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Assessing physical fitness components, obesity, motor skills, health outcomes and academic performance of schoolchildren

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Assessing physical fitness components, obesity, motor skills, health outcomes and academic performance of schoolchildren

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Body Mass Index and Academic Achievement Among Chinese Secondary School Students: The Mediating Effect of Inhibitory Control and the Moderating Effect of Social Support

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Based on Embodied Cognition Theory, Inhibitory Decline Theory, and Risk Protective Factors Model, this study verified that body mass index (BMI) affects secondary school students' academic performance through the mechanism of inhibitory control. In addition, it was verified that the strength of this mechanism depends on the teacher, parent, and peer support received by secondary school students. By using height and weight measurements, the classic stroop task, and the social support scale, 264 secondary school students in Shanxi Province, China, were surveyed and their academic performance was collected. The results showed that students with high BMI had poorer academic performance, and inhibitory control partially mediated the effect between BMI and academic performance, with the inhibitory control mediated effect accounting for 36.68% of the total effect. Support from teachers, parents, and peers can ameliorate the negative effects of BMI on academic performance, with teacher support and parental support also ameliorating the negative effects of BMI on inhibitory control. Thus, high BMI impairs inhibitory control and thus has a negative impact on academic performance, which can be buffered by social support.

Keywords: BMI, academic achievement, inhibitory control, middle school student, social support

INTRODUCTION

Body mass index (BMI), as an important indicator of an individual's physical quality, is used to measure the total amount of body fat. And it is commonly used internationally to judge the degree of obesity, wasting and health of the human body. The World Health Organization reports that the number of obese adolescents worldwide will continue to rise in the next decade. Adolescence is a period of rapid change in body composition (location and amount of body fat) and physical fitness, and obesity at this stage may lead to a variety of physical and mental health problems in adulthood. Physiologically, obese adolescents may suffer from somatic symptoms, such as asthma, fatigue, arthralgia and dyssomnia due to excess weight (Ronghua and Xiaonan, 2006), and present a range of risk factors for chronic diseases, such as cardiovascular disease, diabetes, chronic kidney disease, cancer and musculoskeletal disorders (Afshin et al., 2017). Psychologically, overweight obesity can impede normal Self-Perception and interpersonal interactions, and most obese adolescents have mental health problems highly associated with high-risk behaviors, such as low Self-Esteem, depression, anxiety, stress, and loneliness (Paradise and Kernis, 2002). It has also been found that children with high BMI have corresponding changes in gray matter volume in brain regions, such as the fusiform gyrus, postcentral gyrus and hippocampus, which severely affects cognitive function and is detrimental to high academic achievement (Migueles et al., 2021).

In Chinese culture, academic achievement is highly valued both for students themselves and for their parents and teachers. As the Chinese proverb says, "There is gold in books" and "All things are inferior, but only reading is superior." Academic achievement achieved in reading is considered to be a ladder to the upper class, and better academic performance means a higher social class in the future. It is precisely because academic achievement is so important in Chinese culture that teachers and families pay attention to academic achievement and ignore students' physical quality. Students, moreover, do not have much time to focus on their physical fitness due to academic pressures, such as educational expectations, competition for higher education, and academic burdens. However, good physical fitness is essential to ensure high academic performance, where obesity may hinder students' academic development. Therefore, it is particularly important to study the effect of BMI on academic performance.

The originality of this study is fourfold; first, it has been shown that non-overweight children achieve better academic performance than overweight children (Hermassi et al., 2021). However, criteria for overweight vary across regions and age groups, and few studies have addressed the correlation between BMI, a continuous piece of data, and academic achievement.

Second, some studies have explored why obesity negatively affects academic performance, and these studies have focused on physiological functions, with obesity leading to changes in gray matter volume in brain areas (Migueles et al., 2021) and also diminishing cardiorespiratory function (Muntaner-Mas et al., 2018), which in turn affects academic performance. It has also been demonstrated that obese children have poorer working memory and thus have difficulty achieving academic excellence (Wu et al., 2017). Whether there are more important cognitive factors (e.g., inhibitory control) that are more feasible and efficient than physical interventions require more research in the cognitive domain.

Third, previous studies have found that obese children have poorer academic performance, but there is a general phenomenon that not all overweight obese children have poorer academic performance, and which factors play an important role is currently lacking research. This study selects three groups closely related to children (teachers, parents, and peers) and explores through empirical research whether they can change the adverse effects of overweight obesity on academic performance.

Fourth, a large number of studies have examined the effects on academic achievement from cognitive and environmental aspects. This study establishes a mediated model with moderation, and adopts an interdisciplinary perspective of medicine, education, and psychology to investigate the effects of individual physiological, cognitive, and social dimensions on academic achievement, and to investigate the linkage between physical fitness, cognitive ability, social support, and education.

In the context of the global health concern of adolescent obesity and the neglect of physical fitness in schools, there is a need to explore the joint mechanisms of the effects of BMI, inhibitory control, and social support on academic performance in a study that may draw social attention to physical health and also add more interventions to improve the academic performance of obese children. Therefore, this study analyzed the effect of BMI on academic achievement and the processes and conditions underlying the effect. The first objective of the study was to analyze the correlation between BMI, inhibitory control and academic performance. The second objective analyzed the mechanisms of the effects of BMI, inhibitory control and social support on academic achievement. This study hypothesized that high BMI would have a negative impact on inhibitory control and academic achievement, high social support would improve the negative effect of high BMI on inhibitory control and academic achievement, and would also improve the negative effect of poorer inhibitory control on academic achievement.

LITERATURE REVIEW

BMI and Academic Achievement

Academic achievement is the knowledge and skills acquired by students through learning and training (McCoach et al., 2017). Embodied Cognition Theory addresses the influence of the physical structure of the body on the cognitive abilities of individuals. According to Ye et al. (2019), the way and steps in which cognitive processes are carried out are actually determined by the physical properties of the body. A view of learning based on this theory states that the body is not an irrelevant or obstructive factor in the learning process; the body is the subject of learning and physical health has an important role in shaping the mental activities of learners, such as thinking, judgment and memory (Jiayi and Haosheng, 2018). The negative correlation between BMI and academic achievement has been well verified by different scholars through cross-sectional and follow-up studies. Previous studies based on tracking data of individuals' BMI from kindergarten to eighth grade found that adolescents with progressively and consistently higher BMI performed worse in reading and mathematics (Hsu et al., 2019). Chinese scholars investigated 1,380 fifth- and sixth-grade students and found that BMI was negatively associated with language and mathematics performance (Lv et al., 2020). Thus, BMI is an important factor influencing academic achievement.

The Mediator Effect of Inhibitory Control

Inhibitory control is the ability of individuals to pursue cognitive representational goals by controlling their thoughts, behaviors, and attention to inhibit intrinsic dominant responses and extrinsic temptations (Diamond, 2013). Specifically, in learning activities, the ability of students to inhibit and exclude irrelevant stimuli and dominant responses that affect academic tasks with conscious involvement. More previous studies have demonstrated the relationship between BMI and inhibitory control from behavioral, neuroelectrophysiological, and physiological indices. The results of behavioral studies with cognitive deficits in obese adolescents were most consistent in executive function tests (Smith et al., 2011). There was a negative correlation between inhibitory control task performance and body weight in executive function tests, while for other components of executive function, such as working memory or cognitive flexibility, there is inconsistent results with BMI-related studies (Gunstad et al., 2008). Neuropsychological studies have found that obese subjects exhibit significantly longer N2 latency and smaller P3 wave amplitudes than normal subjects in a stroop task measuring inhibitory control (Wen and Tsai, 2020). The event-related potentials N2 and P3 are important components associated with inhibitory control. N2 is primarily associated with conflict monitoring and impulse control, with greater N2 amplitude associated with poorer inhibitory control. P3 is considered to be associated with later response decision-making and inhibitory control processes, the smaller the P3 wave amplitude, the poorer the inhibitory control (Lun, 2010). In physiological studies, overweight groups had higher leptin concentrations than the normal one. and leptin is considered to be an early indicator of cognitive impairment, with higher leptin levels associated with poorer cognitive functioning, especially in attentional inhibition control tasks (Tsai et al., 2017). Thus, compared to non-overweight secondary school students, the overweight obese have poorer inhibitory control.

As a core component of executive function, inhibitory control is an advanced cognitive function. The higher the individual's cognitive ability, the faster and more accurate attention to key information, efficient memory coding, and produce excellent academic performance (Vock et al., 2011). The Theory of Inhibitory Depression proposed by Husher and Zucks (1988) links inhibition to working memory as well as reading understanding, arguing that the decline of inhibitory control prevents individuals to effectively suppress irrelevant information from the discourse and external environment while reading, thus reducing performance (Husher and Zucks, 1988). Titz and Karbach (2014) explored the relationship between inhibitory control and academic achievement and found that inhibitory control was correlated to some extent with verbal comprehension, writing ability, and mathematical operations. A longitudinal follow-up study of 2- to 5-year-old children also found that inhibitory control was significantly and positively associated with mathematical ability after controlling for age, maternal educational background, and children's linguistic and lexical abilities (Espy et al., 2004). Therefore, this study hypothesized that the stronger inhibitory control of secondary school students, the better their academic performance.

Based on Embodied Cognition Theory, Inhibitory Decline Theory, and previous studies on BMI, inhibitory control, and academic performance, it can be inferred that the higher the BMI the worse the academic performance, and the deficit in inhibitory control caused by high BMI leads to poorer academic performance. Inhibitory control mediates the relationship between academic performance and BMI.

The Moderating Effects of Social Support

It is worth noting that although overweight obesity is an important risk factor for secondary school students' academic performance, not all overweight obese adolescents perform poorly academically, which may be due to environmental protective factors at play, of which social support is one of the important environmental protective factors. Social support is an umbrella term for the spiritual and material help individuals feel in their social life, and its ability to help them get out of trouble and better adapt to society. Based on the direct social environment of secondary school students, support from parents, teachers and peers is an important helper to help secondary school students resist risk factors. According to Risk Protective Factors Model, a classic theory that explains social support as a moderating variable (Masten, 2001), adolescent development is a dynamic interaction between protective factors (e.g., teacher support, parental support, peer support) and risk factors (poorer academic performance), in which risk factors move individuals in undesirable directions and protective factors buffer the development of such undesirable trends.

If adolescents comprehend more social support resources, their level of interpersonal trust will be higher, and the more they will be able to enhance courage and confidence in facing difficulties. Empirical studies have found that teacher support, an important attachment object for secondary school students in the school environment, can buffer the negative effects of negative factors on students' academic performance (Luthar et al., 2000).

Higher parental support can also reduce the negative impact of negative factors on academic achievement. Longitudinal studies have shown that BMI has a negative predictive effect on academic achievement, but girls in the consistently higher BMI group did not experience poor academic achievement when they received parental support (Huang et al., 2019).

In addition, the need to belong as we enter adolescence allows peers to play an increasingly important role in the physical and mental health development of secondary school students. Some studies have shown that obese adolescents have problems with social functioning, particularly in peer relationships. Studies using photographic data have identified negative peer attitudes toward obese children, with peers often using negative terms (e.g., ugly, lazy) to describe obese children (Latner and Stunkard, 2003). Thus, teacher support, family support, and peer support may play an important role in buffering the negative effects of high BMI on inhibitory control and academic performance and the negative effects of poorer inhibitory control on academic performance.

Research Questions

The adolescent stage is a critical period for establishing lifelong healthy behaviors, but there is a lack of national research on how physical health affects educational output at this stage. Based on Embodied Cognitive Theory, Inhibitory Decline Theory, and Risk Protective Factor Model, this study attempts to investigate the effect of individual physical health (BMI) on academic performance, and the mediating role of cognitive factors (inhibitory control) and the moderating role of social support (teacher support, family support, and peer support; **Figure 1**) to further understand the "process" and "conditions" of the effect of BMI on academic performance of secondary school students. The purpose of this study is to further understand the "process" and "conditions" of the influence of BMI on secondary school students' academic performance, so as to understand more objectively the influence of BMI on academic performance and its effects, and to provide an empirical basis for strengthening the concept of health investment and improving the quality education system, which is important for accelerating the implementation of the Health China Strategy.

MATERIALS AND METHODS

Participants

Using a convenience sampling method, this survey was conducted from December 2020 to January 2021, and the sample size was calculated using correlation analysis in G Power software, assuming Effect size = 0.2, $\alpha = 0.05$, and $1-\beta = 0.95$, and 262 subjects were selected for the study according to this assumption. Because this study took continuous data of BMI to calculate the correlation with other variables, it was required that the percentage of overweight among the selected subjects was in line with the current overweight detection rate of secondary school students. According to the China Child Development Report, the rate of overweight among secondary school students in China in 2019 was 21%. In this study, secondary obese subjects were excluded, and the critical value of age-sex BMI according to the national standard (WS/T586-2018) was used as the criterion for judging overweight, and the age range of students in this study was 13.5–17.0 years old, and 264 people were finally included according to the following criteria, including 56 overweight (24 boys and 32 girls) and 208 non-overweight (100 boys and 108 girls) with a mean age of (15.00 ± 0.68) years (**Table 1**).

MEASURES

Body Mass Index

In this study, height and weight were measured using the equipment and methods prescribed by national standards. According to the BMI = weight (kg)/[height (m)]^2, height was measured in "centimeters" and recorded to one decimal place, which was converted to "meters" and retained one decimal place when calculating the BMI.

Inhibitory Control Tasks

The classical stroop task was used to measure subjects' inhibitory control, and it has been demonstrated that this paradigm can effectively measure subjects' inhibitory control (Xuejun and Haijuan, 2018). The stimulus materials were four Chinese characters "red," "green," "yellow," and "blue," respectively written in "red," "green," "yellow," and "blue" colors, which were used as "The size of each character was 1×1 cm. The subjects were asked to respond to the color of the presented stimulus by pressing the key, red by red block, green by green block, yellow by yellow block, and blue by blue block. The entire experiment was divided into practice and formal experiments, and the experimental procedure was the same in both phases. There were 20 practice sessions, and the total number of stimuli in the formal experiment was 160, including 40 word-color consistent stimuli and 120 inconsistent stimuli. First, a gaze point "+" appeared in the center of the screen for 500 ms, then an experimental stimulus (color word) appeared, and the program allowed a response time of 3,000 ms, and the time interval between the correct response and the next experimental stimulus was 500 ms. The subject pressed the correct key and was presented with a 1,000 ms "correct response" message on the screen. If the subject pressed a correct key, a "correct response" message was presented on the screen for 1,000 ms, and if the subject pressed an incorrect key, an "incorrect feedback" message was presented on the screen as a penalty, in order to ensure a high correct rate. The difference in response time between the inconsistent and consistent conditions was used as a measure of individual inhibitory control, and the higher the inhibitory control score, the worse the inhibitory control of the subject.

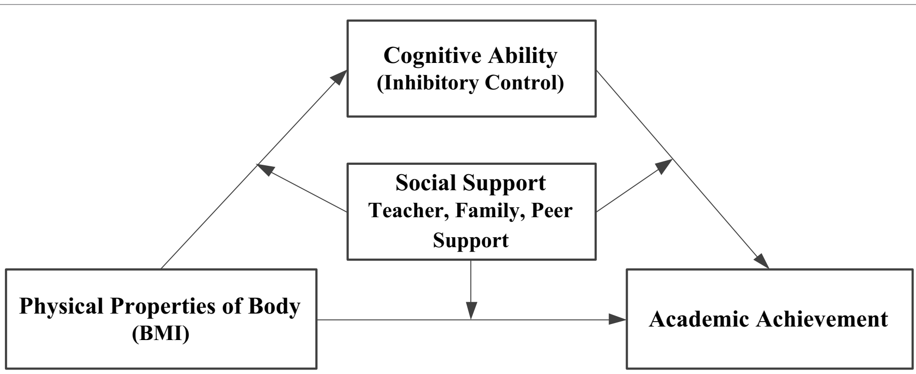

FIGURE 1 | Concept framework.

TABLE 1 | BMI threshold for overweight screening.

Age (year)	Boy (kg/m²)	Girl (kg/m²)
13.5~	21.9	22.6
14.0~	22.3	22.8
14.5~	22.6	23.0
15.0~	22.9	23.2
15.5~	23.1	23.4
16.0~	23.3	23.6
16.5~	23.5	23.7
17.0~	23.7	23.8

items, the higher the score, the higher the level of social support of individual perception. In this study, the Cronbach's α coefficients of the three questionnaires were 0.84, 0.87, and 0.83.

Procedure

Prior to the study, participants gave written informed consent in accordance with the Declaration of Helsinki. Ethical approval for this investigation was obtained from this Shihezi University review board (KJ2020-125-01).

After informed consent from the school director and the subjects, group testing was conducted in classes with two professionally trained master testers in each class. Subjects completed measures of height, weight, inhibitory control, and social support in a comfortable and quiet computer classroom (the same procedure is completed Monday through Friday from 9:30 a.m. to 10:30 a.m., temperature: 18.5 ± 0.5°C; relative humidity: 55 ± 5%). Subjects were advised to maintain their habitual dietary intake and to eat for more than 2 h before the test. Hunger level, thirst level, and eating cravings were all 0.

First, height and weight were measured using the equipment and methods specified in Chinese GB/T 26343. Second, after the main test experimenter filled in the measured height and weight on the questionnaire, they were given to the subjects to fill in other contents, including school, name, class, gender, and other basic information and comprehension of social support. In addition, the subject installed E-prime software on the computer in the school computer room, and the subject completed the test of inhibition control on the computer. Finally, the main examiner obtains the results of the last two exams through the school's Registrar's Office.

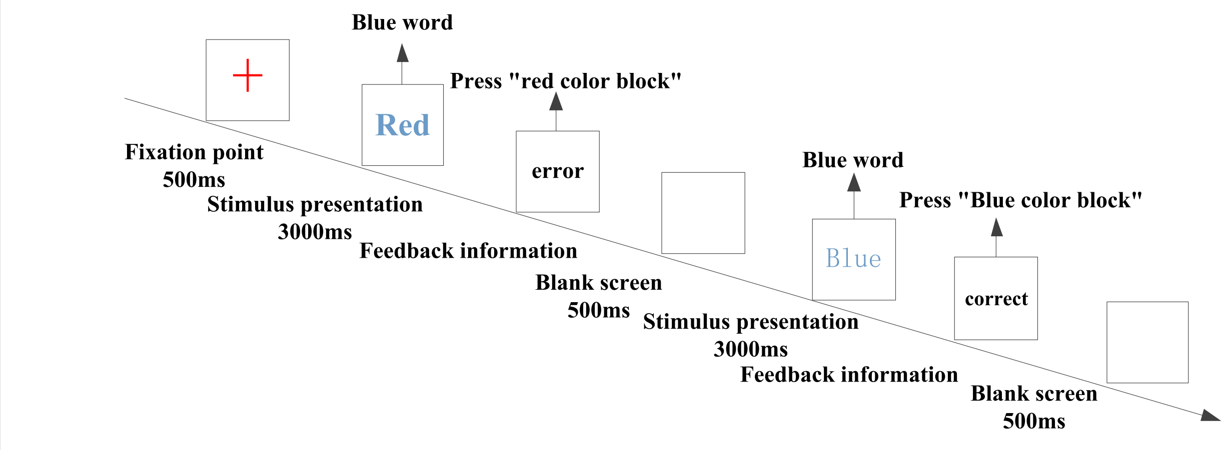

FIGURE 2 | Stroop task program.

Because this study focused on inhibitory control, the inhibitory control score was reverse scored as a measure of inhibitory control. After reverse scoring, the higher the inhibitory control score, the stronger the inhibitory control ability (**Figure 2**).

Academic Achievement

In this study, the results of the last two examinations of senior students in a middle school in Shanxi province were collected, provided by the school's teaching office, including nine subjects: language, mathematics, English, politics, history, geography, physics, chemistry, and biology, and the sum of the nine subject scores was used as a measure of academic achievement, and the larger the value, the higher the academic achievement of the student.

Social Support

In this study, the scale translated and revised by Zemit compiled by Chinese scholars Yan and Xue (2006) was adopted. Two scholars adapted the Understanding Social Support Scale (MSPSS) based on the actual situation, which focused on individuals feeling the social support provided by different groups and measured the degree of individual understanding. The scale includes 12 topics, three dimensions, namely family support, friend support and teacher support, each dimension has four entries, each entry from the level 1–7 scoring method of "extreme disagree" to "extreme consent," which is divided into the total of all scoring

Data Analysis

The statistical analyses were carried out through the IBM SPSS Statistics 22 and the modeling tool PROCESS 3.0 for SPSS (Hayes, 2018).

