.013
	Cognitive flexibility	Non-switch ACC	BMI	Model 1	0.005 (-0.018 ~ 0.054)	0.057	0.017	0.502
				Model 2	0.003 (0.001 ~ 0.005)	0.198	0.106	0.043
		switch ACC	BMI	Model 1	0.005 (-0.013 ~ 0.023)	0.029	0.005	0.308
				Model 2	0.004 (0.001 ~ 0.008)	0.167	0.102	0.038

Note: Model 1 included baseline controls: age and family socioeconomic status (SES). Model 2 extended this by incorporating physical fitness components: BMI, cardiorespiratory endurance, speed, muscle strength, and flexibility

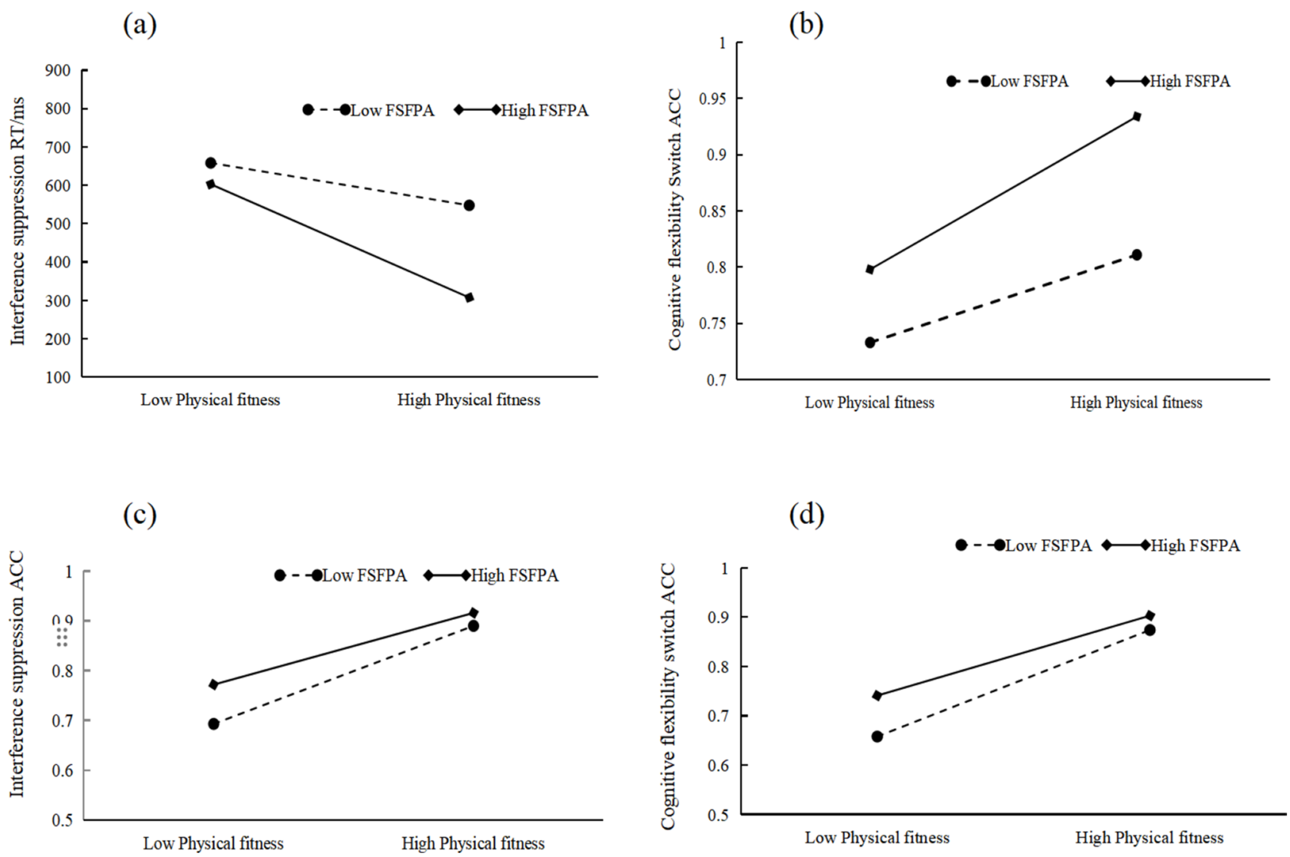

Fig. 1 The moderating effect of FSFPA on children's physical fitness and cognitive control. (**a**) The moderating effect of FSFPA on boys' physical fitness and interference suppression; (**b**) The moderating effect of FSFPA on boys' physical fitness and cognitive flexibility; (**c**) The moderating effect of FSFPA on girl's physical fitness and interference suppression; (**d**) The moderating effect of FSFPA on girl's physical fitness and cognitive flexibility

Analysis of the moderating effect of FSFPA on the relationship between children's physical fitness and cognitive control

Figure 1 shows that FSFPA moderates the relationship between physical fitness level and cognitive control, as evidenced by the significant interaction term ($P<0.001$). Through simple slope analysis, it was observed that for boys, FSFPA significantly moderated the relationship between physical fitness and interference suppression ($F=9.613$, $P<0.001$), with both high and low FSFPA having a positive effect on interference suppression (β_simple slope = -11.944, $P=0.011$; β_simple slope = -5.469, $P<0.001$). FSFPA also moderated the effect of physical fitness on cognitive flexibility ($F=4.543$, $P<0.001$), particularly at higher levels of FSFPA. This positive moderating effect was observed only in high FSFPA environments (β_simple slope = 0.1, $P<0.001$), while it was not significant at low FSFPA levels (β_simple slope = 0.003, $P=0.216$).