RESULTS

In this study, Self-Reported questionnaires were used to collect social support data, and results might be influenced by common method bias. Therefore, the Harman's single-factor test was used to assess common method bias before data analysis. The results showed that eigenvalues of three unrotated factors were greater than 1, and the amount of variation explained by the first factor was 37.72%, which is much less than 40% of the critical value. Accordingly, common method bias was not significant in this study (Hao and Lirong, 2004).

Descriptives and Correlations

Table 2 shows mean and the standard deviation of each of the variables considered in the study, and it presents the Spearman correlation coefficients among all the variables. There was significantly uncorrelated between BMI and teacher support, BMI and peer support. Other variables associations were statistically significant ($p < 0.01$).

Mediating Effect Analysis

According to the theory and hypothesis, the mediating effect model of the inhibitory control on the relationship between BMI and academic achievement was constructed. The mediation role of the inhibitory control between the physical fitness index and the academic performance was analyzed, using the physical fitness index as the independent variable, and using the Model 4 in the PROCESS program developed by Hayes. Stepwise regression analysis showed (**Table 3**) that the regression of academic achievement to BMI ($c = -0.26$, $t = -4.21$, $p < 0.001$), the regression of inhibitory control to BMI ($a = -0.38$, $t = -6.35$, $p < 0.001$), and the regression of academic achievement to BMI ($C' = -0.16$, $t = -2.55$, $p < 0.05$) and inhibitory control ($b = 0.25$, $t = 4.06$, $p < 0.001$) were all significant. Thus, inhibitory control played a partial mediating role in BMI and academic achievement.

In order to validate the significance of the mediating effect, non-parametric Bootstrap method was also used (repeat sampling 5,000 times). As shown in **Table 4**, the results showed that the 95% confidence interval corresponding to each path did not contain 0, indicating that the total effect, direct effect and indirect effect were statistically significant ($p < 0.05$). Thus, the mediating effect of the inhibitory control on the relationship between BMI and academic achievement was statistically significant. The mediation effect value was −0.10, accounting for 38.46% (−0.10)/(−0.26) of the total effect.

Moderated Mediation Effect Analysis

The moderating effects of teacher support, family support and peer support in the mediation model were analyzed by using the model 59 in PROCESS.

The Moderating Effect of the Teacher Support

In the first step, a model (**Figure 3**) is constructed to analyze the moderating role of teacher support in mediating effect. As shown in **Table 5**, the results showed that BMI had a significant effect on inhibitory control ($\beta = -0.34$, $t = -5.87$, $p < 0.001$), and the effect of BMI × teacher support to inhibitory control was significant ($\beta = 0.12$, $t = 2.23$, $p < 0.05$), indicating that the relationship between BMI and inhibitory control was moderated by teacher support. BMI had a significant effect on academic achievement ($\beta = -0.16$, $t = -2.69$, $p < 0.01$), and the effect of BMI × teacher support to academic achievement was significant ($\beta = 0.16$, $t = 2.71$, $p < 0.01$), indicating that the relationship between BMI and academic achievement was moderated by teacher support. Inhibitory control had a significant effect on academic achievement ($\beta = 0.18$, $t = 2.88$, $p < 0.01$), but the effect of inhibitory control × teacher support to academic achievement was not significant ($\beta = 0.08$, $t = 1.34$, $p > 0.05$), indicating that the relationship between inhibitory control and academic achievement was not moderated by teacher support.

To further analyze the moderating effect of the teacher support, the teacher support was divided into the high and low groups, according to the principle of standard deviation, and a simple slope test was performed (**Figures 4, 5**). The results found that for individuals with low score of teacher support, BMI could significantly predict inhibitory control ($\beta = -0.46$, $t = -6.60$, $p < 0.001$). For individuals with high score of teacher support, prediction effect of BMI to inhibitory control decreased ($\beta = -0.23$, $t = -2.62$, $p < 0.01$). For individuals with

TABLE 2 | Descriptive analysis and correlation coefficients of the study variables.

	1	2	3	4	5	6	7
1. BMI	1						
2. Inhibitory control	−0.37***	1					
3. Social support	0.08	0.27***	1				
4. Teacher support	−0.02	0.22***	0.72***	1			
5. Family support	0.19**	0.14*	0.72***	0.22***	1		
6. Friend support	0.01	0.23***	0.78***	0.35***	0.41***	1	
7. Academic achievement	−0.25***	0.31***	0.53***	0.30***	0.41***	0.47***	1
Mean	20.96	-77.67	56.96	16.42	20.10	20.43	446.62
Standard deviation	3.63	63.40	11.24	5.31	4.91	4.92	60.50

**The correlation is significant at the 0.05 level.*
***The correlation is significant at the 0.01 level.*
****The correlation is significant at the 0.001 level.*

TABLE 3 | The mediating effect of the inhibitory control on the relationship between BMI and academic achievement.

Regression equation		Fit indices			Significance of regression coefficient		
Result variable	Predictor variable	*R*	R^2	*F*	*β*	SE	*t*
Academic achievement	BMI	0.25	0.06	17.76***	−0.26	0.06	−4.21***
Inhibitory control	BMI	0.37	0.13	40.29***	−0.38	0.06	−6.35***
Academic achievement	BMI	0.35	0.12	17.66***	−0.16	0.06	−2.55*
	Inhibitory control				0.25	0.06	4.06***

**The correlation is significant at the 0.05 level.*
****The correlation is significant at the 0.001 level.*

TABLE 4 | Total effect, direct effect and mediating effect.

	Mediation path	Standardized effect value	Bootstrap standard error	95% CI	Effect size
Total effect	Path1	−0.26***	0.06	[−0.38, −0.14]	
Direct effect	Path2	−0.16*	0.06	[−0.29, −0.04]	61.54%
Mediating effect	Path3	−0.10***	0.03	[−0.15, −0.04]	38.46%

Path1 BMI→Academic achievement, Path2 BMI→Academic achievement, Path3 BMI→Inhibitory control→Academic achievement.
**The correlation is significant at the 0.05 level.*
****The correlation is significant at the 0.001 level.*

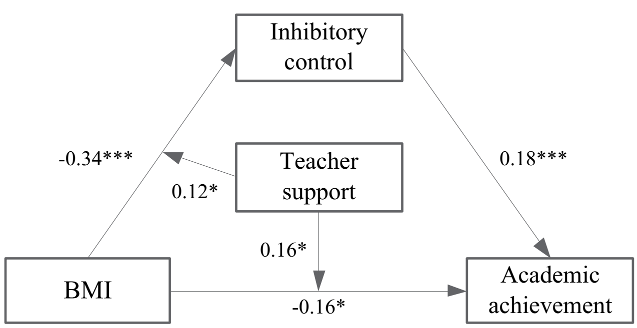

FIGURE 3 | A moderated mediation model of the teacher support. *The correlation is significant at the 0.05 level. ***The correlation is significant at the 0.001 level.

low score of teacher support, BMI could significantly predict academic achievement ($\beta = -0.32$, $t = -4.04$, $p < 0.01$). For individuals with high score of teacher support, prediction of BMI to academic achievement was not significant ($\beta = -0.01$, $t = -0.15$, $p > 0.05$).

The Moderating Effect of the Family Support

Next, a model (**Figure 6**) is constructed to analyze the moderating role of family support in mediating effect. As shown in **Table 6**, the results showed that BMI had a significant effect on inhibitory control ($\beta = -0.47$, $t = -7.49$, $p < 0.001$), and the effect of BMI × family support to inhibitory control was significant ($\beta = 0.13$, $t = 2.19$, $p < 0.05$), indicating that the relationship between BMI and inhibitory control was moderated by family support. BMI had a significant effect on academic achievement ($\beta = -0.34$, $t = -5.36$, $p < 0.001$), and the effect of BMI × family support to academic achievement was significant ($\beta = 0.12$, $t = 2.05$, $p < 0.05$), indicating that the relationship between BMI and inhibitory control was moderated by family support. Inhibitory control had a significant effect on academic achievement ($\beta = 0.13$, $t = 2.27$, $p < 0.05$), but the effect of inhibitory control× family support to academic achievement was not significant ($\beta = -0.02$, $t = -0.32$, $p > 0.05$), indicating that the relationship between inhibitory control and academic achievement was not moderated by family support.

To further analyze the moderating effect of the family support, the family support was divided into the high and low groups, according to the principle of standard deviation, and a simple slope test was performed (**Figures 7, 8**). The results found that for individuals with low score of family support, BMI could significantly predict inhibitory control ($\beta = -0.60$, $t = -5.93$, $p < 0.001$). For individuals with high score of family support, prediction effect of BMI to inhibitory control decreased ($\beta = -0.33$, $t = -4.74$, $p < 0.001$). For individuals with low score of family support, BMI could significantly predict academic achievement ($\beta = -0.46$, $t = -4.55$, $p < 0.001$). For individuals with low score of family support, prediction effect of BMI to academic achievement decreased ($\beta = -0.22$, $t = -3.25$, $p < 0.01$).

The Moderating Effect of the Peer Support

In the third step, a model (**Figure 9**) is constructed to analyze the moderating role of peer support in mediating effect. As shown in **Table 7**, the results showed that BMI had a significant effect on inhibitory control ($\beta = -0.38$,

TABLE 5 | The moderating effect of the teacher support on the mediating effect.

Regression equation		Fit indices			Significance of regression coefficient	
Result variable	**Predictor variable**	***R***	***R*²**	***F***	***β***	***t***
Inhibitory control	BMI	0.44	0.20	21.08***	−0.34	−5.87***
	Teacher support				0.21	3.84**
	BMI × Teacher support				0.12	2.23*
Academic achievement	BMI	0.45	0.20	13.14***	−0.17	−2.69**
	Teacher support				0.26	4.58***
	BMI × Teacher support				0.16	2.71**
	Inhibitory control				0.18	2.88**
	Inhibitory control × Teacher support				0.08	1.34

*The correlation is significant at the 0.05 level.
**The correlation is significant at the 0.01 level.
***The correlation is significant at the 0.001 level.

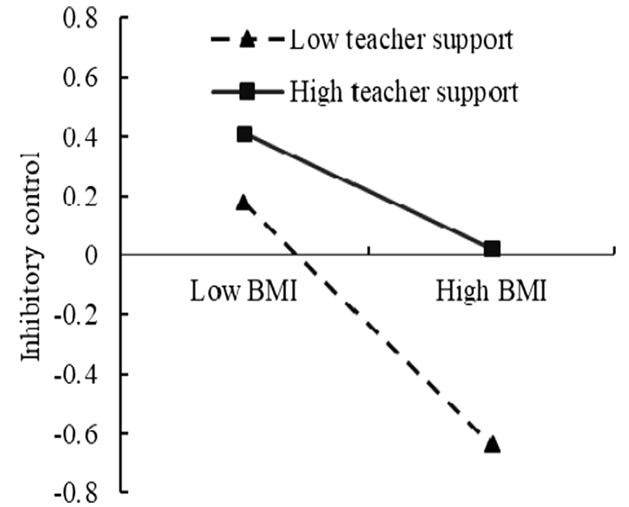

FIGURE 4 | The moderating effect of the teacher support on the relationship between BMI and inhibitory control.

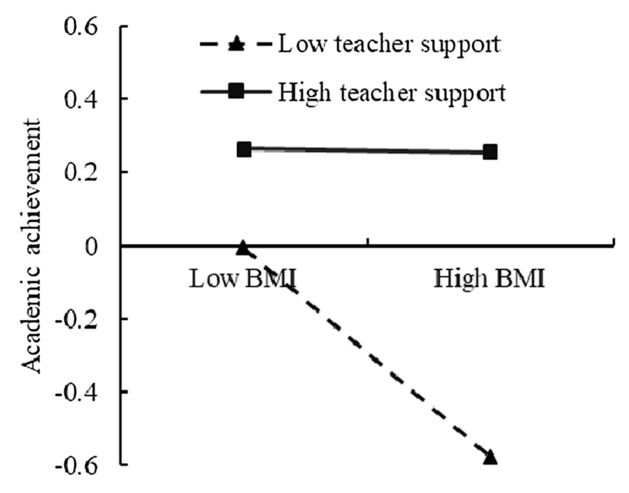

FIGURE 5 | The moderating effect of the teacher support on the relationship between BMI and academic achievement.

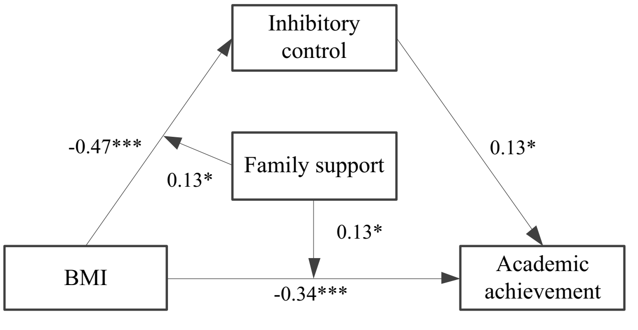

FIGURE 6 | A moderated mediation model of the family support. *The correlation is significant at the 0.05 level. ***The correlation is significant at the 0.001 level.

$t = -6.56$, $p < 0.001$), and the effect of BMI × peer support to inhibitory control was not significant ($\beta = 0.02$, $t = 0.49$, $p > 0.05$), indicating that the relationship between BMI and inhibitory control was not moderated by peer support. BMI had a significant effect on academic achievement ($\beta = -0.21$, $t = -3.67$, $p < 0.01$), and the effect of BMI × peer support to academic achievement was significant ($\beta = 0.10$, $t = 2.03$, $p < 0.05$), indicating that the relationship between BMI and academic achievement was moderated by peer support. Inhibitory control had a significant effect on academic achievement ($\beta = 0.13$, $t = 2.26$, $p < 0.05$), but the effect of inhibitory control × peer support to academic achievement was not significant ($\beta = -0.01$, $t = -0.17$, $p > 0.05$), indicating that the relationship between inhibitory control and academic achievement was not moderated by peer support.

To further analyze the moderating effect of the peer support, the peer support was divided into the high and low groups, according to the principle of standard deviation, and a simple slope test was performed (**Figure 10**). The results found that for individuals with low score of peer support, BMI could significantly predict academic achievement ($\beta = -0.30$, $t = -4.09$, $p < 0.001$). For individuals with high score of peer support, prediction of BMI to academic achievement was not significant ($\beta = -0.12$, $t = -1.57$, $p > 0.05$).

TABLE 6 | The moderating effect of the family support on the mediating effect.

Regression equation		**Fit indices**			**Significance of regression coefficient**	
Result variable	**Predictor variable**	***R***	***R***^{2}	***F***	***β***	***t***
Inhibitory control	BMI	0.44	0.19	20.81***	−0.47	−7.49***
	Family support				0.23	4.01***
	BMI × Family support				0.13	2.19*
Academic achievement	BMI	0.56	0.31	23.47***	−0.34	−5.36***
	Family support				0.46	8.36***
	BMI × Family support				0.12	2.05*
	Inhibitory control				0.13	2.27*
	Inhibitory control × Family support				−0.02	−0.32

**The correlation is significant at the 0.05 level.*
****The correlation is significant at the 0.001 level.*

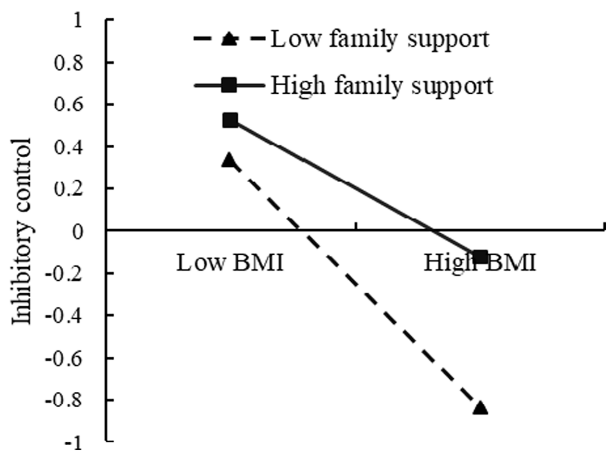

FIGURE 7 | The moderating effect of the family support on the relationship between BMI and inhibitory control.

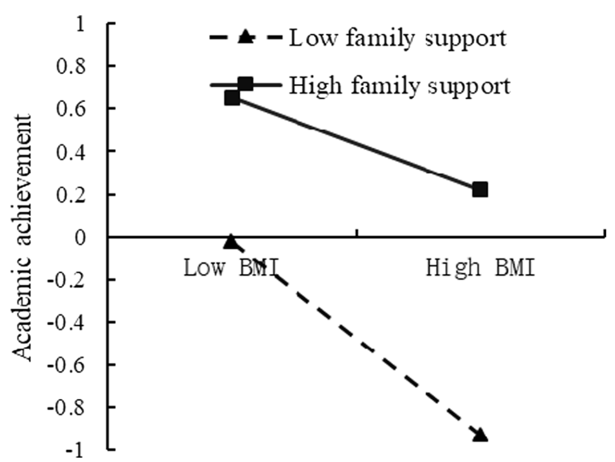

FIGURE 8 | The moderating effect of the family support on the relationship between BMI and academic achievement.

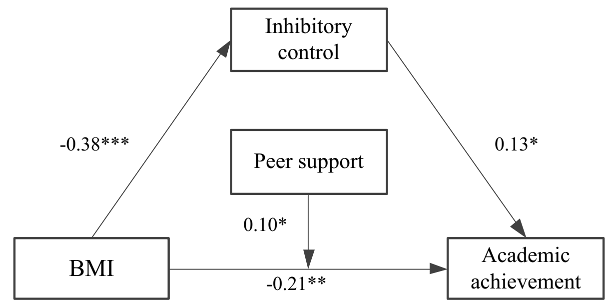

FIGURE 9 | A moderated mediation model of the peer support. *The correlation is significant at the 0.05 level. **The correlation is significant at the 0.01 level. ***The correlation is significant at the 0.001 level.

DISCUSSION

There are three important findings from this study. First, the findings suggest that high BMI secondary school students are associated with poor academic performance. Second, high BMI secondary school students' poor performance in school was partly due to their poor inhibitory control. Third, some high BMI academic performance was not poor because of high social support from teachers, parents, and peers. Similarly, some high BMI secondary school students' inhibitory control is not poor because of high social support from teachers and parents.

Influence of BMI on Academic Achievement

Consistent with the research hypothesis and previous studies, the present study found that high BMI negatively affects academic achievement. Overweight adolescents experience poorer school performance, such as lower math and reading scores, IQ scores, GPA, and absenteeism (Finn et al., 2018). Meanwhile, the results have been argued across cultures, with a review of nine studies from the United States, Western Europe, South America, and Asia showing a significant

TABLE 7 | The moderating effect of the peer support on the mediating effect.

Regression equation		Fit indices			Significance of regression coefficient	
Result variable	**Predictor variable**	***R***	***R*²**	***F***	***β***	***t***
Inhibitory control	BMI	0.44	0.19	20.19***	−0.38	−6.56***
	Peer support				0.23	3.98**
	BMI × Peer support				0.02	0.49
Academic achievement	BMI	0.56	0.32	24.12***	−0.21	−3.67**
	Peer support				0.42	7.54***
	BMI × Peer support				0.10	2.03*
	Inhibitory control				0.13	2.26*
	Inhibitory control × Peer support				−0.01	−0.17

**The correlation is significant at the 0.05 level.*
***The correlation is significant at the 0.01 level.*
****The correlation is significant at the 0.001 level.*

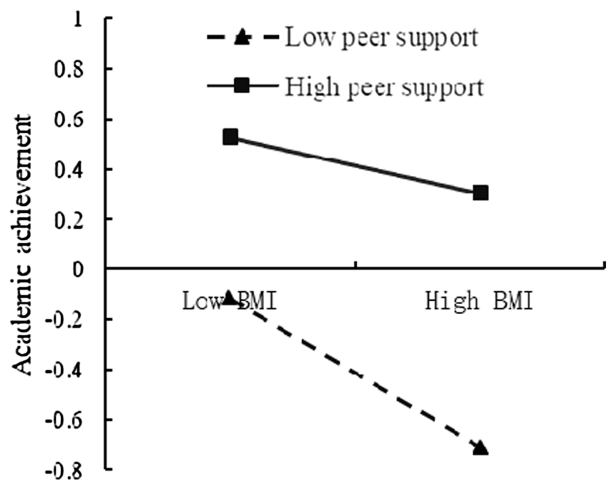

FIGURE 10 | The moderating effect of the peer support on the relationship between BMI and academic achievement.

negative association between BMI and academic performance (Taras and Potts-Datema, 2005). The present study adds to the research related to this area of obesity and academic performance in Chinese adolescents. Conversely, some studies have found that obesity does not affect academic performance (Barrigas and Fragoso, 2012). The measurement methods and standards of obesity, the measurement of academic performance, and the maturity of the subjects may explain this difference. In contrast to previous studies that examined differences in academic achievement between overweight and non-overweight groups, the use of BMI continuous data in this study avoids differences in results due to different criteria for overweight. In this study, the correlation between BMI and academic achievement was small ($r = -0.252$), a result that is consistent with the most recent meta-analysis, which showed a weak negative correlation between BMI and academic achievement ($-0.067 < r < 0.155$), and it was noted in this study that the magnitude of the correlation coefficient was influenced by grade level, compared to elementary and middle school students, the correlation coefficient was the largest for high school students ($r = -0.184$; He et al., 2019). Therefore, the correlation in our study is reasonable because our sample was selected from high school students.

The Mediating Effect of Inhibition Control

Consistent with the research hypothesis, the mediation analysis in this study indicated that BMI was predictive of their academic performance through inhibition control. A systematic review also pointed out the relationship between obesity, cognitive function, and academic achievement, with obese individuals having poorer executive function, attention, and visual space compared to those of normal weight at the same age, and these factors were significant positive predictors of academic achievement (Liang et al., 2014). A meta-analysis that included 4,904 subjects found that overweight obese subjects had significantly impaired inhibitory control compared to normal weight (Yang et al., 2017). Exploring the reasons for the poor inhibitory control, on the one hand, it may be that overweight obese subjects are unable to restrain themselves when confronted with food and may have binge eating, and the negative effects of this behavior may occur in various ways, one of which is impairedt inhibitory control (Balodis et al., 2013). On the other hand obese adolescents have a lower maturation of the right frontal neurological area associated with inhibitory control and a lower level of prefrontal cortex activity, leading to an inability to rapidly activate conflict monitoring abilities (Alatorre-Cruz et al., 2021).

Inhibitory control as a higher cognitive ability has a positive predictive effect on academic performance. Consistent with meta-analytic findings, the present study also confirmed that inhibitory control is a significant predictor variable of academic ability, and that the components of inhibitory control focus attention and inhibit impulsive responses are fundamental to the completion of academic tasks and learning (Cortés Pascual et al., 2019). Compared to previous studies that found obesity to adversely affect academic performance through changes in cardiorespiratory function and brain area volume, the mediating variable inhibitory control in this study was more feasible for intervention. A computer-based intervention study showed a significant increase in students' academic performance following a suppression control "Stop & Think" intervention (Wilkinson et al., 2020).

The Moderating Role of Social Support in the Relationship Between BMI and Academic Achievement

This study found that teacher support, family support, and peer support all mitigate the negative effects of high BMI on academic achievement. Previous studies did not consider the role of social support in the relationship between BMI and academic achievement. When social support was included as a variable, social support determined the strength of the relationship between BMI and academic achievement.

First, there was no significant difference in academic achievement between overweight obese and non-overweight adolescents when receiving high teacher support. This emphasizes the importance of teacher support, When overweight obese adolescents perceive acceptance by their teachers, it stimulates intrinsic motivation to learn and increases classroom participation, which in turn drives academic development (Saeed et al., 2021). This is consistent with previous research findings that teacher support significantly and positively predicts students' academic achievement, especially among disadvantaged groups, which are more sensitive to support from teachers. More emotional support from teachers to disadvantaged students can bring good emotional experiences for students, which can make them feel psychologically warm, which in turn stimulates strong motivation, high attention span, and contributes to superior academic achievement (Liu et al., 2019).

Second, family support can attenuate the negative effects of high BMI on academic performance. This is consistent with previous research, which has found that the negative predictive effect of overweight obesity on academic achievement in girls has been found to be insignificant possibly due to the support girls receive from their families (Black et al., 2015). Also, this result is consistent with Social Learning Theory, which individuals emphasize the importance of imitating objects and their characteristics to motivate specific behaviors (Chavis, 2011). Children often observe and imitate their parents as role models, and their parents' correct attitude toward learning is an indirect moral support, and this support promotes the occurrence of positive learning behaviors.

Finally, there is no significant difference in academic achievement between overweight obese adolescents and non-overweight secondary school students when receiving high peer support, which highlights the importance of peer support for overweight obese secondary school students as reflected in high or low academic achievement. Overweight obese children are more likely to be victims and aggressors of bullying than their normal-weight peers, and studies have found that obese children are subjected to verbal abuse, teasing, and kicking by their peers (Latner and Stunkard, 2003). Lower peer acceptance often predicts lower social support, which severely affects the academic performance of overweight obese children (Lv et al., 2020). In contrast, positive peer relationships are often associated with more material support (e.g., shared learning resources) and emotional support (e.g., mitigating the negative effects of academic stress) from peers, which contributes to superior academic performance (Gallardo et al., 2016).

The Moderating Role of Social Support in the Relationship Between BMI and Inhibition Control

The present study found that in addition to peer support, teacher support and family support can mitigate the adverse effects of high BMI on inhibitory control.

First, teacher support can weaken the negative effect of high BMI on inhibitory control. This result is consistent with the teacher Expectancy Effect Theory, which states that when teachers invest more expectations and positive emotions in students, the more likely students are to develop in the direction teachers expect them to, and teachers expect students to have higher inhibitory control. Previous research has also found that when there is a lack of teacher support, it leads to poor Self-Regulation, and inhibitory control is a cognitive manifestation of Self-Regulation (Curby et al., 2013).

Second, family support can attenuate the negative effects of high BMI on inhibitory control. This result is consistent with Social Control Theory, which suggests that the social environment restricts people from engaging in socially detrimental behaviors, that parental support in the home environment is a constructive way to substantially increase inhibitory control, and that enthusiastic parental support will enhance children's ability to control impulses, which will contribute to the development of their inhibitory control (Wilder, 2014). Thus, healthy parent–child relationships allow adolescents to explore the world fully, gain more energy, and improve the effects of adverse factors on inhibitory control.

Finally, peer support does not diminish the negative effects of high BMI on inhibitory control. There is a proverb in Chinese culture that "those who are close to vermilion are red, those who are close to ink are black," which means that we need to choose our friends carefully, as good friends will fill our lives with positive energy, while bad friends will lead us to the abyss. As in social learning theory, when individuals observe and imitate bad behavior habits, such as get poorer inhibitory control, fail to view peer support correctly and identify "same absenteeism" as high peer support from companionship, this support can instead hinder inhibitory control development.

Social Support Has No Moderating Effect on the Relationship Between Inhibitory Control and Academic Achievement

This study found that teacher support, family support, and peer support did not mitigate the negative effects of low inhibitory control on academic achievement. This is inconsistent with the research hypothesis, and the results of this study reveal that not all negative effects of adverse factors on academic achievement can be ameliorated by social support, highlighting the importance of inhibitory control as a relatively stable cognitive ability on academic achievement.

One manifestation of poor inhibitory control is classroom distraction. Classroom learning is the most effective way for students to improve their academic performance, and if teachers fail to recognize that students' attention has been diverted from the classroom during instruction, students' academic performance does not improve even when they appreciate higher teacher support outside of class. In addition, in Chinese culture, teachers teach in large classes with approximately 40 students in each class, and these students have high and low levels of inhibitory control. Although teachers decide how fast to teach based on the cognitive level of the students, there are still students with poor inhibitory control who are unable to keep up with the teacher's lectures, and this poor learning status can lead to poor academic performance.

For parents, BMI and academic achievement as a direct observation, overweight/obesity and low academic achievement are more easily perceived by parents, while inhibitory control as a cognitive ability that is not easily observed is easily ignored by parents, resulting in the inability to make targeted changes.

As mentioned above, poor inhibitory control in secondary school students may be due to the presence of peers with poor inhibitory control around them, and even though they give high social support, this social support does not correlate with inhibitory control and still does not improve the poor academic performance of inhibitory control secondary school students.

Educational Suggestions

Research has found that high BMI negatively affects academic achievement. This requires relevant educators to reverse the value bias of "emphasizing academic achievement over physical fitness" and to re-examine the positive role of physical fitness in cognitive ability and academic achievement by conducting lectures and regular studies. At the same time, schools should focus on strengthening students' physical and mental health literacy education. From the cognitive point of view, students should scientifically estimate their BMI and clarify the dangers associated with overweight and obesity. On this basis, schools should take action to improve the comprehensive quality evaluation system for students, assess physical fitness, and include it in students' academic performance.

The study found that the impaired inhibitory control of high BMI middle school students will lead to poor academic performance, which reveals that the inhibitory control and academic performance of overweight and obese adolescents can be effectively improved through intervention inhibitions, and schools, parents and individual students can improve inhibitory control through coordinated aerobic exercise and inhibitory control task training, and coordinated aerobic exercise includes physical activity in the form of cycling, basketball, rope skipping and other sports. These forms of physical activity can should be added to the student's physical activity. Commonly used inhibitory control training tasks include Go/No-Go tasks, Stop Signal tasks, Stroop tasks, and Flanker tasks, which can be combined with video games, where students enjoy improving inhibitory control.

Teacher support, family support, and peer support were found to mitigate the negative effects of high BMI on academic performance. Teacher support and family support also mitigated the negative effects of high BMI on inhibitory control. Teachers should play a motivational role in teaching evaluation. Teachers should fully explore the strengths and potential of each student, especially overweight and obese students, give full recognition and motivation to the strengths, build students' Self-Confidence, and give targeted help to the weaknesses. This requires that teachers must master the knowledge of educational psychology. Parents should give full play to their sense of responsibility. On the one hand, parents should learn about physical fitness and avoid underestimating their children's weight. On the other hand, families should conduct regular meetings to ask about their children's material and emotional needs and to create a harmonious and loving family atmosphere. Increasing peer acceptance, to make peer relationships harmonious, mental health teachers bear the main responsibility. Teachers promote listening and companionship among students by means of group counseling, such as forming mutual help groups and group game competitions, which highlights the need for mental health programs in schools.

Limitations and Future Studies

First, this study adopted the convenient sampling method, selected only the first-year senior high school students in a middle school in Shanxi Province. The narrow age range of participants made the generalizability of the results of this study unknown, and further verification of the applicability of the findings to other samples is needed.

Second, the social support investigated in this study was the social support of all subject teachers, which did not take into account the correlation between teacher support and the corresponding academic achievement in different subjects and the measurement of social support by student Self-Report method, which is still somewhat different from objective teacher support.

Finally, this study hypothesized the relationship between BMI, inhibition control, and academic achievement based on previous studies and existing theories, and proved this relationship by collecting cross-sectional data, which would have been more convincing if a follow-up study method had been used.

Therefore, future research should consider expanding the types of teacher support to interdisciplinary and using a combination of observational methods, tracking studies, and standardized academic proficiency tests to explore in depth the effects of BMI, inhibitory control, and social support on academic achievement.

CONCLUSION

This study investigated the effect of BMI on academic achievement and the role of inhibitory control and social support in it. Overweight obesity in secondary school students diminishes their inhibitory control and consequently reduces academic performance, while support from teachers, parents, and peers can ameliorate the negative effects of overweight obesity on academic performance, and teacher and parental support can also cushion the negative effects of overweight obesity on inhibitory control. Future studies need additional parameters (e.g., body fat percentage, GPA) to confirm our findings.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary Material.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The First Affiliated Hospital of Shihezi University, Shihezi University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

YS designed the experiment, collected data, and prepared the manuscript. HY collected the data and made data analysis. SD corrected the whole language of the manuscript and made final approval. CM gave technique supports and valuable suggestions in experiment designing. All authors contributed to the article and approved the submitted version.

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Differences in Health-Related Physical Fitness and Academic School Performance in Male Middle-School Students in Qatar: A Preliminary Study

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This study examined the differences in the level of physical fitness and academic performance among male middle-school children based on different body status categories. A total of 69 male children [age: 12.4 ± 0.7 years; body mass: 58.5 ± 7.2 kg; height: 1.62 ± 0.09 m; and body mass index (BMI): 22.4 ± 3.3 kg/m^2] participated and were divided into BMI age-adjusted groups (i.e., lowest, middle, and highest BMI). Height, mass, BMI, stork test of static balance, 10 and 15 m sprint as an indicator for speed, hand-grip strength test, agility T-half test, medicine ball throw (MBT), and the Yo-Yo Intermittent Recovery Test level 1 (Yo-Yo IR1) were assessed. School records were retrieved for grade point averages (GPA) of mathematics, science, and Arabic. We found significant group differences regarding anthropometric (height: $\eta_p^2 = 0.24$, mass: $\eta_p^2 = 0.33$, and BMI: $\eta_p^2 = 0.66$), physical (sprint 10 m: $\eta_p^2 = 0.26$), and academic (mathematics: $\eta_p^2 = 0.19$ and science: $\eta_p^2 = 0.15$) performance parameters. The largest difference ($p < 0.001$) was observed between the lowest and highest group for the 10 m sprint. All pairwise differences were between the lowest and highest BMI group or the lowest and middle BMI group. No relevant ($r > 0.5$) correlation between parameters of different dimensions (e.g., anthropometric vs. physical performance parameters) was found. In conclusion, the highest BMI group exhibited similar physical and academic performances than the lowest group. Thus, these data emphasize the importance and appropriateness to engage young Qatari schoolchildren in physical activity as it associates with superior academic performance.

Keywords: anthropometrics, GPA, schoolchildren, performance diagnostic, interactions

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INTRODUCTION

A worldwide epidemiological transition has occurred in the past 20 years, involving a shift from communicable diseases to non-communicable diseases (NCDs), such as obesity and type II diabetes mellitus (Popkin and Doak, 1998; GBD 2015 Risk Factors Collaborators, 2016). In this context, the WHO reported that since 1975, obesity has nearly tripled worldwide (NCD Risk Factor Collaboration (NCD-RisC)., 2017). Being overweight and obese evaluated using body fat is associated with excessive adipose tissue. In contrast, athletes who are extremely muscular show usually a normal or lower body fat but a higher body mass index (BMI) level than average (Longo et al., 2019). Excessive adipose tissue is implicated in several pathologies (Malecka-Tendera and Mazur, 2006; Hermassi et al., 2021a). Concerningly, the obesity epidemic has spread from almost exclusively adult obesity to a greater prevalence of childhood and adolescent obesity in recent decades (Hales et al., 2015).

Physical activity (PA) and exercise improve cardiorespiratory and musculoskeletal fitness, which are associated with increased academic achievement in children and adolescents (Ruiz et al., 2010; Raine et al., 2013; Rauner et al., 2013; El-Sayes et al., 2019; Padulo et al., 2019, p. 13). Specifically, physical fitness (i.e., aerobic fitness, muscular strength, and speed agility) is considered as a powerful, robust measure of health in children and adolescents (Raghuveer et al., 2020). Previous literature is aerobic fitness-centric in relation to academic achievement, concluding higher aerobic fitness is associated with a superior academic achievement. The role of aerobic fitness over muscular strength and speed on driving associations with academic achievement in overweight/obese children is well-described (Cadenas-Sanchez et al., 2020). However, components, such as muscular strength or speed, are less investigated, and there have been calls for further research in this area (Kao et al., 2017).

Previously considered a "disease of affluence" [although this paradigm has attracted some criticism (Ezzati et al., 2005)], obesity now affects those of low-income and middle-income countries and, consequently, displays an inverted U-shaped curve in terms of normalized income and BMI (Ezzati et al., 2005; Sahoo et al., 2015). Socioeconomic status (SES) can thus be considered a covariate; however, cultural experiences of specific countries should also be considered (Dinsa et al., 2012).

Several studies have suggested a positive association between markers of physical health and academic achievement in schoolchildren (Novello et al., 1992; Ruff et al., 2019). Moreover, a systematic review noted that academic performance was improved by some health programs embedded within schools (Murray et al., 2007). Relationships between body mass and brain function (particularly, cognitive function) have been demonstrated in several reviews (Reinert et al., 2013; Martin et al., 2018; Barbosa et al., 2020). Childhood overweightness impacts self-esteem, impairing cognitive and social development (Tremblay et al., 2000; Datar et al., 2004; Hesketh et al., 2004). In addition to evident associations, a systematic review and meta-analysis of 20 studies found that overweight and obese individuals who underwent body mass loss improved their performance across various cognitive domains (Veronese et al., 2017).

The overweight and obesity prevalence among schoolchildren in Qatar is greater (Al-Thani et al., 2018) than the global prevalence of obesity and overweightness (18%) reported by the WHO in 2016. In fact, overweightness and obesity prevalence was 45 and 40% among male and female children and 46 and 41% among Qatari and non-qatari school students, respectively (Al-Thani et al., 2018). Odds of obesity and overweight status were significantly higher among 10–14 and 15–19 years age groups than 5- to 9-year-olds. By sex, male subjects had 1.5 times greater odds of being obese than female subjects, and Qatari nationals had 1.4 times greater odds of obesity than non-qataris (Al-Thani et al., 2018). Due to an often-sedentary lifestyle, the number of overweight adolescents in Qatar is increasing, while PA levels and motor skills are declining.

The association between BMI and academic performance has been reported in several cultures and geographical locations. However, recent systematic reviews found that the relationship between BMI and academic achievement was stronger in American and European samples than in Asian samples, including the Gulf region (Martin et al., 2014). For example, a review of nine studies performed in the United States, Western Europe, South America, and Asia suggested a consistent and significant association (Taras and Potts-Datema, 2005). Similarly, another review showed positive associations between parameters of health (e.g., school-based physical activities) and academic outcomes/performance (Trudeau and Shephard, 2008). Conversely, a systematic review from Santana et al. (2017) reported that in 34 studies, less than half demonstrated an association between obesity and academic performance when controlling for covariates, such as SES and parental education.

Evidence for improved cognitive function as a result of physical health is relatively strong (Keeley and Fox, 2009; Donnelly et al., 2013; Mandolesi et al., 2018). This supposition has led researchers and policymakers to consider the importance of appropriate levels of physical health (including limiting adiposity) for academic performance in children. This is important, as academic performance is a predictor of lifelong health and quality of life across various cultures (Schoenbaum and Waidmann, 1997). Clear mechanistic evidence exists through which physical health leads to improved cognitive health [e.g., cerebral blood flow, brain-derived neurotrophic factor (BDNF), and reduced neurodegeneration, for a detailed review see (Khan and Hillman, 2014)]. However, mechanisms by which academic performance improves lifelong health and quality of life (i.e., the reverse causal relationship) are currently not well-understood. It is widely considered, however, that education, health, and social outcomes are closely interdependent (Kolbe, 2002).

Recent research has begun to establish an association between physical fitness, academic skills, and cognitive variables, demonstrating that PA is not merely coincidentally related to cognitive function (Donnelly et al., 2013; Fernandes et al., 2018; Cadenas-Sanchez et al., 2020; Gil-Espinosa et al., 2020). Aerobic exercise increases levels of neurotrophic factors and brain neuroplasticity, so physical fitness and PA are consequently associated with neurodevelopment and cognitive development (Berchicci et al., 2015). As such, improvements in cognition are seen following aerobic exercise training (Stillman et al., 2016) resultant from signaling-mediated molecular and cellular events resulting in improved cognition (Stillman et al., 2016). Furthermore, increases in gray matter volume and neural activity are apparent (Stillman et al., 2016). Several studies have consistently shown a positive association between fitness level and motor skill acquisition (Etnier and Landers, 1998; Kelsey et al., 2014; Wang et al., 2016). Although it has not been studied directly, improvements in motor performance are potentially mediated by the same mechanisms mediating cognitive improvements.

The negative effects of obesity on academic performance have been demonstrated by some (Esmaeilzadeh and Ebadollahzadeh, 2012; Esmaeilzadeh and Kalantari, 2013; Esteban-Cornejo et al., 2014; Hermassi et al., 2021b) but not all (Santana et al., 2017). However, the interdependence of body mass, physical fitness, and body composition on academic performance in schoolchildren has been examined with academic success associated with higher fitness levels (Datar and Sturm, 2006; Torrijos-Niño et al., 2014).

This cross-sectional study investigated school performance (e.g., Arabic, mathematics, and science) and physical fitness of normal, overweight, and obese middle-school children in Qatar. The primary aim was to identify physical fitness and academic attainment in school students stratified based on BMI-determined obesity. A secondary aim was to examine interactions between physical fitness, BMI, and academic attainment. We hypothesized *a priori* that differences in physical fitness-related health and academic school achievement would be apparent between obese and non-obese school students. In addition, we hypothesized an association between fitness and academic performance would be present.