For girls, FSFPA moderated the effect of physical fitness on interference inhibition and cognitive flexibility. Specifically, FSFPA significantly moderated the relationship between physical fitness and interference inhibition ($F=20.591$, $P<0.001$), with both high and low FSFPA having a positive effect on interference inhibition (β_simple slope = 0.014, $P<0.001$; β_simple slope = 0.009, $P<0.001$). FSFPA also moderated the effect of physical fitness on cognitive flexibility ($F=16.523$, $P<0.001$), with both high and low FSFPA levels having a significant positive effect on cognitive flexibility (β_simple slope = 0.015, $P<0.001$; β_simple slope = 0.009, $P<0.001$).

Discussion

Sex differences in children's physical fitness level and cognitive control

The analysis in this study reveals significant gender differences in both physical fitness and cognitive control, suggesting a complex, multifaceted relationship between these domains that warrants further exploration. This study found that girls' overall physical fitness scores were higher than those of boys, and their BMI values were also lower. These differences were statistically significant. These findings are inconsistent with previous research and general expectations. This study posits that these discrepancies can largely be attributed to the specific scoring standards used in this assessment. Specifically, this study adopted the national student physical fitness test standards set by the Ministry of Education of China [28]. First, there are differences in the test items for boys and girls. For example, in the cardiopulmonary fitness test, boys are required to run 1,000 m while girls run 800 m. In the strength test, boys perform pull-ups while girls do sit-ups. Secondly, the scoring criteria differ significantly. For instance, in the 50-meter sprint, even if boys and girls complete the run at the same time, girls receive higher scores according to the physical fitness test standards. In conclusion, it is possible that the higher physical fitness scores for girls, despite potentially lower absolute athletic abilities compared to boys, result from these differences in test items and scoring criteria. Regarding BMI, girls' values were lower than those of boys. BMI is an indicator of body composition and reflects an individual's body shape control [37]. In this study, both boys' and girls' average BMI values were within the normal range, but girls had lower values. This may indicate that junior high school girls are more focused on maintaining a healthy body shape and body image [38].