MATERIALS AND METHODS

Participants

This cross-sectional study followed the guidelines and the Declaration of Helsinki, and the protocol was approved by the university's institutional review board (QU-IRB 1542-FBA/21) and the Ministry of Education and Higher Education Qatar (REF: 18/2021). Independent from the generally accepted criteria for obesity and overweight and population levels, participants were divided into three groups depending on BMI age-adjusted values (Harrington et al., 2013; Hermassi et al., 2021a), namely, lowest ($n = 21$; BMI: 18.0–20.9 kg/m^2), middle ($n = 23$; BMI: 21.0–22.9 kg/m^2), and highest ($n = 25$, BMI: $>$ 23.0 kg/m^2). A total of 69 male schoolchildren (age: 12.4 $\pm$ 0.7 years of age, range: 11–14 years; body mass: 58.5 $\pm$ 7.2 kg; stature: 1.62 $\pm$ 0.09 m; and BMI: 22.4 $\pm$ 3.3 kg/m^2) were analyzed. Of them, 85% ($n = 59$) of the children aged 12 or 13 years. Only 6 (9%) and 4 (6%) were younger (i.e., 11 years) or older (i.e., 14 years). Children were recruited by convenience sampling from one school in a Doha Community (Qatar). Participants were excluded if they were: (1) diagnosed with a psychological disorder (e.g., anxiety, depression, or attention-deficit disorder) or (2) on medication (e.g., antidepressants or medication affecting the nervous system). Moreover, participants that failed to present a signed informed consent form by their legal guardians were further excluded. Study objectives were communicated to the parents, school, and the management team. Parents or legal guardians of the participants were provided with an information sheet explaining the purpose of the experiment and a consent form. Of these participants, 65% returned a signed consent form and were eligible to participate. Participants and their respective guardians and teachers were debriefed about the experimental procedure, right to withdraw from the experiment, and provided with a consent form to complete for participation in the experiment, in accordance with the Helsinki Declaration.

Procedures and Evaluations

Data collection took place between 08:00 h and 10:00 h every day in an indoor sport court with consistent environmental conditions (temperature 24.5°C $\pm$ 0.5°C and relative humidity 65% $\pm$ 5%). Participants were asked to maintain regular food and drinks habits but to abstain from drinking caffeinated products, performing vigorous PA, and eating for 24, 4, and 2 h before testing, respectively. Testing was performed in a fixed order over a period of 4 days to ensure consistent fatigue levels and learning effects between participants. The tests for this experiment were selected based on the suitability for middle-school students and to evaluate these dimensions:

1. Sprinting performance (10 and 15 m) and agility performance,
2. Medicine ball overhead throw and hand-grip strength,
3. Endurance performance (Yo-Yo IR1),
4. Static balance performance.

After a general warm-up consisting of 5 min low-intensity running, 3 $\times$ 15 m progressive accelerations and a maximal 20 m sprint, interspersed with 3 min periods of passive recovery were performed. In addition to the low-intensity running, submaximal dynamic stretches and throws were performed, consistent with our previous work. Day 1 consisted of anthropometric testing and the Yo-Yo IR1. On day 2, the stork test of static balance was performed. Day 3 consisted of sprint performance and handgrip force. On day 4, testing consisted of the agility T-half test and medicine ball throw. Test-retest reliability was assessed by repeating fitness tests from day 1 to 3 after 2 weeks of the initial testing period. The second set of test scores generated for the test-retest reliability purposes was included in final analyses. Anthropometric and Yo-Yo IR1 test assessments were performed once at the initial testing period, for players' limited time commitments and schedules.

DAY 1

Anthropometry

Anthropometric measurements incorporated body height (Holtain stadiometer, Crosswell, Crymych, Pembrokeshire, United Kingdom) and body mass (model TBF 105; Tanita Corporation of America, Inc, Arlington Heights, Illinois) measured to the nearest 0.1 cm and 0.1 kg. BMI was calculated as the ratio between body mass (kg) and body height squared (m^2).

The Yo-Yo Intermittent Recovery Test Level 1

The Yo-Yo IR1 was conducted in line with Krustrup et al. (2003). A standardized warm-up consisted of 5 min of low-intensity running. Next, 20 m shuttle runs were performed at increasing velocities until exhaustion, with 10 s intervals of active recovery (2 $\times$ 5 m of jogging) between runs. The test was terminated if it met objective criteria (with the participant twice failing to reach the front line in time) and/or subjective criteria (with the participant feeling unable to complete another shuttle at the required speed). The total distance covered was considered as the test "score."

DAY 2

Static Balance Performance

To assess static balance, we utilized the stork balance test (Miller, 2002). Participants stood with their opposite foot against the inside of the supporting knee with both hands on the hips. On the "go" signal, subjects raised the heel from the floor and held this position for as long as possible. The test was terminated when the heel of the supporting leg touched the ground, or the foot moved away from the kneecap. The test was timed using a stopwatch.

DAY 3

Sprint Tests

A 15-min warm-up with 10 min running, change of direction activities, and dynamic stretching was performed. Next, participants sprinted 15 m from a standing position 0.2 m behind the first photocell beam. The 15 and 30 m sprint times were recorded by paired photocells (Racetime 2 SF, Microgate, Italy) located 1 m above the ground at the start and finish. Three trials were separated by 6–8 min of recovery, and the fastest trial was retained for further analyses.

Handgrip Strength Test

A standard adjustable digital hand-grip dynamometer (T.K.K. 5401, Tokyo, Japan) was employed to measure grip strength of the dominant hand, with a sensitivity of 10 N. The anthropometric apparatus and hand-grip dynamometer were calibrated before use. Participants were tested 3 min after a separate warm-up and before a throwing velocity test, following the anthropometry assessment. This test was conducted with the arm extended parallel to the body. Participants were not allowed to display movements of the arm or wrist. Peak force was recorded. Players performed two repetitions of maximum intensity with 3 min break between each repetition to minimize fatigue. The final analyses included the best trial only.

DAY 4

Change of Direction (T-Half Test)

Prior to each test, a 10 min warm-up consisting of jogging, jumping, lateral displacements, and dynamic stretching was performed. Electronic timing sensors (photocells, Kit Racetime 2 SF, Microgate, Italy) were employed to record T-half tests (Sassi et al., 2009) data. The electronic timing sensors were set 0.75 m above the floor, 3 m apart, and facing each other at the starting line A. Participants started each trial with their front foot 0.2 m behind line A. Next, participants sprinted forward to cone B and touched its base with their right hand. Without crossing their feet and facing forward, participants shuffled to the left of cone C and touched the base of this cone with their left hand. Thereafter, participants shuffled right to cone D, touched its base with their right hand, then ran back to the left of the cone, and touched its base. At last, participants ran backward, returning to line A as quickly as possible. Participants had to repeat a trial if they crossed one foot in front of another, failed to touch the base of the cone, and/or failed to face forward throughout the trial. Participants repeated until they completed two successful trials; there was a 3 min break between the trials, and only the best trial was included in the final analyses.

Medicine Ball Throw

Prior to this test, participants performed a 5 min warm-up that included a 3 min run and dynamic activities. Throws were performed using rubber medicine balls with a diameter of 21.5 cm and a weight of 2 kg. Participants were debriefed about the optimal technique, determining an optimal release angle for obtaining the maximum distance (Negrete et al., 2010). The sitting participant clasped the medicine ball using both hands and pushed the ball forcefully from their chest when given a signal. The score was determined based on the place the ball landed from the sitting line's front. Each participant performed three trials with 1 min break between, and the best result was reported to 0.01 m.

Academic Performance

Academic performance was evaluated through school records. Academic performance consisted of actual grade point average (GPA) and score (0–100) as endorsed in the Qatar State in mathematics and science from the second semester of the academic year 2020–2021. The reason for only including two academic subjects was due to our interest in science-related courses. We focused on mathematics and science due to the greater association with fitness.

Statistical Analysis

The Statistical Package for the Social Sciences (SPSS) version 28.0 (IBM, Armonk, NY, USA) software was utilized to perform all analyses. Retest reliability was described using the intraclass correlation coefficient (ICC) and the coefficient of variation (CV) (Schrama et al., 2014). Previously reported guidelines helped to inform reliability (Shrout and Fleiss, 1979; Hopkins, 2000; Portney and Watkins, 2009; Hopker et al., 2010). A power calculation (nQuery Advisor 4.0; Statistical Solutions, Saugus, MA, USA) showed with $n = 7$ in each group; we would have been able to detect a mean difference of 0.4 s in 10 m sprint using a two-sided t-test with the α level of 0.05 and a pooled standard deviation (SD) of 0.3 s, with a statistical power of 0.8 (Bortz, 1999). Data were analyzed for homogeneity of variance (Levene's test), and normality (Shapiro-Wilk test). Based on the sample size of $n = 69$ and the symmetrical sample distribution ($n = 21$, $n = 23$, and $n = 25$), it was possible and legitimate to use parametric tests (Weiß, 2002), such as one-way analysis of variance (ANOVA), to examine the anthropometric and performance differences between BMI groups. Differences were considered meaningful if $p < 0.05$ and partial eta-squared (η_p^2) > 0.15 (Bortz, 1999; Richardson, 2011), to refrain from overestimating the differences. T-tests with Bonferroni correction were conducted for pairwise comparison purposes (0.05/17 or $p = 0.003$) to protect against type I error (Bortz, 1999). Pearson's product moment correlation coefficients (r) were conducted to determine relationships between anthropometric, physical performance, and academic performance variables and interpreted employing Cohen's thresholds (Cohen, 1988). Magnitudes of correlations (r) were thus interpreted as follows: $r < 0.1$; the correlation was trivial; 0.1–0.3, it was small; in the range of 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large, and 0.9–1.0, almost perfect (Cohen, 1988).

RESULTS

Intrarater Reliability

All six performance tests showed excellent relative reliability (ICC $\geq$ 0.75). ICC ranged from 0.87 (stork balance test) to 1.00 (all other tests with the omission of medicine ball throw). Apart from the stork balance test (CV = 13.9%), all variables had excellent absolute reliability, with CV < 5% (**Table 1**).

Normal Distribution and Variance Homogeneity

Only two variables (i.e., sprint 15 m: $p = 0.285$; medicine ball throw: $p = 0.059$) were normally distributed. Only the parameters, such as 10 m sprint ($p = 0.001$), Yo-Yo IR1 ($p = 0.001$), and science ($p = 0.007$), were heterogeneous in variance. Otherwise, all p-values were >0.110.

Age and Anthropometric Data

All three groups were not different concerning age ($\eta_p^2 = 0.03$) but showed differences regarding anthropometric parameters (**Table 2**).

The largest difference was observed for the parameter BMI (${\eta_p}^2 = 0.69$). The BMI of the lowest group (19.1 ± 1.5 kg/m²) was markedly lower than for the middle group (25.5 ± 2.2 kg/m²) and the highest group (25.6 ± 2.3 kg/m²). Differences in body height (${\eta_p}^2 = 0.30$) and body mass (${\eta_p}^2 = 0.35$) were of a smaller magnitude.

Physical Performance Academic Performance Data

Regarding physical performance and academic performance parameters, we found three significant group differences (i.e., 10 m sprint, mathematics, and science) (**Table 3**). The largest difference was calculated for 10 m sprint (${\eta_p}^2 = 0.26$).

Significant effects were observed only between the middle and highest groups (i.e., medicine ball throw, sprint 10 m, mathematics, and science) or between lowest and middle participants (i.e., sprint 10 m, Arabic, mathematics, and science). The largest difference ($p < 0.001$) was observed between overweight (2.25 ± 0.22 s) and obese (2.68 ± 0.34 s) subjects for the 10 m sprint. The largest number of pairwise differences (5) was calculated for academic performance parameters. The differences ranged from $p = 0.002$ (mathematics: middle vs. highest) to $p = 0.035$ (science: middle vs. highest).

In contrast to the academic performance (all maxima in the middle group), the performance maxima concerning physical performance are distributed among the three groups (**Table 3**). Most of the maxima (5) were found for the middle group (parameters: Yo-Yo IR1, sprint 10 m, sprint 15 m, storck balance test, and agility T-half). The subjects of the highest group showed the highest performance for the medicine ball throw (5.16 ± 0.61 m) and handgrip force (30.1 ± 11.9 N).

Relationships Between Parameters

We did not find any relevant ($r > 0.5$) correlation between parameters of different dimensions (e.g., academic vs. physical performance; anthropometric vs. physical performance). The parameters medicine ball throw and handgrip force showed the highest interaction ($r = 0.470$) with each other. Regarding the differentiating parameter BMI, all product moment correlations were below $r = 0.303$ (95% CI: 0.071–0.504, medicine ball throw).

DISCUSSION

This study explored physical fitness and academic attainment differences in school students stratified by BMI. An initial outcome was that participants with the lowest BMI did not exhibit the greatest performance in any parameter. The middle group, however, displayed the greatest physical performance level in 5 of 7 parameters (71%), but differences only reached the $p < 0.05$ level for the 10 m sprint. Regarding academic performance, the middle-BMI group exhibited the greatest performance in all three parameters, particularly mathematics and science. There were no relevant relationships between both dimensions (i.e., physical vs. academic performance), and so we surmised no transfer effects were evident. In this context should be noted that a slightly increased BMI is an indication for acceleration in the sense of sexual maturity (i.e., biological maturation), with differences in anthropometrics due to various patterns in the growth spurt (Tanner, 1989). The growth spurt is generally preceded by a quick increase in body fatness, a phenomenon known as the "prepubertal fat wave" (Tanner, 1989). However, a highly significant variability in timing biological maturation can be reported between individuals of the same sex, resulting in early and late maturers (Tanner, 1989; Armstrong and McManus, 2011), which may imply a substantial difference in body mass and fat associated with sprint performance. As information about the biology maturation of the school students is missing, we must consider that some results (e.g., handgrip force and medicine ball throw) can be more a function of biology maturation than body composition alone. This could partly explain why the lowest and highest BMI groups performed worse in several tests. It could be that the highest and lowest BMI group were on different maturation trajectories (i.e., early or late maturers), and each physical fitness attribute peaks at different stages of maturation according to the peak height velocity (Towlson et al., 2021).

Physical Performance Data

During school physical education classes, short sprints, changes of direction, accelerations, and decelerations are fundamental abilities developed and utilized (Hermassi et al., 2021c). It is well-known that obesity is negatively associated with physical fitness. However, it has been reported that BMI is a poor surrogate for obesity (which is purportedly a disease of excessive

TABLE 1 | Physical fitness tests obtained from two sessions (time interval: $n = 23$).

Test	Session one mean ± SD	Session two mean ± SD	ICC (95% CI)	CV (%) (95% CI)
10 m sprint (s)	2.51 ± 0.36	2.53 ± 0.37	**1.00** (0.99–1.00)	**0.6** (0.4–0.9)
15 m sprint (s)	3.15 ± 0.35	3.18 ± 0.35	**1.00** (0.98–1.00)	**0.7** (0.5–1.1)
Agility T-half test (s)	8.40 ± 1.67	8.53 ± 1.70	**1.00** (0.98–1.00)	**1.6** (1.2–2.5)
Medicine ball throw (m)	4.95 ± 0.80	4.80 ± 0.80	**0.97** (0.90–0.99)	**3.7** (2.8–5.8)
Stork balance test (s)	46.1 ± 22.2	42.6 ± 15.0	**0.87** (0.70–0.95)	**13.9** (10.9–23.6)
Handgrip force (N)	29.6 ± 12.3	28.2 ± 12.3	**1.00** (0.78–1.00)	**2.0** (1.5–3.1)

Descriptive statistics [mean ± standard deviation (SD)] and intrarater reliability are presented for each test. Intraclass correlation coefficient (ICC) ≥ 0.75 and coefficient of variation (CV) ≤ 10% marked in bold.

TABLE 2 | Comparison of age and anthropometric characteristics between three groups.

	Lowest group ($n = 21$)	Middle group ($n = 23$)	Highest group ($n = 25$)	ANOVA		Significant partial effects
				p	η_p^2	***p***
Age (years)	12.6 ± 0.81	12.3 ± 0.70	12.3 ± 0.68	0.344	0.03	–
Anthropometric parameters						
Body height (m)	1.68 ± 0.06	1.61 ± 0.09	1.58 ± 0.08	**<0.001**	**0.24**	Lowest vs. middle: 0.012 Middle vs. highest: <0.001
Body mass (kg)	53.7 ± 5.17	57.3 ± 6.20	63.6 ± 6.47	**<0.001**	**0.33**	Highest vs. middle: 0.002 Highest vs. lowest: <0.001
BMI (kg/m²)	19.1 ± 1.46	22.1 ± 1.90	25.6 ± 2.28	**<0.001**	**0.66**	Lowest vs. middle: <0.001 Lowest vs. highest: <0.001 Middle vs. highest: <0.001

Values are given as mean ± SD. Significant effects (main effect criteria: $p < 0.05$ and $\eta_p^2 \geq 0.15$) marked in bold.

TABLE 3 | Comparison of physical performance and academic characteristics between three groups (differentiation criterion: percent body fat).

	Lowest group ($n = 21$)	Middle group ($n = 23$)	Highest group ($n = 25$)	ANOVA		Significant partial effects
				p	η_p^2	***p***
Physical performance parameters						
Yo-Yo IR 1 (m)	480 ± 185	628 ± 281	532 ± 184	0.086	0.07	–
Medicine ball throw (m)	4.96 ± 0.68	4.64 ± 0.67	5.16 ± 0.61	0.027	0.10	Middle vs. highest: 0.023
Agility T-half (s)	8.58 ± 1.07	8.03 ± 1.05	8.66 ± 1.55	0.187	0.05	–
Stork balance test (s)	44.5 ± 22.7	51.6 ± 25.8	43.5 ± 23.0	0.456	0.02	–
Handgrip force (N)	27.4 ± 9.56	26.0 ± 8.28	30.1 ± 11.9	0.357	0.03	–
Sprint 10 m (s)	2.53 ± 0.34	2.25 ± 0.22	2.68 ± 0.34	**<0.001**	**0.26**	Lowest vs. middle: 0.012 Middle vs. highest: <0.001
Sprint 15 m (s)	3.24 ± 0.38	3.11 ± 0.34	3.25 ± 0.29	0.287	0.04	–
Academic performance parameters						
Arabic	77.0 ± 9.31	84.4 ± 9.02	79.7 ± 9.41	0.029	0.10	Lowest vs. middle: 0.028
Mathematics	81.0 ± 8.26	87.3 ± 4.73	80.8 ± 5.79	**0.001**	**0.19**	Lowest vs. middle: 0.005 Middle vs. highest: 0.002
Science	77.6 ± 10.2	85.0 ± 5.81	79.2 ± 6.86	**0.005**	**0.15**	Lowest vs. middle: 0.007 Middle vs. highest: 0.035

Values are given as mean ± SD. Significant effects (main effect criteria: $p < 0.05$ and $\eta_p^2 \geq 0.15$) marked in bold.

fatness, although not if measured by BMI) in adolescents (Shang et al., 2010; Kruschitz et al., 2013; Hermassi et al., 2021d). We found significant group differences regarding 10 m sprint performance, and the largest difference was observed between the middle and highest BMI group ($p < 0.001$). This has implications for school student's success as they commonly sprint for ∼10–30 m in game-defining epochs during physical education classes.

Most of the maximal values (5) were exhibited by the middle BMI group (parameters: Yo-Yo IR1, 10 m sprint, 15 m sprint, stock balance test, and agility T-half). The highest BMI group exhibited the greatest performance for the medicine ball throw and handgrip force. This is relatively unsurprising, as the highest BMI group would exhibit the greatest absolute volume of lean mass, which is a key determinant of muscle force (Bandini et al., 1990; Esmaeilzadeh and Ebadollahzadeh, 2012; Esmaeilzadeh and Kalantari, 2013). In this context, Esmaeilzadeh and Kalantari (2013) controlled for body fat mass and observed that in some physical fitness tests (such as sit and reach, standing long jump, and run speed tests), overweightness was associated with improved performance compared with underweight counterparts, indicating fat mass as a limiting factor for test performance. Results of Esmaeilzadeh and Kalantari (2013) indicated that underweight adolescents possessed the highest cardiorespiratory fitness among the weight statuses, but being underweight was related to poorer performance of some physical fitness tests (primarily related to muscle strength). It is possible that their poorer performance resulted from lower fat-free mass compared with that in normal and overweight counterparts, which was supported by these results when controlling for fat-free mass.

Academic Performance

We found relevant group differences regarding the academic performance parameters mathematics ($\eta_p{}^2 = 0.19$) and science ($\eta_p{}^2 = 0.15$). For Arabic language ($\eta_p{}^2 = 0.10$), the group difference did not reach the level of relevance ($p < 0.05$ and $\eta_p{}^2 \geq 0.15$). Furthermore, the largest number of pairwise differences (5) was calculated for academic performance parameters. The differences ranged from $p = 0.002$ (mathematics: middle vs. highest) to $p = 0.035$ (science: middle vs. highest). These data corroborate previous cross-sectional studies that observed fitter students exhibited greater academic attainment (Davis and Cooper, 2011; Hraste et al., 2018). To date, some investigations reported an association between body composition (not part of our study) and academic performance (Sabia, 2007; Sigfúsdóttir et al., 2007; Shore et al., 2008). For example, our previous work demonstrated that a nonobese adolescent group had a higher mean academic performance than the obese group (Hermassi et al., 2021d). The observed difference between groups was markedly greater for mathematics ($\eta_p{}^2 = 0.367$) than for science ($\eta_p{}^2 = 0.195$).

It is well-known that adiposity has negative effects on cognition, learning, and memory (Li et al., 2008; Yu et al., 2009). However, weight-related bias or discrimination may further influence self-esteem and behavioral problems, mediating or moderating obese children's academic performance (Fowler-Brown et al., 2010; Griffiths et al., 2010). Uncertainty remains whether excess adiposity itself affects academic performance or if this effect is mediated by other factors observed in individuals with obesity. A systematic review noted a relationship between obesity, cognitive function, and academic attainment in adolescents (Kamijo et al., 2012). In this study, the highest group had poorer academic achievement, suggesting that being obese during adolescence has profound academic consequences. Paradoxically, other studies have observed no effect of obesity on academic achievement in children (Kwak et al., 2009; Van Dusen et al., 2011). Reasons for result divergence remain unclear, but differences in methods for quantifying obesity (i.e., body fat or BMI), participant characteristics, growth stages, or analysis procedures for academic attainment (Kwak et al., 2009; Ruiz et al., 2010) may explicate some ambiguity. Furthermore, if previous studies are interpreting results solely on the alpha level and using an arbitrary threshold of $p < 0.05$ with small sample sizes, it is possible these studies fell afoul of type II error. In this context, based on Cohen's thresholds (Cohen, 1988), the present magnitudes were classified as "small," and thus the highest BMI group may only experience a small negative effect on academic performance, which may be missed by underpowered research studies. If studies use different analysis procedures for academic attainment, this may also explain differences in results as obesity is not associated with lower test scores (Datar and Sturm, 2006) but does associate with lower GPA (Li et al., 2008). This is puzzling, as one may assume lower test scores would result in lower GPA; however, it does emphasize (a) the importance of specifying how academic performance was quantified and (b) the multifactorial nature of how obesity associates with GPA, as it is clearly not simply a case of poorer test performance.

Limitations

Limitations of this investigation include not assessing sexual maturity (i.e., biological maturation) as growth spurt timing differences could influence BMI and relationships between BMI and physical fitness. A further limitation is that since the study was cross-sectional, it is difficult to attribute causality. For a wider interpretation and scope, it is necessary to involve female subjects. In addition, the parameter body fat should be assessed to distinguish between fat and lean mass. Finally, we did not use the generally accepted criteria for obesity and overweight. Instead of this, we divided the sample into tertiles based on BMI.

CONCLUSION

This study determined physical fitness and academic achievement in BMI-stratified obese and non-obese adolescents. Surprisingly, the middle BMI group (not the lowest group) displayed the highest physical and academic performance levels in most parameters. These data suggest that an excess body mass may have an impact on academic attainment in children. Conversely, students with higher academic performance may be more able to maintain a healthy body mass. Future studies utilizing the gold standard for body composition measures or lean mass measures (e.g., hydrostatic weighing or D_3-creatine) and additional parameters (e.g., sexual maturation status and SES) are required to confirm our preliminary observations.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Qatar University's institutional review board (QU-IRB 1542-FBA/21) and the Ministry of Education and Higher Education Qatar (REF: 18/2021). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

SH and RS conceptualized the study and validated the manuscript. SH contributed to methodology, project administration, funding acquisition, visualization, formal analysis, investigation, resources, software, and wrote the original draft preparation. RS contributed to supervision and data curation. SH, NS-H, and LH contributed to writing, reviewing, and editing. All authors have read and agreed to the published version of the manuscript.

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Contextual Factors and Motor Skills in Indigenous Amazon Forest and Urban Indigenous Children

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This study investigated the contextual factors, motor performance, and body mass index across indigenous land children, indigenous urban children, and non-indigenous urban children. A number of 153 children, both sexes (71 girls, 46.4%), from 8 to 10 years were assessed. The Test of Motor Gross Development-3 was utilized. Indigenous land children showed higher motor performance ($\eta^2_\rho = 0.37$ and $\eta^2_\rho = 0.19$ locomotor and object control, respectively) than indigenous urban children ($p < 0.03$) and non-indigenous urban children ($p < 0.01$); Indigenous urban children showed higher motor performance than non-indigenous urban children ($p < 0.01$). Body mass index was similar across groups ($\eta^2_\rho = 0{,}02$; $p = 0.15$). Motor performance of indigenous land children was explained by the contextual factors that lead to a more active lifestyle, unsupervised free time, and play outside. In urban areas, behavior was similar, and although indigenous urban children kept some play tradition, it was not strong enough to be a protective factor for the motor performance.

Keywords: child development, motor skills, ethnical groups, children, indigenous peoples

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INTRODUCTION

Several studies have reported lower motor performance (MP) and a high prevalence of overweight and obesity among children across several countries [(1–7). This scenario may be explained, in part, by the contextual factors (3, 8–12). The lack of opportunities and parental support for motor practices and the inadequate physical spaces inside and outside the home negatively affect children's behavior toward sports and exercise, bodyweight status, and MP (13–16). Other vital factors related to lower MP included higher time spent in sedentary tasks and the lower participation in moderate to vigorous physical activities and restrict opportunities the motor practices experienced in the community in which they live (12, 17–22). Although a substantial body of research focuses on the relationship of several factors and MP in children, contextual factors are still underinvestigated. Besides, most of the research has been conducted in Western, Educated, Industrialized, Rich, and Democratic (WEIRD) countries. Less is known about developing countries and even less about diversity groups, such as indigenous children living in those countries.

In Brazil, 12.2% of the national territory is indigenous land (i.e., lands that indigenous people have the original right and whose demarcation was regulated by the Brazilian Federal Constitution); its concentration is highest in the legal Amazonas (54%) (23). Migration from the indigenous land to nearby cities is a current factor, considering the Sateré-Mawé people; about 1,000 live outside the indigenous land in cities and rural areas near the Andirá-Marau indigenous land (24). The determinants of the migration are related to the increasing contacts with the non-indigenous population, growing access to information, searching for work and better education, and the relative facility to move to cities that are getting close to the indigenous lands. These factors had led to the changes in the traditional indigenous way of living, leading to indigenous communities' economic, social, and cultural transformations (24). Indigenous children, across 23 countries, had poor health outcomes and were disadvantaged regarding access to health services, the elevated prevalence of inadequate height-for-age, and anemia [(25–31)]. Less is known about other health parameters and behavioral factors. Up to date, we have not found studies that investigated how the contextual factors may affect the MP in indigenous children.

For example, in the Brazilian Amazonas indigenous land villages, indigenous children tend to spend most of their free time playing outdoors without supervision and enjoying greater mobility and autonomy to explore the village houses and the neighborhoods (32–34). Boys and girls also participated in several activities that imitated the adult world. Boys endeavor to hunt small animals with toy weapons on the outskirts of the village and expeditions in the woods to find fruits. Girls had the autonomy to get together to play with dolls, model clay, and paint wood and clay crafts (35). So, it is plausible to consider that these contextual factors promote or reinforce appropriate weight status and motor development by participating in daily activities, promoting a more active lifestyle, enabling higher levels of physical activity (PA), physical fitness, and motor coordination.

Besides, the evidence of the relationship between an active lifestyle and higher PA levels, physical fitness, and motor coordination is reported in children (22, 36–38); however, these findings are not examined among indigenous children living in villages in the indigenous land and urban areas. Many indigenous families have left the indigenous land and lived in urban areas, the so-called urban indigenous (24); how this new kind of life changes their lifestyle and may affect health and motor components is unknown. The migration of indigenous people to urbanized areas is increasing due to the cities' progressive proximity to the indigenous land, the lack of health support and schools in the village in the indigenous land, and conflict with the leaders or community members (24, 39). The migration of indigenous groups to the cities may change their behavior due to the contextual factors experienced in the urbanized environment, reflecting changes in their lifestyle (24). For example, the free time and use of spaces previously allowed to indigenous children living in the indigenous land may not be the same in the urbanized areas.

Children's MP still needs to be investigated in the light of contextual factors, within a geographic region, the diversity in motor experiences, and the importance placed on learning motor skills within different cultures (9, 19, 40–42). Therefore, this study investigates the differences in MP, body mass index (BMI), and contextual factors across three groups of children–indigenous children living in indigenous land in the forest, indigenous urban children living since infancy in the city, and non-indigenous urban children, and if BMI and contextual factors were related to MP for those children, as a secondary objective, sex differences were also examined.

METHODS

Participants

The study included 153 children, 8 to 10 years old ($M_{age} = 8.26$, $SD = 0.48$ years), and their families (parents or guardians) living in two Amazonas cities (Barreirinha and Parintins), Brazil. The inclusion criteria included: (1) being 8-to-10-year old indigenous and non-indigenous children; (2) attend to public school at the urban area or village; (3) proof of being Sateré-Mawé by presenting the registry of indigenous birth and the self-declaration of ethnicity; (4) parental declaration that children never resided in the urban space–for the indigenous children living in the village, that children lived in the city of Parintins since birth or 2 years old–for urban indigenous children, of non-indigenous heritage for non-indigenous children. In this study, no child showed motor impairments or any health issue that might interfere with their ability to perform the motor tests. This information was obtained by parental declaration.

The study was composed of three distinct groups: 43 indigenous land children (20 girls and 23 boys)–children living in the of Andirá-Marau lands of the Sateré-Mawé ethnic group in the Ponta Alegre village (Barreirinha city–state of Amazonas). The second group was composed of 46 indigenous urban children (22 girls, 24 boys) from the Sateré-Mawé ethnic group, living in an urban area of Parintins. The third group was formed by 64 non-indigenous urban children (29 girls, 35 boys) living in Parintins. The number of indigenous children living in indigenous land encompassed the entire children's population in this age group in the Ponta Alegre village; children attended the village school. In addition, indigenous and non-indigenous children residing in the city of Parintins were enrolled in public schools. This research project was approved by the University Ethics Committee and the National Research Ethics Council (protocol number 62705916.1.0000.5149). The parents provided informed consent and children verbal assent.

The Context

The study was conducted, enrolling the Sateré-Mawé people. The Sateré-Mawé people, a population approximately of 8,500, are the part of the Tapajós-Madeira culture, living in the indigenous land of the Andirá-Marau, a region in the mid-Amazon River, located in the Maués, Barreirinha, Parintins, Itaituba, and Aveiro counties, on Amazonas and Pará states border. The Andirá-Marau lands hold 91 villages, approximately 1,600 families, with 7,502 inhabitants, along the main rivers, Madeira and Tapajós, and several streams across this area (43). The Sateré-Mawé people speak Setere–a language that integrates the linguist Tupi-Guarani family and maintains their language despite the three centuries of exposure to the national society and Portuguese language (44).

Our study focused on the three groups of children: the Sateré-Mawé indigenous children living in the forest and an urban area, and the non-indigenous children from the same region.

The Sateré-Mawé indigenous children lived in the Ponta Alegre village in the Amazon Forest. The access to the village is *via* the Andirá River. The village has around 800 people and the largest migration of residents, mainly to Parintins, Barreirinha, and Manaus (45, 46). The monthly per capita income is approximately ¼ of the minimum wage in Brazil (near 57 dollars). The village has 127 wooden homes, with no running water and no electricity. The village has a diesel generator to provide electricity; however, there is hardly any fuel. When fuel is available, usually provided by visitors, the power is turned on for around 2 h daily. The water consumed is taken from the river with buckets and kept in pots. The eating habits of the families included fruits and vegetables obtained from the village plantations and the forest. Fish and hunted wild animals are also part of the diet. Only one adult is responsible for hunting for the whole village, with one apprentice, but other adults cooperate with hunting according to the animal size if necessary.

The village has a school–conducted strictly by indigenous teachers, an indigenous health basic unit, and a soccer field, where adults play soccer in the evenings. The families' routine starts around 6'o clock in the morning. Fathers go farming or fishing. The mothers prepare their children for school–the school has only the morning shift–and deal with the housework (i.e., go to the river to wash clothes, clean the house, and prepare lunch). Children came back from school at noon, had lunch with the family, and then spent the rest of the day playing around the village. At nightfall, the children return home for dinner and bedtime. At the age of 5, the children go to the school in the village; Portuguese lessons were provided. All children are bilingual; they speak Sateré and Portuguese.

Our study also focused on the indigenous children born in the village who left the village, with their families, as toddlers (2 years old) and grew up in Parintins. Parintins has the second-highest density in the state of Amazonas; the city is also located in the lower Amazon region, with a population estimated at 111,575 inhabitants and a family's per capita income near 1/2 of Brazilian minimum wage (around 100 dollars) (47, 48). The city has a median human development index (HDI 0.658) (49). The indigenous population of the Sateré-Mawé ethnic group living in Parintins (AM), a total of 512 people, reside in 86 houses with a monthly per capita income of around ¼ of Brazilian minimum wage. There are no specific urban indigenous neighborhoods in the city of Parintins. However, close to the sanitary indigenous special district of Parintins, on the banks of the Amazon River, there lived approximately 20 families; the rest of the urban indigenous families lived in the city's neighborhoods, mainly in the poorest ones.

Our study also focused on non-indigenous children. The non-indigenous children were born and raised in Parintins; they lived with their families in the poorest neighborhoods and attended the same public schools that the urban indigenous children attend. **Figure 1** shows the Brazilian map with the current indigenous lands, the Andirá-Marau land, and the geographic location of the Ponta Alegre village and the city of Parintins.

Measures and Assessment Procedures

Motor Performance

Motor Performance was measured with the Test of Gross Motor Development–Second Edition (TGMD-2) (50), validated in the Brazilian population (51). The TGMD-2 is a qualitative measure in which each skill is scored based on 3 to 5 criteria as present or absent; it has two subtests, locomotor skills (running, galloping, hopping, leap, horizontal jump, and sliding) and object control skills (striking a stationary ball, stationary dribbling, catching, kicking, overhand throwing, and underhand rolling). The test took ∼20 min to administer for each child. Before each skill assessment, one demonstration was presented to the child, and then, the child performed one trial of practice and two actual trials. The assessments were conducted in an adequate and safe place with approximately 20 m in length and 9 m in width, following the test protocol (50). The assessments were conducted in an adequate and safe place with approximately 20 m in length and 9 m in width, following the test protocol (50). The assessments were video-recorded; two digital cameras were used (Sony Model DCR-SR 42, frequency of 60 hertz). One camera was positioned in front and another on the side to record the participants performing the locomotor and ball skills; the camera on the side was used to obtain additional information on ball skills. The videos were independently coded by three raters, experts in motor development and with 10 years of experience in motor assessment; high inter-rater reliability (intraclass correlation coefficient–ICC locomotor skills = 0.94, 95% CI: 0.91–0.96; ICC object control skills = 0.96, 95% CI: 0.93–0, 98) and intra-rater reliability for locomotor (ICC: Rater A = 0.81, 95% CI: 0.79–0.85; Rater B = 0.87, 95% CI: 0.84–0.91; Rater C = 0.89, 95% CI: 0.87–0.93) and object control skills (Rater A = 0.92, 95% CI: 0.87–0.94; Rater B = 0.93, 95% CI: 0.89–0.96; Rater C = 0.89, 95% CI: 0.87–0.93) were observed. In this study, we used the raw scores for locomotor and object control subtests (range from 0 to 48).

Body Mass Index

Body mass index was obtained by measuring the body mass (kg) and height (cm) following the World Health Organization guidelines (52). Body mass was determined on a Plenna® digital scale, scaled in kilograms, with an accuracy of 100 g. Height was obtained using an aluminum stadiometer (Balmak EST-222) with a 1 mm scale, ranging from 0 to 240 cm; BMI categorization was obtained according to the cutoffs established by the World Health Organization (52): severe thinness ($<$ z-score -3); thinness ($>$ z score -3 and $<$ z score -2), eutrophic ($>$ z score -2 and $<$z score $+1$), overweight ($>$ z score $+1$ and $<$ z score $+2$), obesity ($>$ z score $+ 2$ and $<$ z score $+ 3$), and severe obesity ($>$ z score $+ 3$).

Contextual Factors

A questionnaire was used to assess contextual factors; parents' responses were obtained from the interviews conducted by the principal researcher. Questions are related to the child's home environment, spaces, and free activities outside school, home, streets, and other places, such as the number of adults (2 or $<$ 2) and siblings at home (2, 3-to-4, $<$ 4); free time ($>$1, 1 to 2 h, $<$

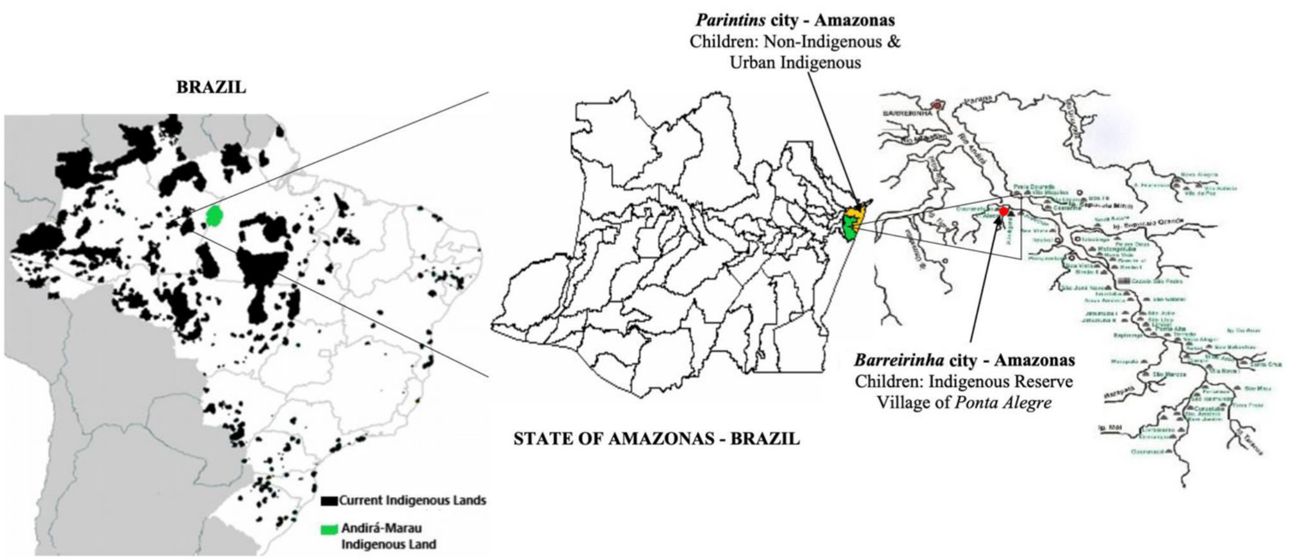

FIGURE 1 | Brazilian map and the current Indigenous Lands in the Amazon Forest, Andirá-Marau Land, the geographic location of the Ponta Alegre village, and the city of Parintins–state of Amazonas.

2 h); physical spaces to play (inside the home or out of home); sleep (> 9, 9 to 12, < 12 h), television (no TV time, > 2 or <2 h), computer (no computer time, > 2 or < 2 h) time; school commuting (non-motorized or motorized); playmates sex (same or opposite sex); and playmates age (younger, same age, older).

Procedures

The study was approved by the university and indigenous councils' ethical committee. To conduct the study in the indigenous land in the forest, the researchers contacted the Tuchaua (the Ponta Alegre village leader); the Tuchaua was responsible for authorizing the researcher's entry into the village and contacting the children's families. Then, a meeting was conducted with the families to inform the research goals, procedures, and assessment schedule. The schoolteacher, a native resident of Ponta Alegre village, supported the researchers during the meetings with the families and data collection, translating the information from Portuguese to Sateré language when necessary, facilitating the dyad with the native families. The researchers adjusted the study schedule to avoid the rain periods to collect the data in the Ponta Alegre village. They traveled by boat for 2 days and spent 5 days in the village.

We contacted the special indigenous sanitary district, a governmental healthcare agency for indigenous people, to mediate the contact with the urban indigenous residents in the city. For the non-indigenous children, the contact was initiated at the schools with the administrators. Information regarding the research goal, procedures, and schedules was provided for all families. Interviews and BMI were conducted at the residences, and the MP was conducted in the schools where children were enrolled. All parents signed the informed consent, and children verbally agreed to participate in the study.

Statistical Analysis

The measures of central tendency (mean: M), dispersion (standard deviation: SD), and confidence interval (95%CI) were used for MP (locomotor and object control) and BMI. Absolute frequencies and percentage were used for describing the children's weight status, and contextual factors. The models' assumptions–normal distribution (Shapiro–Wilk test values between 0.856 and 0.189), homogeneity of variances (Levene's test values between 4.232 and 1.223; *p*-values between 0.865 and 0.198), and the presence of significant outliers (visual inspection by boxplots, histograms, and scatterplots) were assessed. After checking the assumptions, the two-way ANOVA (group x sex) was used to compare locomotor and object control and BMI; Bonferroni's *post hoc* tests were used. The effect size was estimated using partial eta squared (η^2_ρ); values < 0.05 were adopted as a small effect, between 0.06 and 0.25 as a moderate effect, between 0.26 and 0.50 as high, and values > 0.50 as a very high effect (53, 54). Linear-by-linear association, with Bonferroni correction, were used to verify possible differences in the proportion of the categorical variables (weight status and contextual factors) among children's groups.