Gender differences in cognitive control were particularly pronounced in tasks involving interference suppression and cognitive flexibility. Girls demonstrated significantly higher accuracy rates than males in these tasks, aligning with prior findings that females tend to outperform males in attention control and executive function paradigms [39, 40]. This gender-specific advantage may stem from neurodevelopmental disparities in prefrontal cortex (PFC) maturation: earlier myelination of the PFC in females enhances top-down regulation of the anterior cingulate cortex (ACC) during conflict monitoring, enabling more refined executive functioning [41]. Notably, accuracy advantage in interference suppression tasks coincided with marginally prolonged reaction times. This speed-accuracy tradeoff suggests a cautious cognitive strategy prioritizing precision over processing speed, potentially linked to stronger inhibitory control within the default mode network (DMN). In contrast, males exhibited significantly shorter reaction times in impulse control tasks (Go/No-Go paradigms), indicating superior efficiency in rapid responses to simple stimuli. This divergence may reflect gender-specific impulse control mechanisms—males appear to rely more on automated processing via the basal ganglia-thalamic pathway, whereas females predominantly engage in PFC-mediated goal-directed control [42, 43].

Relationships between children's physical fitness and cognitive control

This study revealed significant sex-specific associations between physical fitness components and cognitive control performance, thereby confirming Hypothesis 1. For boys, cardiorespiratory endurance demonstrated a robust positive correlation with interference suppression accuracy and emerged as a significant predictor of reduced reaction times in interference suppression tasks. Furthermore, muscular strength exhibited a distinct positive association with impulse control accuracy, highlighting the critical role of musculoskeletal fitness in cognitive domains requiring precise behavioral regulation [44].In contrast, for girls, the results revealed a different pattern. Speed and cardiorespiratory endurance were positively related to interference suppression accuracy, with cardiorespiratory endurance having a stronger impact on reducing reaction time. According to the analysis of this study, while both boys and girls showed positive effects of cardiorespiratory endurance on cognitive control, girls appeared to rely more heavily on cardiorespiratory endurance. The study also revealed that BMI positively correlated with cognitive flexibility in boys and girls, highlighting the importance of body composition in influencing cognitive flexibility, particularly in both non-switching and switching tasks [45].

The observed gender-divergent associations may be mediated through distinct neurobiological mechanisms. In males, the cardiorespiratory-cognitive control linkage likely involves exercise-induced hippocampal-prefrontal angiogenesis, which enhances the oxygen-dependent synthesis of dopamine and brain-derived neurotrophic factor (BDNF) crucial for impulse inhibition [46]. In females, the prominence of aerobic fitness in cognitive flexibility may originate from estrogen's dual regulation of cerebral glucose utilization and dorsolateral prefrontal cortical plasticity, where enhanced cerebral blood flow potentiates estrogen-mediated neuroprotection of task-switching neural circuits [47].

Notably, physical flexibility showed no significant associations with cognitive control measures, aligning with prior developmental studies demonstrating domain-specific physical-cognitive relationships [48]. This absence of association reinforces the functional segregation between motor adaptation and executive control systems, suggesting that cognitive enhancement interventions should specifically target cardiorespiratory fitness rather than generalized flexibility training.

The moderating effect of FSFPA

The study revealed that family support for physical activity (FSFPA) serves as a significant moderator in the physical fitness-cognitive control relationship among children, demonstrating gender-specific patterns that confirm Hypotheses 2 and 3. For boys, FSFPA significantly moderates the influence of physical fitness on both interference suppression and cognitive flexibility. Both high and low levels of FSFPA positively affect interference suppression, but only in a high-FSFPA environment does physical fitness significantly enhance cognitive flexibility. For girls, the moderating effect of FSFPA is more pervasive:

regardless of FSFPA level, it significantly enhances the impact of physical fitness on both interference suppression and cognitive flexibility, with higher FSFPA yielding stronger effects.

FSFPA may regulate the relationship between physical fitness and cognitive control through multiple mechanisms. Neurobiologically, physical exercise increases prefrontal cortex (PFC) activation and brain-derived neurotrophic factor (BDNF) expression, promoting neuroplasticity and cognitive function [49]. High FSFPA likely amplifies these neural benefits by ensuring consistent exercise, a process that aligns with Bronfenbrenner's microsystemic focus on direct family influences sustaining proximal biological processes [50]. Psychologically, FSFPA provides emotional support and behavioral supervision, fostering self-discipline and stress resilience, thereby indirectly enhancing cognitive control [51]. This psychological scaffolding exemplifies the mesosystem's role in connecting familial emotional resources (microsystem) to individual self-regulation capacities. Additionally, social interactions such as role model imitation and peer activities can strengthen cognitive function, exemplified by task switching and interference suppression training in group sports. These exosystemic interactions (e.g., community sports networks) further extend FSFPA's impact beyond the immediate family environment, highlighting the ecological systems' layered contributions to cognitive development.

Gender differences in the moderating effects of FSFPA may arise from variations in neurodevelopment, social-cultural expectations, and behavioral preferences. Boys with high FSFPA tend to engage in high-intensity, structured sports (e.g., team sports) [52], which may enhance interference suppression by strengthening the prefrontal-striatal circuit. Conversely, insufficient stimulation from random activities under low FSFPA weakens the regulatory effect on cognitive flexibility. Girls benefit from low-intensity, social activities (e.g., dance, yoga), even with low FSFPA, through emotional support and dopamine reward pathways, indirectly boosting cognitive control. Furthermore, societal expectations for competitive behavior in boys and cooperative behavior in girls may shape the differential regulatory patterns of FSFPA on cognitive function [53].

Research significance and implications

This study provides valuable insights into the relationship between children's physical fitness and cognitive control, highlighting the differential impact of various physical fitness components on specific cognitive control sub-components and emphasizing significant gender differences. Based on these findings, this research can be translated into the following integrated application schemes: implement gender-specific customized physical education programs in primary and secondary schools—design tasks for boys that integrate cardiorespiratory training with impulse control (such as answering distractor questions during shuttle runs), and develop activities for girls that combine dynamic balance with cognitive flexibility (such as single-leg hopping with eyes closed while performing graphic memory tasks). It is recommended to upgrade the national student physical fitness monitoring system by incorporating a "body-brain coordination index" into traditional physical fitness tests (for example, integrating signal inhibition tasks during pull-ups for boys and impulse control tests during sit-ups exercises for girls). Establish a family exercise point system through home-school collaboration, where parents' daily participation in physical activities can be exchanged for rewards from the school. The education department should utilize smart wristbands to track real-time data on physical fitness levels and cognitive control, ultimately establishing a four-dimensional promotion system encompassing "classroom precise training - family point incentive - community practice reinforcement - policy standard guidance" to achieve dual improvements in children's physical fitness and cognitive development.

Research limitations

This study has several limitations that warrant discussion. First, the sample was restricted to junior high school students aged 12–14, primarily from Guangzhou, Guangdong Province, China. This narrow age range and regional specificity may reduce the generalizability of the findings to other age groups and populations. Future research should consider recruiting participants from a broader and more diverse age range, as well as from varying cultural and socioeconomic backgrounds, to enhance the external validity of the results. Second, the cross-sectional design of this study precludes the ability to infer causation. While the analysis identified significant relationships between physical fitness, cognitive control, and the moderating role of FSFPA, it cannot establish whether changes in physical fitness lead to improvements in cognitive control. To address this limitation, future studies should employ longitudinal or experimental designs to explore causal pathways and further elucidate the mechanisms through which FSFPA influences the relationship between physical fitness and cognitive control. Third, FSFPA was the only moderating variable examined in this study. Although the findings underscore the critical role of family support in strengthening the link between physical fitness and cognitive control, the influence of other contextual factors remains unexplored. Future research should investigate additional moderators, such as peer support, school environment, or socioeconomic status, to provide a more comprehensive understanding of the factors shaping this relationship.

Lastly, certain dimensions of physical fitness, such as flexibility, did not exhibit significant associations with cognitive control in this study. While this finding aligns with previous research, it suggests that the measurement tools employed may not fully capture the multifaceted contributions of various physical fitness components to cognitive outcomes. Future studies should consider utilizing more refined or alternative measurements to better elucidate these relationships.