Univariate multiple linear regression analysis was used by the stepwise method, adopting that the last model was used to verify the associations between the BMI, contextual factors, and the MP (locomotor and object control). The models' assumptions, normal distribution, homogeneity, and independence of errors, were assessed. Normal distribution and homogeneity were assessed graphically, and the independence of errors was assessed using the Durbin–Watson test. The presence of outliers was assessed using the square distance of Mahalanobis (D^2) and, when detected, was removed (54). Multicollinearity was assessed using the variance inflation factor (VIF) test; values greater than five were adopted as an indicator of the presence of multicollinearity (54). No indication of multicollinearity was observed. All analyses were conducted using the Statistical Package for Social Science (SPSS®), version 26. For all analyses, statistical significance was set at $p < 0.05$.

RESULTS

Motor Performance, Body Mass Index, and Contextual Factor Comparisons Across Groups

Figure 2 shows the locomotor scores and **Figure 3** shows the object control scores by groups. The ANOVA showed a significant group effect for locomotor [$F_{(2,147)} = 43.43, p < 0.001, \eta^2_\rho = 0.37$] and object control [$F_{(2,147)} = 16.92, p < 0.001; \eta^2_\rho = 0.19$) skills. Indigenous land children showed higher motor scores than indigenous urban children (locomotor $p = 0.034$; object control $p = 0.019$) and non-indigenous urban children (locomotor $p < 0.001$; object control $p < 0.001$). Indigenous urban children showed higher scores than non-indigenous urban children (locomotor $p < 0.001$; object control $p = 0.015$). Significant sex effect was observed for locomotor [$F_{(1,147)} = 4.44$, $p = 0.037$; $\eta^2_\rho = 0.03$] and object control [$F_{(1,147)} = 18.87$, $p < 0.001$; $\eta^2_\rho = 0.11$] skills; boys demonstrated higher scores than girls.

Table 1 shows the BMI and contextual factor frequencies across the three groups. The ANOVA showed non-significant group [$F_{(2,147)} = 1.88$; $p = 0.157$; $\eta^2_\rho = 0{,}02$] and sex [$F_{(1,147)} = 0.33$; $p = 0.569$; $\eta^2_\rho = 0.00$] effects for BMI. The linear-by-linear association test indicated that BMI categorization did not significantly associate with groups ($\chi^2 = 0.77$, $p = 0.380$; Cramer's V = 0.18) and sex ($\chi^2 = 0.04$, $p = 0.845$; Cramer's V = 0.04).

Regarding the contextual factors, the linear-by-linear test showed a significantly higher proportion of the non-indigenous urban children living with more than two adults at home [χ^2 (1) = 5.66, $p = 0.017$, Cramer's V = 0.23], mainly the grandparents and uncles and aunts. In contrast, indigenous land children and indigenous urban children lived with at the maximum of two adults at home–their parents.

The analysis also showed a significantly higher proportion of the non-indigenous urban children that had < 2 h of free time [χ^2 (1) = 7.23, $p = 0.007$, Cramer's V = 0.36] and that the most prevalent space of playing was the inside home [χ^2 (1) = 29.74, $p < 0.001$, Cramer's V = 0.53] compared to the indigenous children from the forest and the urban area. The activities in the free time were unsupervised for the three groups and involved similar games for the urban area. Indigenous urban children played kite, soccer, and run-and-catch games, and non-indigenous urban children played kite, soccer, and dodgeball, whereas indigenous land children usually played run-and-catch, balance games on lines, and games in the river. Although there was a soccer field in the Ponta Alegre village, the indigenous land children played very little soccer; the field and the ball were reserved for adult men. The inside home activities were similar across the three groups, the girls helped the mother with the home chores and the care of siblings, and the boys helped the fathers chop wood and clean fish.

The analysis also showed a significantly higher proportion of the non-indigenous urban children, compared to the indigenous urban children, with screen time–watching television [χ^2 (1) = 4,685, $p = 0.030$, Cramer's V = 0.27] and using the computer [χ^2 (1) = 22.01, $p < 0.001$, Cramer's V = 0.49], more than 2 h daily each device; indigenous land children had no screen time.

Relationship Between Body Mass Index, Contextual Factors, and Motor Performance

Table 2 shows the linear regression results for BMI and contextual factors significantly associated with locomotor and object control performance across groups. For indigenous land children, the regression showed that play freely for more than 2 h daily positively explained 40% of the variance in locomotor scores [$F_{(1,42)} = 29.06$, $p < 0.001$, $r^2_a = 0.40$]; for object control scores, 28% of the variance was explained by play freely more than 2 h daily and by playing outside [$F_{(2,42)} = 9.04$, $p < 0.001$, $r^2_a = 0.28$].

For the indigenous urban children, the regression analysis showed that living with more than two adults at home and sleeping between 9 to 12 h negatively explained 23% of the variance of the locomotor scores [$F_{(2,45)} = 7.92$, $p < 0.001$, $r^2_a = 0.23$]. For indigenous urban children, living with more than two adults at home and spending more than 2 h watching television negatively explained 30% of the variance in object control scores [$F_{(2,45)} = 10.67$, $p < 0.001$, $r^2_a = 0.30$].

For non-indigenous urban children, the results showed that living with three or more than four siblings and spending more than 2 h on the computer negatively explained 30% of the variance in locomotor scores [$F_{(3,63)} = 10.21$, $p < 0.001$, $r^2_a = 0.30$] and stay on the computer for more than 2 h negatively explained 13% of the variance in object control scores [$F_{(1,63)} = 10.59$, $p = 0.002$, $r^2_a = 0.13$].

DISCUSSION

This cultural study investigates the differences in MP, BMI, and contextual factors across three groups of children–indigenous children living in the Amazon Forest in the indigenous land, indigenous urban children living since infancy in the city, and non-indigenous urban children, and if BMI and contextual factors were related to MP for those children, as a secondary objective, sex differences were also examined.

Our main findings were the higher MP for the indigenous children living in the forest and that contextual factors were associated with MP. The children living in the Amazon Forest in the Ponta Alegre village showed higher MP than urban indigenous and non-indigenous children. The higher MP in locomotor and object control showed by indigenous land children was related to their way of living–they had daily unsupervised free time (more than 2 h) and spent this time playing outside the home. They also had no screen time daily as they have no television or computer.

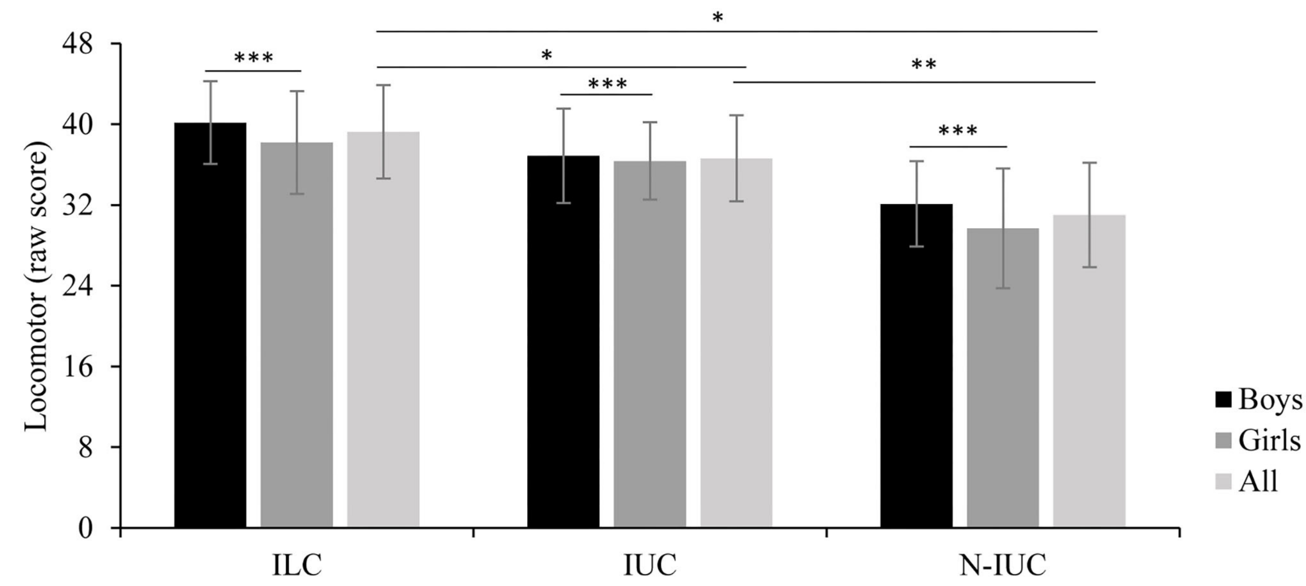

FIGURE 2 | Locomotor scores by group; ILC, Indigenous Land Children; IUC, Indigenous Urban Children; N-IUC, non-indigenous urban children. Significant differences: *ILC > IUC ($p < 0.001$) and N-IUC ($p < 0.001$), **IUC > N-IUC ($p < 0.015$), ***All boys > All girls ($p < 0.001$).

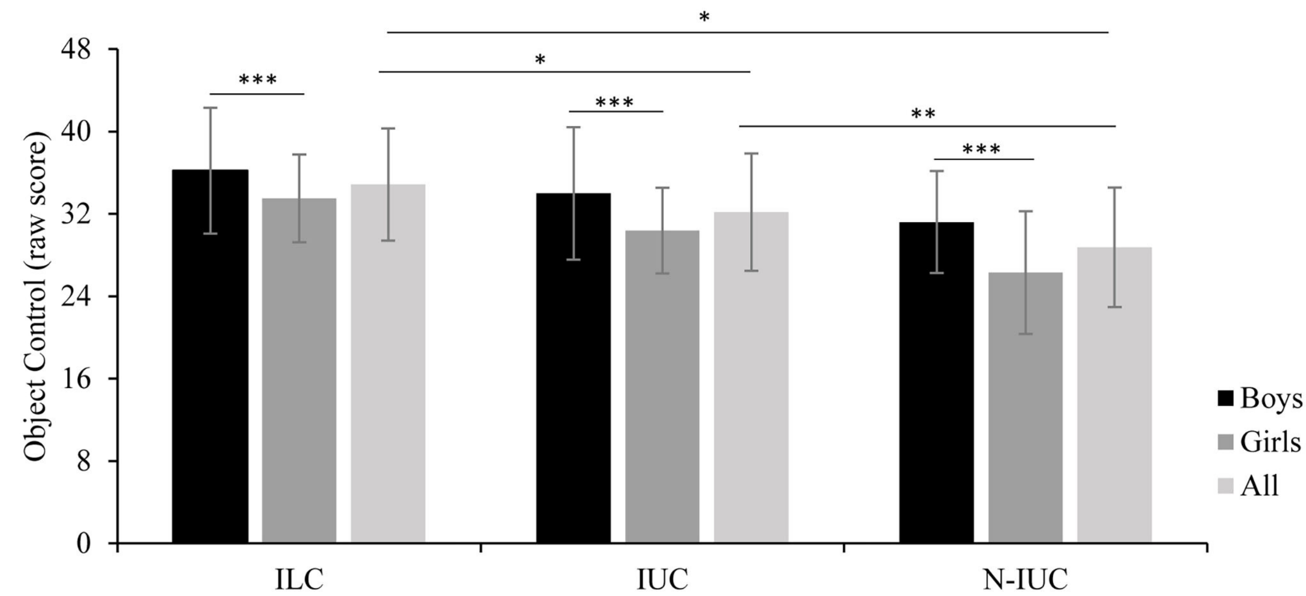

FIGURE 3 | Object control scores by group; ILC, Indigenous Land Children; IUC, Indigenous Urban Children; N-IUC, non-indigenous urban children. Significant differences: *ILC > IUC ($p = 0.019$) and > N-IUC ($p < 0.001$), **IUC > N-IUC ($p < 0.015$), ***All boys > All girls ($p < 0.001$).

In this unsupervised free time outside the home, indigenous land children explore the environment, move freely around all the houses in the village, and use the central village courtyard for their games. Children play and live among trees and rivers, and nature was a part of their daily life. Playing games, walking in the forest, following parents around, imitating parents' behaviors, and playing and bathing in the river are the daily activities observed in indigenous children living in the forest village, similar as reported in the previous study (55). Besides, in many ethnic groups, indigenous children spend most of their free time in playing; as an example, like our findings, Parakanã indigenous children spent most of their free time in playing outside (39, 56). Active leisure lifestyle has been reported as a health-protective factor among urban children; here, we provided the evidence for indigenous children living in the forest (56, 57). Therefore, we added

TABLE 1 | BMI and contextual factors of indigenous children living in the village, urban indigenous, and non-indigenous–N(%).

Body mass index and contextual factors			Indigenous land children			Indigenous urban children			Non-indigenous urban children		
			Boys (*n* = 23)	Girls (*n* = 20)	All (*n* = 43)	Boys (*n* = 24)	Girls (*n* = 22)	All (*n* = 46)	Boys (*n* = 35)	Girls (*n* = 29)	All (*n* = 64)
BMI categorization		Severe thinness	3 (13)	0 (0)	3 (7)	2 (8.3)	2 (9.1)	4 (8.7)	1 (2.9)	5 (17.2)	6 (9.4)
		Thinness	3 (13)	1 (5)	4 (9.3)	3 (12.5)	3 (13.6)	6 (13)	1 (2.9)	4 (13.8)	4 (6.3)
		Eutrophic	16 (69.6)	19 (95)	35 (81.4)	14 (58.3)	10 (45.5)	24 (52.2)	33 (94.3)	15 (51.7)	47 (73.4)
		Overweight	1 (4.3)	0 (0)	1 (2.3)	2 (8.3)	2 (9.1)	4 (8.7)	0 (0)	5 (17.2)	5 (7.8)
		Obese	0 (0)	0 (0)	0 (0)	3 (12.5)	5 (22.7)	8 (17.4)	0 (0)	0 (0)	2 (3.1)
Contextual Factors	Adults at home*	2 adults	11 (47.8)	5 (25)	16 (39.5)	11 (45.8)	6 (27.3)	17 (37)	4 (11.4)	7 (24.1)	11 (17.2)
		> 2 adults	12 (52.2)	15 (75)	27 (60.5)	13 (54.2)	16 (72.7)	29 (63)	31 (88.6)	22 (75.9)	53 (82.8)[a]
	Siblings at home	2 siblings	3 (13)	–	3 (7)	4 (16.7)	2 (9.1)	6 (13)	6 (14.3)	7 (24.1)	12 (18.8)
		3 to 4 siblings	6 (26.1)	6 (30)	12 (27.9)	13 (54.2)	9 (40.9)	22 (47.8)	18 (51.4)	11 (37.9)	29 (45.3)
		> 4 siblings	14 (60.9)	14 (70)	28 (65.1)	7 (29.2)	11 (50)	18 (39.1)	12 (34.3)	11 (37.9)	23 (35.9)
	Unsupervised Free time*	< 2 h	8 (34.7)	5 (25)	13 (30.3)	12 (50)	10 (45.5)	22 (47.8)	20 (57.1)	26 (89.7)	47 (71.9)[a]
		> 2 h	15 (65.3)	15 (75)	30 (69.8)	12 (50)	12 (54.5)	24 (52.2)	15 (42.9)	3 (10.3)	23 (28.1)
	Place to play*	Inside home	3 (13)	3 (15)	6 (14)	5 (20.8)	5 (22.7)	10 (21.7)	24 (68.6)	21 (72.4)	45 (70.3)[a]
		Out of home	20 (87)	17 (85)	37 (86)	19 (79.2)	17 (77.3)	36 (78.3)	11 (31.4)	8 (27.6)	19 (29.4)
	Sleeping time	< 9 h	2 (8.7)	12 (60)	14 (32.6)	6 (25)	8 (36.4)	14 (30.4)	15 (42.9)	7 (24.1)	22 (34.4)
		9 to 12 h	10 (43.5)	7 (35)	17 (39.5)	16 (66.7)	7 (31.8)	23 (50)	15 (42.9)	15 (53.1)	30 (46.9)
		> 12 h	11 (47.8)	1 (5)	12 (27.9)	2 (8.3)	7 (31.8)	9 (19.6)	5 (14.3)	7 (24.1)	12 (18.8)
	Television time**	No time	23 (100)	20 (100)	43 (100)	5 (20.8)	0 (0)	5 (10.9)	0 (0)	0 (0)	0 (0)
		< 2 h	0 (0)	0 (0)	0 (0)	11 (45.8)	2 (9.1)	13 (28.3)	9 (25.7)	6 (20.7)	15 (23.4)
		> 2 h	0 (0)	0 (0)	0 (0)	8 (33.3)	20 (90.9)	28 (60.9)	26 (74.3)	23 (79.3)	49 (76.6)[a]
	Computer time**	No time	23 (100)	20 (100)	43 (100)	10 (41.7)	8 (36.4)	18 (39.1)	6 (17.1)	4 (13.8)	10 (15.6)
		< 2 h	0 (0)	0 (0)	0 (0)	11 (45.8)	13 (59.1)	24 (52.2)	13 (37.1)	5 (17.2)	18 (28.1)
		> 2 h	0 (0)	0 (0)	0 (0)	3 (12.5)	1 (4.5)	4 (8.7)	16 (45.7)	20 (69)	36 (56.3)[a]
	School commute	Non-motorized	23 (100)	20 (100)	43 (100)	6 (25)	9 (40.9)	15 (32.6)	13 (37.1)	4 (13.8)	17 (26.6)
		Motorized	0 (0)	0 (0)	0 (0)	18 (75)	13 (59.1)	31 (67.4)	22 (62.9)	25 (86.2)	47 (73.4)
	Playmates Sex	Same sex	20 (87)	18 (90)	38 (88.4)	21 (87.5)	20 (90.9)	41 (89.1)	26 (74.3)	20 (69)	46 (71.9)
		Opposite sex	3 (13)	2 (10)	5 (11.6)	3 (12.5)	2 (9.1)	5 (10.9)	9 (25.7)	9 (31)	18 (28.1)
	Playmates Age	Younger	9 (39.1)	1 (5)	10 (23.3)	1 (4.2)	3 (13.6)	4 (8.7)	12 (34.3)	10 (34.5)	22 (34.4)
		Same age	14 (60.9)	18 (90)	32 (74.4)	19 (79.2)	17 (77.3)	36 (78.3)	18 (51.4)	19 (65.5)	37 (57.8)
		Older	0 (0)	1 (5)	1 (2.3)	4 (16.7)	2 (9.1)	6 (13)	5 (14.3)	0 (0)	5 (7.8)

**Significant differences across the three groups; **Significant differences between the two groups: indigenous urban children and non-indigenous urban children–no variation was observed for indigenous land children, and therefore, they were excluded from the analysis; [a]Significant higher proportion than the other groups.*

new evidence to the present knowledge showing that MP is related to cultural beliefs for the indigenous children living in the forest.

Another major finding of this study was related to urban indigenous children. Urban indigenous children, even with the migration to the urban environment during infancy, still play unsupervised for more than 2 h outside than the non-indigenous urban children and had higher MP scores than non-indigenous urban children. It is plausible to assume that the indigenous children playing' routine was preserved by the indigenous parents even when living in the urban environment; the previous studies with the Sateré-Mawé people support their resilience to acculturation in urban environments (24). However, indigenous children in the urban area watch television and use computers, although the frequency was not as high as for non-indigenous urban children.

Moreover, although they spend time in playing outside, it was not related to MP, contrary to the children in the forest.

TABLE 2 | Linear regression: factors associated with locomotor and object control performance by groups.