Conclusion

This study identified a significant relationship between physical fitness and cognitive control in middle school students, with notable gender differences. Girls demonstrated superior performance in overall physical fitness and specific cognitive control tasks, particularly in interference suppression and cognitive flexibility. For boys, muscular strength and cardiorespiratory endurance significantly impacted cognitive control, while girls were primarily influenced by speed and cardiorespiratory endurance. FSFPA moderated the relationship between physical fitness and cognitive control, with higher levels of FSFPA being associated with stronger positive relationships between physical fitness and cognitive control. These findings suggest that promoting physical fitness, particularly through family-based physical activity support, may be beneficial for improving children's cognitive control abilities.

Abbreviations

FSFPA	Family support for physical activity
BMI	Body Mass Index
CI	Confidence interval
RT	Reaction time
SES	Socioeconomic status
ACC	Accuracy rate
PSSS	Perceived Social Support Scale
VIF	Variance inflation factors

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Author contributions

The study design and text revision were overseen by L X; data processing, analysis, and the initial draft were completed by F I Z, with X Q W contributing to the creation of figures and text revision to the article, K P contributing to the text revision to the article. All authors have reviewed and approved the final version of the manuscript to be published.

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Data availability

The data are not publicly accessible due to the exclusion of this type of use in the written consent form but are available from the corresponding author (Lei Xu, spxulei@scut.edu.cn) on reasonable request.

Declarations

Ethics approval and consent to participate

Firstly, this study strictly adheres to the Helsinki Declaration, and all methods are implemented by relevant guidelines and regulations. Secondly, this study was approved by the Ethics Committee for Scientific Research of Guangzhou College of Commerce (NO.GCC2023-003). Finally, informed consent was obtained from each participant's legal guardian before participation.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Quka N, Selenica R. Physical fitness on academic performance in youth. Eur J Med Nat Sci. 2022;5(1):1–8.
2. Donnelly JE, Hillman CH, Castelli D, Etnier JL, Lee S, Tomporowski P, et al. Physical activity, fitness, cognitive function, and academic achievement in children: a systematic review. Med Sci Sports Exerc. 2016;48(6):1197.
3. World Health Organization (WHO). Global status report on physical activity 2022: more active people for a healthier world. Geneva: WHO; 2022.
4. Chen YJ, Ma N, Song Y, Ma L. Blue Book on Children: Report on Chinese Children's Development (2021). Beijing: Social Sciences Academic Press. 2021. (In Chinese).
5. Diamond A. Executive functions. Annu Rev Psychol. 2013;64:135–68.
6. Chaddock L, Erickson KI, Prakash RS, Kim JS, Voss MW, VanPatter M, et al. A neuroimaging investigation of the association between aerobic fitness, hippocampal volume, and memory performance in preadolescent children. Brain Res. 2010;1358:172–83.
7. Chaddock L, Erickson KI, Prakash RS, VanPatter M, Voss MW, Pontifex MB, et al. Basal ganglia volume is associated with aerobic fitness in preadolescent children. Dev Neurosci. 2010;32(3):249–56.
8. Moradi A, Damirchi ES, Narimani M, Esmaeilzadeh S, Dziembowska I, Azevedo LB, et al. Association between physical and motor fitness with cognition in children. Medicina. 2019;55(1):7.
9. Mora-Gonzalez J, Esteban-Cornejo I, Solis-Urra P, Migueles JH, Cadenas-Sanchez C, Molina-Garcia P, et al. Fitness, physical activity, sedentary time, inhibitory control, and neuroelectric activity in children with overweight or obesity: the activebrains project. Psychophysiology. 2020;57(6):e13579.
10. Haynes A, McVeigh J, Hissen SL, Howie EK, Eastwood PR, Straker L, et al. Participation in sport in childhood and adolescence: implications for adult fitness. J Sci Med Sport. 2021;24(9):908–12.
11. Morrissey JL, Janz KF, Letuchy EM, Francis SL, Levy SM. The effect of family and friend support on physical activity through adolescence: a longitudinal study. Int J Behav Nutr Phys Act. 2015;12:1–9.
12. Dowda M, Dishman RK, Pfeiffer KA, Pate RR. Family support for physical activity in girls from 8th to 12th grade in South Carolina. Prev Med. 2007;44(2):153–9.
13. Guy-Evans O. Bronfenbrenner's ecological systems theory. Simply Psychology. 2020. Available from: https://www.simplypsychology.org/bronfenbrenner.html
14. Kamionka A, Lipowska M, Lizińczyk S, Lipowski M. The impact of parents' physical activity goals and parental attitudes on physical activity during leisure time among children in middle childhood. Front Public Health. 2023;11:1170413.
15. Shajie K, Raoof M, Nayerabadi M, Houshyar K. Effect of parental attitude toward physical activity on sport participation of their children in school. Adv Environ Biol. 2014:2211–6.
16. Lian Y, Chen P, Wang K, Zhang T, Li H, Yang J, et al. The influence of family sports attitude on children's sports participation, screen time, and body mass index. Front Psychol. 2021;12:697358.
17. Kovács K, Oláh ÁJ, Pusztai G. The role of parental involvement in academic and sports achievement. Heliyon. 2024;10(2):e24678.