Groups	Factors	*B*	*SE*	*β*	*t*	*p*
Indigenous land children						
Locomotor	Unsupervised Free time > 2 h[a]	6.43	1.19	0.64	5.39	< 0.001
Object control	Unsupervised Free time > 2 h[a]	6.72	1.62	0.57	4.14	< 0.001
	Place to play-outside home[b]	4.84	2.15	0.31	2.25	0.030
Indigenous urban children						
Locomotor	Adults at home > 2 adults[a]	−3.96	1.14	−0.45	−3.48	0.001
	Sleeping time 9 to 12 h[b]	−2.30	1.10	−0.27	−2.09	0.042
Object control	Adults at home > 2 adults[a]	−4.96	1.15	−0.42	−3.30	0.002
	Television time > 2 h[c]	−2.52	1.06	−0.30	−2.38	0.022
Non-indigenous urban children						
Locomotor	Siblings-3 to 4[a]	−3.86	1.48	−0.37	−2.60	0.012
	Siblings > 4[a]	−6.78	1.61	−0.63	−4.20	< 0.001
	Computer time > 2 h[b]	−1.58	0.78	−0.23	−2.01	0.048
Object control	Computer time > 2 h[a]	−3.04	0.93	−0.38	−3.25	0.002

Indigenous Land Children: [a]reference category: free time < 1 h; [b]reference category: play inside home; Indigenous Urban Children: [a]reference category: 2 adults; [b]reference category: sleeping time < 9 h; [c]reference category: no TV time; Non-Indigenous Urban Children: [a]reference category: 2 siblings, [b]reference category: no computer time.

More than two adults living at home, sleeping for long hours (9 to 12 h), and spending more than 2 h watching television were negatively related to MP. The number of adults at home has been referred to as a factor that can negatively influence children's motor development (58). The studies have found that, in large families, the home environment suggests being less stimulating for children due to sharing parents' attention and the limited space inside the house to do more active tasks (59–61). Adopting inactive lifestyles with sedentary activities, such as watching television, were previously related to the deficits in MP in non-indigenous children since it takes children away from vigorous activities to the authors' knowledge, it is the first study that provided evidence for urban indigenous children (22, 36, 38).

Regarding non-indigenous urban children, these children had the higher frequencies of more than two adults living in their homes, more time in sedentary activities, television and computer, and less time for play, and they play primarily inside the homes. Play inside the home seems to be a cultural characteristic of non-indigenous children who play in parks or outside the home for a short time and spend time inside in more sedentary activities, such as watching television and computers, a fact in this study for non-indigenous urban children (56, 57). Besides, the number of siblings at home and computer time was negatively related to MP; both factors were also previously related to lower scores in MP, like our findings (22, 38, 59, 61). Large families with many siblings prevent the parents from giving full attention to child development, providing stimulating activities, and promoting environment exploration; besides, sharing toys and physical space to be active are related to lower MP, and our results confirm this trend. Besides, nowadays, children have more access and time using computers and, consequently, are less involved in active body play, and in our results, it was related to lower MP (22, 38, 61, 62). This study results give support to the relationship between less active behavior and low MP in children, especially those who live in urban contexts.

There was no previous study that assessed MP and correlated contextual factors in indigenous (living in the forest and urban areas) and non-indigenous children to the authors' knowledge. Nevertheless, the previous studies suggested that PA levels were higher among indigenous adolescents than non-indigenous (56, 57). For example, Malta et al. (57) revealed a 22.5% higher prevalence of PA among indigenous adolescents compared to non-indigenous. Behaviors and attitudes differ concerning the sociocultural environment; as observed in the present results, the way of living in the forest was the primary influence in the avoidance of sedentary behavior, the children had no screen at home and a physical environment full of opportunities to explore, and they did explore unsupervised. The number of adults and siblings did not influence their MP, possibly because they have more freedom to explore the spaces of the house since they stay for a short time inside their home; that is, the time spent inside the residence was mainly used to help with some chores and sleep. If the environment affords adequate opportunities for the children can actively engage in a diversity of motor activities, consequently they will improve their MP. Our results supported this contention for indigenous children living in the forest (19, 41, 63).

We also analyzed the sex effect in MP. Independent of the groups, boys showed better MP than girls in locomotor and object control skills. Similar results have been found in several studies for non-indigenous low-income children [(6, 19, 64, 65)]. Vigorous motor activities and incentives to practice sports are often more vital for boys (6). Therefore, boys are generally more involved with the games that require gross motor components in wide physical spaces (e.g., ball games). On the other hand, girls engage more in stationary play that requires fine motor skills and verbal communication, such as playing with dolls, and it was not different in this study; girls were more required to help the mothers inside the home, and distinctive gender roles were observed in the inside home activities (6, 59, 66).

Urban children, indigenous or not, share a common factor they live in more crowded houses and use more screens; these factors were harmful to their MP. It is even more complex for the indigenous urban children; this was a change in the previous way of living, and although they enjoyed some unsupervised time, this freedom was not used to be outside in contact with nature but spent in front of screens. The lack of physical spaces that allow for outdoor play prevents children from developing motor skills. The results emphasize the need to implement public policy to create physical spaces in urban areas to support children's mobility and outdoor play, exposing children to active contexts that positively influence choices for more active activities in urban areas.

Regarding BMI, most of the indigenous children living in the forest village, urban indigenous children, and non-indigenous children (81.4, 52.2, and 73.4%, respectively) were eutrophic. Although no difference was found for weight status across groups, many indigenous children (forest village: 16.3%; urban area: 21.7%) were severely thin or thin. Although notably higher, these results are comparable to the previous data from indigenous Sateré-Mawé children from Amazonas, which identified 3.63% with thinness or severe thinness (67). Unfortunately, poverty is the underlying condition for this factor; as reported in the present study, Sateré-Mawé people's monthly income is meager, placing them in Brazil's poverty line. At the other end of the curve, urban indigenous children showed a high percentage of overweight and obesity (26.1%). As the present study results, data from the food and nutrition surveillance system −22.1% of overweight and obese indigenous children and previous research regarding weight status of indigenous children – showed this trend in increasing obesity [(33, 68); Fávaro et al., 2019; Ferreira et al., 2021; (67, 69, 70)]. Changes in dietary practices, more frequent consumption of caloric, inadequate, industrialized foods, and the adoption of a more sedentary behavior resulting from the migration of these indigenous children to urban areas may explain this scenario (71, 72).

CONCLUSION

Contextual factors experienced by indigenous children living in the forest village were more favorable for adopting an active lifestyle that positively impacted MP. Associated factors with the MP of children in this study were different, demonstrating the strength of contextual factors on motor development across groups. Indigenous children in the village do not have screen time (TV and computer); therefore, they spend more time enrolled in free activities in contact with nature, and they have more space to play than their urban peers. On the other hand, urban children (indigenous or non-indigenous) have less free time, smaller play areas, and more screen time. The unlimited physical space in the forest and being free to explore the environment autonomously is a characteristic of the indigenous culture and a protective factor for MP. These characteristics cannot be exported to other cultures; each investigated group had cultural particularities and values, and social expectations within each investigated context. However, our results support the notion that urban children need to have more free time outside and, if possible, more contact with nature to become more motor proficient. Providing urban children with accessible and challenging experiences to explore their motor repertoire may improve their MP. Regarding indigenous children living in the forest, although they lived with fewer resources in the village, they had what was necessary to develop motor skills–free time and physical space. This study advances by providing a further understanding of a population that has been less investigated and with very restricted access and for a better understanding of contextual factors that promote MP in different sociocultural environments. Following these children for a long time to investigate whether the cultural factors affecting MP would change as different opportunities would be experienced seems to be a future direction to pursue. Understanding the value of indigenous children and parents' place in motor activities was a limitation of this study and a recommendation for future research.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Universidade Federal de Minas Gerais. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

MD and RB participated in the design of the study. MD participated in the design of the study and contributed to data collection. MD, RB, GN, and NV contributed to data reduction/analysis and interpretation of results. All authors contributed to the manuscript writing and have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

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The Association Between Physical Activity and Mathematical Achievement Among Chinese Fourth Graders: A Moderated Moderated-Mediation Model

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This study explored the association between out-of-school physical activity (PA) and mathematical achievement in relation to mathematical anxiety (MA), as well as the influence of parents' support for their children's physical activity on this association, to examine whether parental support for physical activity affects mental health and academic performance. Data were collected from the responses of 22,509 (52.9% boys) children in Grade 4 from six provinces across eastern, central, and western China who completed the mathematics component and the physical education and health component of the national-level education quality assessment. A moderated moderated-mediation model was tested using PROCESS v3.4 and SPSS v19.0, with socioeconomic status, school location, and body mass index as controlled variables. Out-of-school physical activity had a positive effect on children's mathematical achievement, and math anxiety partially mediated this association. The indices of conditional moderated mediation through the parental support of both girls and boys were, respectively, significant, indicating that children can benefit from physical activity, and that increased perceived parental support for physical activity can alleviate their children's math anxiety and improve their mathematics, regardless of gender. However, gender differences were observed in the influence of parental support for physical activity on anxiety: Although girls' math anxiety levels were significantly higher, the anxiety levels of girls with high parental support were significantly lower than those of boys with low parental support.

Keywords: mathematical achievement, mathematical anxiety, physical activity, parental support, conditional process model, moderated moderated-mediation model

INTRODUCTION

Physical activity (PA) refers to any bodily movement produced by skeletal muscles that requires energy expenditure (Donnelly et al., 2016) and plays a vital role in the growth and health of children; however, it has not received the attention it deserves. The World Health Organization's survey of 72,845 schoolchildren from 34 countries showed that most children did not get enough exercise, while nearly a third were sedentary (Guthold et al., 2010). Moreover, studies related to physical activity have also indicated that many children do not meet national physical activity guidelines—from a systematic review and meta-analysis (Watson et al., 2017). Although schools provide the ideal environment for promoting children's physical activity, it is difficult to increase physical activity during school days due to factors such as competition among the key learning areas and the limited time children spend in school. The above survey also revealed that parents do not pay sufficient attention to physical activity after school. In countries or regions with high academic pressure in particular, though parents may know that physical activity is a key factor for their children's growth and health, they may still only prioritize it after academic performance when the time available is limited. Thus, it can be seen that it is challenging to integrate physical activity into children's daily lives.

In fact, empirical studies have reported that physical activity aids not only children's physical and mental health but also their academic achievement (Ashcraft, 2002; Wang et al., 2019; Hermassi et al., 2021). While related research has covered several academic areas (e.g., language, mathematics, spelling, reading, science, and geography), mathematics has been studied the most and the results are diverse (Sibley and Etnier, 2003; Esteban-Cornejo et al., 2015; de Greeff et al., 2018; Bedard et al., 2019; Barbosa et al., 2020). In general, physical activity is an effective way of enhancing physical and mental health. Research has shown that the potential benefits of physical activity on cognitive performance, learning, brain structure and brain function may be the foundation for improved academic performance (Donnelly et al., 2016). Evidence suggests that physical activity improves physiology, like executive function (EF), which in turn improves academic performance (Álvarez-Bueno et al., 2017; de Greeff et al., 2018; Ishihara et al., 2018b). However, the relationship between physical activity and mental health is not a simple causal link and can be affected by other factors (Lagerberg, 2005).

In addition, the research on the impact of physical activity on academic performance has been inconsistent. On the one hand, the extant research has considered physical activity from different perspectives, such as enhanced and enriched physical activity, or aerobic, acute, and chronic exercise (Petruzzello et al., 1991; Álvarez-Bueno et al., 2017). On the other hand, most of the research on this association has focused on physical activity in schools, such as curricular physical education (PE), extracurricular physical activity (active recess, or lunch time or sports programs), and integrated physical activity (active breaks or teaching subjects such as math through physical activities), and little attention has been given to out-of-school physical activity. This diversity of research perspectives makes it extremely valuable to further explore the impact of physical activity on children's mental health and academic performance.

Many typical psychological factors have been used as intermediary variables to explore the influence mechanism of physical activity on mental health and academic performance. The results are diverse and should be further verified and enriched (Tremblay et al., 2000; Dapp and Roebers, 2019). The distraction hypothesis provides a basis for exploration, maintaining that diversion from unpleasant stimuli or painful somatic symptoms leads to effect improvements following exercise sessions (Greist et al., 1979; Morgan, 1985; Hill, 1987; Paluska and Schwenk, 2000). Research results have demonstrated that many psychological factors play a mediating role between physical activity and academic performance (Tremblay et al., 2000; Sigfusdottir et al., 2007; Dapp and Roebers, 2019; Wang et al., 2019); however, it remains necessary to add more psychological intermediary factors to the analysis to provide more reliable evidence in support of the distraction hypothesis.

Furthermore, according to social cognitive theory, strong social support networks increase an individual's self-efficacy, thereby allowing them to overcome barriers to being physically active (Bandura, 1999). As an indispensable social support in childhood, parents are likely to provide the support necessary for participation in physical activity when they value the outcomes associated with regular physical activity. This idea is consistent with the central tenets of the major attitude–behavior theories (theory of reasoned action, planned behavior, and social cognitive theory) (Trost et al., 2003). Studies have explored the role of parental support for physical activity among boys and girls (Brustad, 1996; Henriksen et al., 2016; Lijuan et al., 2017), thus far, little research has comprehensively examined the relationship between physical activity and academic achievement in relation to mental health, or the influence of parental support for their children's physical activity on this association. Since this relationship remains unclear, the current research explores this issue.

What kind of influence does the parental support for physical activity perceived by a boy or girl have on their mental health and academic performance? If parental support for physical activity is confirmed to promote mental health and academic performance, this will enable parents and education departments to not only further realize the potential value of physical activity for improved mental health and academic performance but also increase the level of support for physical activity in terms of opinions, awareness, and behaviors and strengthen the communication between school and families. This support for physical activity will increase the expected positive effects, which will prove valuable for children's growth, mental health, and academic performance.

LITERATURE REVIEW

Out-of-School Physical Activity and Mathematics

The effectiveness of physical activity interventions for promoting children and adolescents' cognition and academic achievement has been reported since 1997 (Etnier et al., 1997; Donnelly et al., 2009, 2016; Langford et al., 2014; Diamond, 2015; Esteban-Cornejo et al., 2015). In recent years, more than 200 studies have explored the association between physical activity and academic success in school-aged children. It can, thus, be concluded that there is a significant positive relationship between physical activity and cognitive functioning in children (Esteban-Cornejo et al., 2015; Donnelly et al., 2016). A number of exercise and brain experiments have clearly shown that regular physical activity alters specific brain structures and functions, particularly in tests that require more executive function (EF) (Miyake et al., 2000; Diamond, 2015; Gunnell et al., 2019). This provides evidence for the executive function hypothesis, which says that exercise has the potential to induce vascularization, nerve growth, and altered synaptic transmission, thereby modifying thinking, decision-making, and behavior in brain regions associated with EF (Kopp, 2012). In addition, physical activity can also help mental health by improving skeletal and musculoskeletal functions to help relieve or reduce depression, anxiety, and stress (Eveland-Sayers et al., 2009; Teferi, 2020). The mechanism of the association between physical activity, cognition, and mental health can be explained by a conceptual model hypothesis, that is, a neurobiological, psychosocial, and/or behavioral linkage mechanism and may be affected by the frequency, intensity, timing, type and context of physical activity (Lubans et al., 2016; Barth Vedøy et al., 2020).

So far, systematic reviews show no indication that increases in physical activity negatively affect cognition or academic achievement (Donnelly et al., 2016). The overall effect of different modes of physical activity had null or small to medium effects on academic achievement (Barbosa et al., 2020). The findings varied due to the diversity of cognitive domains and physical activity indicators involved (Esteban-Cornejo et al., 2015; Donnelly et al., 2016; de Greeff et al., 2018; Barbosa et al., 2020; Wassenaar et al., 2020). And inconsistent results were observed across multiple subject areas, including mathematics, reading, language (Fedewa and Ahn, 2011; Martin et al., 2014), science, spelling, and geography (de Greeff et al., 2018; Bedard et al., 2019).

Compared with other disciplines, the discussion on the relationship between physical activity and mathematics attracted more attention (Barbosa et al., 2020). Indeed, mathematics has an irreplaceable position as a fundamental and important discipline. In China, mathematics has become a compulsory subject in grades 1-12, and is a compulsory subject for taking college entrance examinations and senior high school entrance examinations. It strongly supports other science and engineering disciplines and subsequent learning practices. This explains why researchers pay more attention to mathematics when exploring the relationship between physical activity and academic performance (Fedewa and Ahn, 2011). Although most studies have documented that physical activity has a positive effect on mathematics (Ericsson and Karlsson, 2014; Mullender-Wijnsma et al., 2015; Riley et al., 2016), some results are contradictory (Sallis et al., 1999; Reed et al., 2010; Tarp et al., 2016), with null or small to medium effects (Barbosa et al., 2020).

In addition, most of the relevant research focused on intramural sports, with little attention paid to extramural sports. Systematic review studies have shown that most studies on physical activity have focused on physical education and active tasks in schools, revealing that math-related skills benefit from both curricular and integrated PE, as well as from extracurricular physical activity. Few studies focused on out-of-school physical activity, and there is a lack of research on the impact of out-of-school physical activity on academic performance (Álvarez-Bueno et al., 2017). The different perspectives taken to explore physical activity are one of the key reasons for the inconsistent results in the literature. Moreover, most of the previous research samples have not been large samples, posing limitations in sample representation and to our understanding of the large-scale situation. Does a large sample of data provide evidence of the positive effect of out-of-school physical activity on mathematics? This study attempts to fill these gaps.

Mediating Effect of Math Anxiety Between Physical Activity and Mathematics

In order to further explore the inconsistent relationship between physical activity and mathematics, researchers have delved into the influencing factors according to the above-mentioned influence mechanism. For example, the mediating physiological, cognitive and motor variables (e.g., aerobic and physical fitness; Ashcraft, 2002; Wang et al., 2019), and psychological variables also are important aspects that researchers focus on (Tremblay et al., 2000; Dapp and Roebers, 2019; Kyan et al., 2019). Based on the psychological mechanisms of the distraction hypothesis (Greist et al., 1979; Morgan, 1985; Hill, 1987; Paluska and Schwenk, 2000), some classical psychological variables have been analyzed, such as self-concept, self-confidence and interest, self-efficacy, self-esteem, motivation, and depressive mood. The mediating roles of different psychological factors between physical activity and academic performance have been confirmed over time—one variable after another (Tremblay et al., 2000; Sigfusdottir et al., 2007; Dapp and Roebers, 2019; Kyan et al., 2019; Wang et al., 2019). However, as one of the most common mental health problems (Kessler et al., 2012), anxiety has not been included among these psychological variables.

The ability of exercise to relieve anxiety has been validated by some meta-analyses (Long and van Stavel, 1995; Guszkowska, 2004). Within the framework of self-decision theory, researchers have observed that behaviors that promote the satisfaction of individuals' basic psychological needs can reduce social anxiety to a certain degree (Brunet and Sabiston, 2009), with physical activity representing one such behavior (Ren and Li, 2020). In similar results, frequent physical activity was associated with lower levels of depression and anxiety and a greater sense of well-being (McMahon et al., 2017). Nevertheless, since the concept of physical activity differs across the literature and the potential influencing factors have not been considered, the association between physical activity and anxiety remains unclear (Williams et al., 2016; Kandola et al., 2018).

Meanwhile, mathematics anxiety (MA), defined as fear and worry related to math stimuli and situations (Richardson and Suinn, 1972), is related to poor performance on mathematics achievement tests (Hembree, 1990). Meta-analyses from the 1990s previously established a significant, small-to-moderate, and negative correlation between math achievement and math anxiety (Ma, 1999; Barroso et al., 2021). Although anxiety has been employed as an intermediary variable that has a negative effect on mathematics (Liu et al., 2020), few studies have applied anxiety as a mediator to assess the effects of physical activity on academic achievement. Does math anxiety play a mediating role between out-of-school physical activity and mathematics? This is the second question this study attempts to explore.

Moderating Role of Parental Support According to Gender

There is a non-negligible relationship between out-of-school physical activity and family factors for primary school students. And as one of the most important social supports in childhood, parental support plays a necessary role in children's physical activity behaviors (Trost et al., 2003; Van Der Horst et al., 2007; Hennessy et al., 2010; Bassett-Gunter et al., 2017). However, the results regarding the association between parental support and children's physical activity levels have been inconclusive (Gustafson and Rhodes, 2006). This inconsistency can be attributed to the different measures of social support used, their differing reliability and validity, and the different modes of physical activity measurement adopted (Prochaska et al., 2002).

The positive effect of parental support on alleviating anxiety has previously been identified (Ma, 1999; Ren and Li, 2020). There is also evidence that social support moderates psychological distress (Solberg and Viliarreal, 1997; Constantine et al., 2003) and that the dimensions of perceived social support (including familial support) exert a mediating effect on social anxiety in sports and play a moderating role in the relationship between physical exercise and social anxiety (Ren and Li, 2020), although the moderating role of social support in previous studies was not specifically related to physical activity. Does parental support for physical activity perceived by children play a moderating role in the relationship between physical activity and mathematics through math anxiety? This study believes that this is another question worthy of further exploration.

Moreover, gender also constitutes an influencing factor in relation to physical activity (Kremers et al., 2007; Simen-Kapeu and Veugelers, 2010; Kyan et al., 2019), exerting a direct or indirect relationship between parental social support and children's physical activity in a manner that differs between genders (Peterson et al., 2013). However, in one report on the critical nature of activity-related support from family and friends, no gender differences in the impact of activity-related support were identified (Davison, 2004). Another review reported that there were significant correlations between parental support and children's physical activity levels, although the results regarding an association between parental and child physical activity levels were mixed (Gustafson and Rhodes, 2006). Thus, the role of parental support in different gender groups deserves further attention.