18. Lindqvist A, Kostenius C, Gard G, Rutberg S. Parent participation plays an important part in promoting physical activity. Int J Qual Stud Health Well-being. 2015;10(1):27397.
19. Desforges C, Abouchaar A. The impact of parental involvement, parental support and family education on pupil achievement and adjustment: A literature review. London: DfES; 2003.
20. Costa-Cordella S, Arevalo-Romero C, Parada FJ, Rossi A. Social support and cognition: A systematic review. Front Psychol. 2021;12:637060.
21. Moorman SM, Pai M. Social support from family and friends, educational attainment, and cognitive function. J Appl Gerontol. 2024;43(4):396–401.
22. Irani ZA, Sheridan AM, Silk TJ, Anderson V, Weinborn M, Gavett BE. Modeling the development of cognitive reserve in children: A residual index approach. J Int Neuropsychol Soc. 2024;30(3):264–72.
23. Matthews JS, Ponitz CC, Morrison FJ. Early gender differences in self-regulation and academic achievement. J Educ Psychol. 2009;101(3):689.
24. Coyne MA, Vaske JC, Boisvert DL, Wright JP. Sex differences in the stability of self-regulation across childhood. J Dev Life Course Criminol. 2015;1:4–20.
25. Rodríguez-Negro J, Huertas-Delgado FJ, Yanci J. Motor skills differences by gender in early elementary education students. Early Child Dev Care. 2021;191(2):281–91.
26. Olvera Astivia OL, Gadermann A, Guhn M. The relationship between statistical power and predictor distribution in multilevel logistic regression: a simulation-based approach. BMC Med Res Methodol. 2019;19:1–20.
27. Fedewa AL, Ahn S. The effects of physical activity and physical fitness on children's achievement and cognitive outcomes: a meta-analysis. Res Q Exerc Sport. 2011;82(3):521–35.
28. Chinese Ministry of Education. National Student Physical Fitness Standards. 2014. Available from: http://www.moe.gov.cn
29. Scarpina F, Tagini S. The Stroop color and word test. Front Psychol. 2017;8:557.
30. Gomez P, Ratcliff R, Perea M. A model of the go/no-go task. J Exp Psychol Gen. 2007;136(3):389.
31. Schmitz F, Krämer RJ. Task switching: on the relation of cognitive flexibility with cognitive capacity. J Intell. 2023;11(4):68.
32. Jiang QJ, Shen XH. Handbook of mental health assessment scales. Beijing: Chinese Mental Health Journal; 1999. (In Chinese).
33. Hu T. Development of the perceived social support scale for children and adolescents. J Guizhou Norm Coll. 2010;26(3):71–5. (In Chinese).
34. Ye Q, Zhu LY. Applicability of the perceived social support scale in adolescents. Educ Obs. 2022;11(2):29–32. (In Chinese).
35. Galvan MJ, Payne BK, Hannay J, Georgeson AR, Muscatell KA. What does the MacArthur scale of subjective social status measure? Ann Behav Med. 2023;57(11):929–41.
36. Giatti L, Camelo LDV, Rodrigues JFDC, Barreto SM. Reliability of the MacArthur scale of subjective social status-Brazilian longitudinal study of adult health (ELSA-Brasil). BMC Public Health. 2012;12:1–7.
37. Peltzer C, Khanna D, Kahar P, Parmar M. BMI: A screening tool analysis. FASEB J. 2022;36:S1.
38. Kim J, Son S, Lee J, Kim J, Jung I. The effects of body image satisfaction on obesity stress, weight control attitudes, and eating disorders among female junior high school students. J Korean Home Econ Assoc. 2009;47(4):49–59.
39. Darda KM, Butler EE, Ramsey R. Individual differences in social and non-social cognitive control. Cognition. 2020;202:104317.
40. Christakou A, Halari R, Smith AB, Ifkovits E, Brammer M, Rubia K. Sex-dependent age modulation of frontostriatal and temporo-parietal activation during cognitive control. NeuroImage. 2009;48(1):223–36.
41. Johnston K, Levin HM, Koval MJ, Everling S. Top-down control-signal dynamics in anterior cingulate and prefrontal cortex neurons following task switching. Neuron. 2007;53(3):453–62.
42. Girgenti MJ, Wohleb ES, Mehta S, Ghosal S, Fogaca MV, Duman RS. Prefrontal cortex interneurons display dynamic sex-specific stress-induced transcriptomes. Transl Psychiatry. 2019;9(1):292.
43. Diekhof EK, Keil M, Obst KU, Henseler I, Dechent P, Falkai P, et al. A functional neuroimaging study assessing gender differences in the neural mechanisms underlying the ability to resist impulsive desires. Brain Res. 2012;1473:63–77.
44. Davis CL, Tomporowski PD, McDowell JE, Austin BP, Miller PH, Yanasak NE, et al. Exercise improves executive function and achievement and alters brain activation in overweight children: a randomized, controlled trial. Health Psychol. 2011;30(1):91.
45. Best JR. Effects of physical activity on children's executive function: contributions of experimental research on aerobic exercise. Dev Rev. 2010;30(4):331–51.
46. Szuhany KL, Bugatti M, Otto MW. A meta-analytic review of the effects of exercise on brain-derived neurotrophic factor. J Psychiatr Res. 2015;60:56–64.
47. Barha CK, Hsiung GR, Best JR, Davis JC, Eng JJ, Jacova C, et al. Sex difference in aerobic exercise efficacy to improve cognition in older adults with vascular cognitive impairment: secondary analysis of a randomized controlled trial. J Alzheimers Dis. 2017;60(4):1397–410.
48. Ruiz-Ariza A, Grao-Cruces A, de Loureiro NEM, Martinez-Lopez EJ. Influence of physical fitness on cognitive and academic performance in adolescents: A systematic review from 2005–2015. Int Rev Sport Exerc Psychol. 2017;10(1):108–33.
49. Cefis M, Prigent-Tessier A, Quirié A, Pernet N, Marie C, Garnier P. The effect of exercise on memory and BDNF signaling is dependent on intensity. Brain Struct Funct. 2019;224(6):1975–85.
50. Kaushik D, Garg M, Mishra A. Exploring developmental pathways: an in-depth analysis of Bronfenbrenner's bioecological model. Int J Multidiscip Res. 2023;5(6).
51. Hostinar CE, Johnson AE, Gunnar MR. Parent support is less effective in buffering cortisol stress reactivity for adolescents compared to children. Dev Sci. 2015;18(2):281–97.
52. Rodrigues D, Padez C, Machado-Rodrigues AM. Active parents, active children: the importance of parental organized physical activity in children's extracurricular sport participation. J Child Health Care. 2018;22(1):159–70.
53. Sinke C, Forkmann K, Schmidt K, Wiech K, Bingel U. Expectations impact short-term memory through changes in connectivity between attention-and task-related brain regions. Cortex. 2016;78:1–14.

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