The results on gender difference (between male, female, and non-binary individuals; Ahn and Fedewa, 2011) as a moderator in relation to physical activity and mental health have been significant (Ishihara et al., 2018a). However, in a previous study on gender, anxiety, and social support, the three-way interaction between gender and anxiety was such that boys and girls differed with respect to perceived social support but not anxiety (Landman-Peeters et al., 2005). In general, the findings regarding gender as a moderator in the relationship between physical activity and mental health have been inconsistent (Ishihara et al., 2018a). Does gender have a secondary moderating effect on the moderated-mediation model? For a deeper exploration of the crucial role of the parent–child relationship in children's math anxiety (Ren and Li, 2020; Ma et al., 2021), gender differences in the benefits of physical activity for their mental health warrant further study.

In addition, socio-economic status (SES) and school location are also important factors influencing academic performance (Alordiah et al., 2015). Body mass index (BMI; calculated using a formula to determine an individual's height and body weight index) is a key indicator used in the physical activity-related research (Hansen et al., 2014; Torrijos-Niño et al., 2014; Li Y. et al., 2020). These variables would be effectively controlled in the moderated moderated-mediation relationship explored in the present study.

The Present Study

In summary, few studies in the past have explored (a) the mediating effect of math anxiety between out-of-school physical activity and mathematics, or (b) the double moderating effect of children's perceived parental support for their physical activity in terms of different genders on this mediation effect. The results of such an analysis can act as a valuable reference for the practical promotion of children's physical activity by schools and families. A moderated moderated-mediation model based on these four research questions was investigated (**Figure 1**), with perceived parental support for physical activity acting as the primary moderator *W* and gender acting as the secondary moderator *Z*, on the basis of hypothetical mediating effect between physical activity and mathematics through math anxiety. We propose the following hypotheses (see **Figure 1**):

Hypothesis 1: Physical activity should be associated with mathematics, and math anxiety partially mediates this association.

Hypothesis 2: Physical activity should be associated with mathematics through math anxiety, and perceived parental support and gender could, respectively, play a primary and secondary moderating role in this mediating relationship.

MATERIALS AND METHODS

Participants and Data Collection

The research data were collected from the national-level education quality assessment of China, which is a national monitoring system for the quality of school education in China, and the subjects tested include mathematics, sciences, Chinese language, physical education, arts, and moral education (Jiang et al., 2019). The data used in this research were specifically drawn from the mathematics component and physical education and health component (PEH) (Wu et al., 2019). Each participant in this study took a mathematics test, a set of physical fitness tests, and two self-reported questionnaires (including mathematics and physical education and health). All questionnaire and exam data for this study were collected on the same day. The sample of this study was distributed across six provinces in eastern, central, and

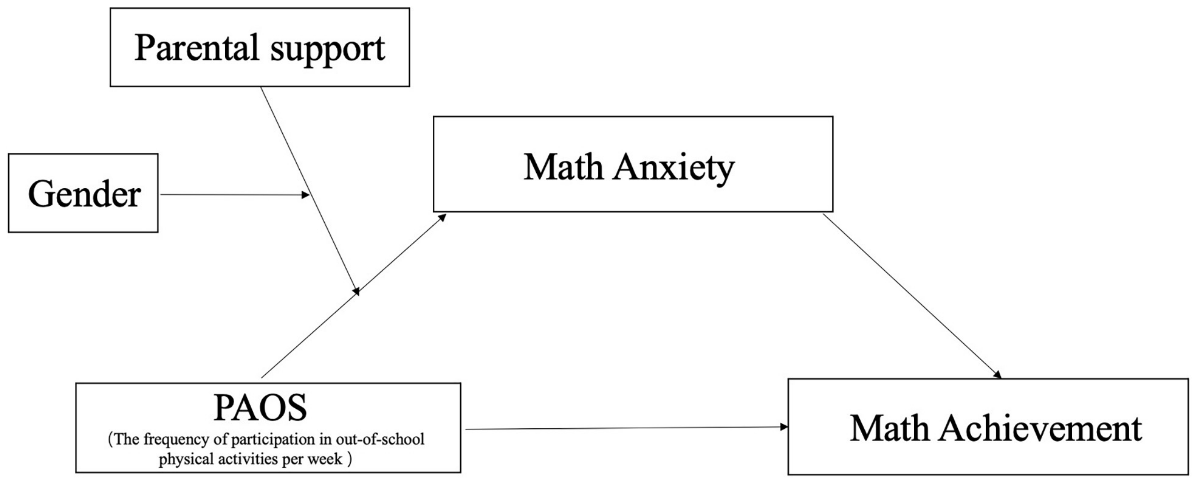

FIGURE 1 | Proposed theoretical framework.

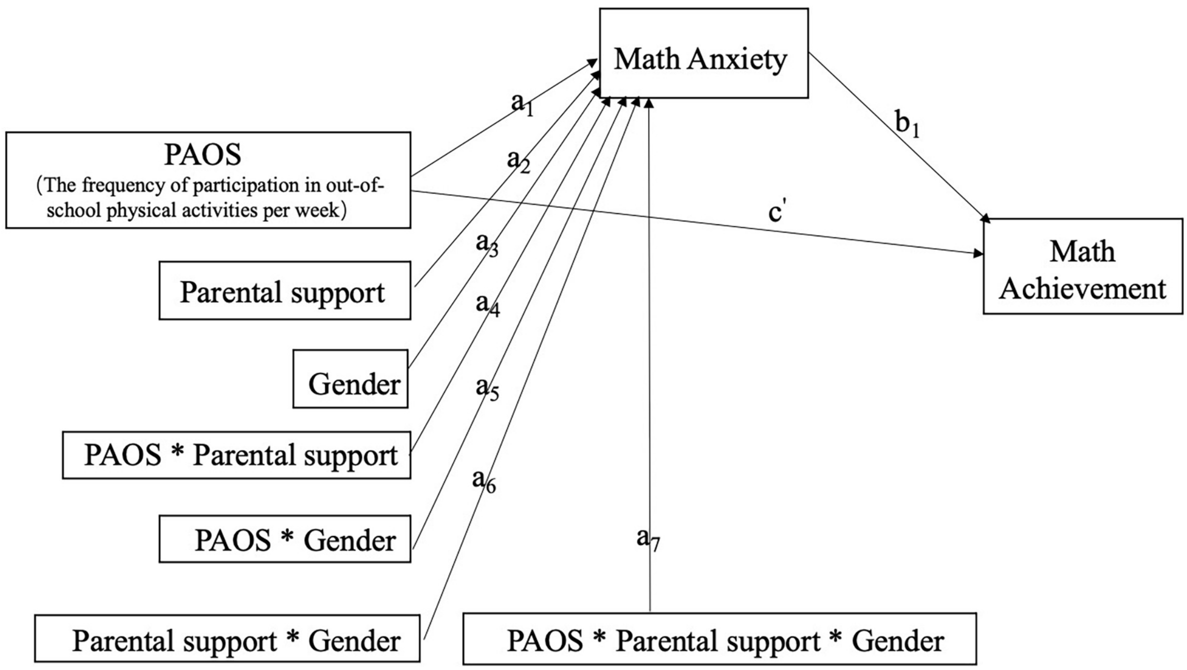

FIGURE 2 | Statistical model of the moderated moderated-mediation model.

western China. The assessment was conducted simultaneously for every province.

All participants were in the fourth grade (excluding mathematics learning disorders). After the screening and removal of cases with missing values for age, gender, or BMI, 22,509 students (52.9% boys, coded as 0) were included in the present study's sample. Students were aged 7.42–14.33 years (10.32 ± 0.52), with their schools located in cities (5,598, 24.9%), towns (4,421, 19.6%), and rural areas (12,490, 55.5%).

Fourth-year students were selected as subjects for the following reasons. Firstly, research showed that the association between math anxiety and math achievement starts in childhood – from grades 3 through 5 (Hill et al., 2016), while some other evidence suggested that this association is not significant for 6 to 9-year-olds (Krinzinger et al., 2009), which deserves further attention. Second, the fourth grade was considered a critical period for exploring learning disabilities, children's learning and habit development. Additionally, since they are more cognitively developed than their younger counterparts, their reading comprehension and written expression are more likely to be reliable (Wu et al., 2019). Third, from the perspective of social support theory, the fourth-grade group with an average age of about 10 is more in line with the research characteristics of parental support (Bandura, 1999; Trost et al., 2003; Gustafson and Rhodes, 2006).

Measures

Mathematics Achievement

The math achievement test came from the national education quality assessment of China. This was developed by mathematicians, mathematics educators, mathematics teaching and research staff, and experienced mathematics teachers from western, central, and eastern China. All the items for the national examination had undergone two pilot tests, multiple rounds (at least three rounds) of expert review, and pre-examination. This applies to the test and all questionnaires below (in this study refers to the mathematics component and physical education and health component).

The fundamental framework contains the following three modules: (a) numbers and algebra, (b) space and shape, and (c) statistics and uncertainty (Ministry of Education of the People's Republic of China [MOE], 2012). Six parallel tests were used; each of the test booklets was composed of 15 multiple-choice items and 5 construct response items. The internal consistency of the test booklets was above 0.84. Due to the test's time restriction and the equal weight given to all these modules in the test, a balanced incomplete block design was adopted when the test paper was designed. Each student was randomly assigned to complete one of the six test manuals.

The mathematics tests were assessed using the paper-and-pencil tests. The Rasch model and concurrent calibration were used to link scores of different test booklets to an identical scale provided by Conquest 1.1 (Wu et al., 1998). The item difficulty ranged from −2.270 to 2.597 logits. The total mathematics scores were uniformly converted to an IRT (item response theory) scale, with an average score of 500 and a standard deviation of 100 (Jiang et al., 2019; Wang et al., 2019).

Math Anxiety

Math anxiety was measured using the five-item self-reported questionnaire from the mathematic component of the national education quality assessment in China. The collection of questionnaire data was conducted on the same day as the mathematics and physical education tests. These items focused on math anxiety, such as "I am worried that math class would be difficult" and "I am nervous when I have to do math homework". This instrument employs a 4-point Likert-type scale ranging from 1 (*strongly disagree*) to 4 (*strongly agree*). The responses indicated the extent of the participant's agreement with each item, with a high score indicating a high level of math anxiety. The mean score of the items ranging from 1 to 4 was used and standardized during analysis. Internal consistency Cronbach's alpha index was 0.847.

Physical Activity Index

The physical activity index was collected from a self-reported questionnaire in the physical education and health component of the national education quality assessment of China on the same day. One of the questions that participants were required to answer related to the frequency of their participation in out-of-school physical activities each week (abbreviated as PAOS in Tables and Figures). The options ranged from 1 to 8, meaning the frequency of student's participation in out-of-school physical activities per week ranged from 0 to 7 and above. To demonstrate the question's validity, we selected responses from other closely related questions from the questionnaire of the physical education and health component and identified a series of correlations. The correlation results detailed in **Supplementary Appendix 1** indicated that the frequency of physical activity was significantly correlated with several related conditions at a moderate level, especially sweat frequency ($r = 0.370$, $p < 0.01$), physical activity for weekend ($r = 0.383$, $p < 0.01$), intramural physical activity ($r = 0.330$, $p < 0.01$), and duration ($r = 0.422$, $p < 0.01$).

Parental Support for Physical Activity

The perceived parental support variable was also adopted from the physical education and health component of the national education quality assessment of China in the questionnaire. The question "Do your parents support your participation in physical activities in your spare time?" was evaluated with response options of "very unsupportive," "moderately unsupportive," "moderately supportive," and "very supportive" (coded as 1–4, respectively). Same to the physical activity index, we selected responses from other closely related questions in the same questionnaire and identified a series of correlations to strengthen the validity of this question. The correlation results detailed in **Supplementary Appendix 2** indicate that perceived parental support was significantly correlated with several related conditions at a weak or moderate level.

Confounding Variables

In the process of determining the moderated moderated-mediating relationship, SES, school location, and BMI were controlled in the analysis to control for confounding factors in the relation between the implementation of the physical activity index and mathematics through math anxiety (Ericsson and Karlsson, 2014; Hansen et al., 2014; Torrijos-Niño et al., 2014; Alordiah et al., 2015; Li S. et al., 2020).

The association between various socioeconomic variables and academic achievement has been well established (White, 1982; Sirin, 2005; Duncan et al., 2011; Li S. et al., 2020). To determine the participants' SES, principal component analysis was conducted based on three indicators, namely the highest occupational status of their parents, highest educational level of their parents, and type and amount of possessions in the home (Jiang et al., 2019). The school's location was used to indicate which part of China (east/central/west) and what type of environment (city/town/rural) the student was living in. The children's BMI was calculated as BMI = weight (kg)/height^2 (m^2) (Fredriks et al., 2000). The age factor was not controlled in this model for two main reasons. First, the entrance age in China is strictly unified by the Ministry of Education; generally, the difference between students in the same academic year is less than 1 year. Second, the proportion of extreme age data was very small (less than 0.6%), and all the key results after adding the age variable were consistent. In accordance with the principle of model simplicity, we did not control for age in this study.

Statistical Analysis

The descriptive statistics and correlations were calculated using SPSS v19.0 for Windows, and all further analyses were conducted using PROCESS v3.4 for SPSS[1]. In this moderated moderated-mediation model, standardized weekly frequency of out-of-school physical activity and standardized mathematics were the independent variable (X) and dependent variable (Y), respectively; standardized math anxiety was an intermediary variable (M); and standardized perceived parental support for physical activity and gender were the primary and secondary moderators (W and Z), respectively. School location, SES, and BMI were the control variables. The core continuous variables were standardized during data analysis, including math achievement, math anxiety, weekly frequency of out-of-school physical activity and parental support. The regression coefficients presented were standardized regression coefficients in the mediation model results, and were unstandardized regression coefficients in the moderated moderated-mediation model results (PROCESS software can only provide standardized regression coefficients for mediation-only models).

The statistical model of the moderated moderated-mediation model can be represented by the following two equations (Hayes, 2018; Hayes and Rockwood, 2020):

$$\hat{M} = i_M + a_1X + a_2W + a_3Z + a_4XW + a_5XZ + a_6WZ + a_7XWZ \quad (1)$$

$$\hat{Y} = i_Y + c'X + bM \quad (2)$$

The coefficients in the model are shown in **Figure 2**. From Eq. (1), the effect of X on M can be expressed as:

$$\theta_{X\rightarrow M} = a_1 + a_4W + a_5Z + a_7WZ \quad (3)$$

Multiplication of the effect of X on M and the effect of M on Y yields the indirect effect of X on Y through M:

$$\theta_{X\rightarrow M}b = (a_1 + a_4W + a_5Z + a_7WZ)b = a_1b + a_4bW + a_5bZ + a_7bWZ \quad (4)$$

Through algebraic manipulation, Eq. (4) can be written in the following equivalent form:

$$\theta_{X\rightarrow M}b = a_1b + (a_4b + a_7bZ)W + a_5bZ \quad (5)$$

The slope of the line relating W to the indirect effect of X is $a_4b + a_7bZ$, which is called the index of conditional moderated mediation by W in this model. The coefficient values had a one-to-one correspondence in the results.

[1] http://processmacro.org/index.html

RESULTS

Descriptive Statistics and Correlations

The descriptive statistics are listed in **Table 1**, which includes the mean and standard deviations of the core variables (school location, SES, gender, age, BMI, mathematics, math anxiety, parental support, and weekly frequency of out-of-school physical activity) are presented. As described in **Table 1**, mathematics had significant moderate or weak negative correlations with math anxiety ($r = -0.376$, $p < 0.01$) and school location ($r = -0.239$, $p < 0.001$) and significant moderate positive correlations with SES ($r = 0.418$, $p < 0.01$). Math anxiety exhibited a significant weak correlation with weekly frequency of out-of-school PA ($r = -0.121$, $p < 0.001$) and parental support ($r = -0.172$, $p < 0.01$). Parental support was significantly correlated with all core variables; it exhibited weak correlations with weekly frequency of out-of-school PA ($r = 0.228$, $p < 0.01$), math anxiety ($r = -0.121$, $p < 0.01$), and SES ($r = 0.113$, $p < 0.01$).

Mediating Effect of Math Anxiety

Table 2 presents the direct, indirect, and total effects of mathematics anxiety as a mediator in the relationship between physical activity and mathematics performance in great detail. According to the standardized regression results, the effect of physical activity frequency per week on math anxiety was significant (β = 0.136, $p < 0.001$; LLCI = −0.153; ULCI = −0.131), and the effect of math anxiety on mathematics was also significant (β = 0.278, $p < 0.001$; LLCI = −45.748; ULCI = −42.163). According to the results of mediating effects, a significant indirect effect of weekly frequency of out-of-school physical activity on mathematics through math anxiety (Indirect effect: $m = ab = 2.117$, $p < 0.001$; LLCI = 1.945; ULCI = 2.404; $R_M = 56.62\%$) was observed; a 95% C.I. was obtained with 5,000 bootstrapping resamples. The direct effect of weekly frequency on mathematics was significant [Direct effect: $c' = 1.668(0.327)$, $p < 0.001$; LLCI = 1.026; ULCI = 2.309; $R_M = 43.38\%$], indicating a partial mediation relationship between weekly frequency and mathematics through math anxiety. In the total effect model [$c = c' + ab = 3.845(0.340)$, $p < 0.001$; LLCI = 3.178; ULCI = 4.512], weekly frequency of out-of-school physical activity exhibited a significant positive relation to mathematics. The signs of ab and c' were the same, and the effect size index $p_m = ab/c$ (range from 0 to 1) indicated the proportion of the mediation effect to the total effect (Preacher and Kelley, 2011; Wen and Fan, 2015). The effect size index p_m in this mediation model was 0.566, meaning that the mediating effect of math anxiety accounts for 56.6% of the total effect between physical activity and mathematics.

Consequently, the mediating effect of weekly frequency of out-of-school physical activity on mathematics through math anxiety was statistically significant, and Hypothesis 1 was fully supported (see **Table 2**). The effect size index $f^2 = R^2/(1 - R^2)$ was used to measure the power of the mediation model, f^2 values equal to 0.02, 0.15, and 0.35 correspond to small, medium, and large effect sizes, respectively (Cohen, 2009). The effect size of the mediation model to math anxiety $f^2_{to\ MA} = 0.078/(1\text{-}0.078) =$

TABLE 1 | Descriptive statistics and correlations of core variables.

	Min	Max	Mean	*SD*	1	2	3	4	5	6	7	8
(1) Mathematics	126.72	834.83	513.15	125.80	1.000							
(2) Math anxiety	1.00	4.00	2.02	0.82	−0.376**	1.000						
(3) SES	−3.08	3.29	0.00	1.05	0.418**	−0.232**	1.000					
(4) School location	1.00	3.00	2.31	0.84	−0.239**	0.152**	−0.453**	1.000				
(5) Gender	0.00	1.00	0.47	0.50	−0.048**	0.054**	−0.008	0.016*	1.000			
(6) BMI	8.30	50.30	17.14	3.06	0.069**	−0.044**	0.133**	−0.106**	−0.129**	1.000		
(7) PAOS	1.00	8.00	4.51	2.26	0.138**	−0.172**	0.165**	−0.082**	−0.023**	0.029**	1.000	
(8) Parental support	1.00	4.00	3.37	0.83	0.082**	−0.121**	0.113**	−0.062**	0.052**	0.033**	0.228**	1.000

Parental support, perceived parental support for their children's participation in out-of-school sports activities; PAOS, the frequency of participation in out-of-school physical activities per week.
These variables were standardized during data analysis: math achievement, math anxiety, physical activity, parental support.
$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

TABLE 2 | Mediation analysis of the association between PAOS and math achievement through math anxiety.

	Math anxiety				Math achievement (total effect model)				Math achievement (direct effect model)			
Variables	**β (*S.E.*)**	***P***	**95% C.I.**	***R*²**	**β (*S.E.*)**	***P***	**95% C.I.**	***R*²**	**β (*S.E.*)**	***P***	**95% C.I.**	***R*²**
PAOS	**−0.136**	**0.000*** **	**−0.153**	**0.078*** **	**0.069**	**0.000*** **	**3.178**	**0.186*** **	**0.030**	**0.000*** **	**1.026**	**0.261*** **
	(0.002)		**−0.131**				**4.512**		**(0.327)**		**2.309**	
SES	−0.181	0.000***	−0.153		0.375	0.000***	43.524		0.324	0.000***	37.339	
	(0.006)		−0.131				46.759		(0.796)		40.462	
School_location1	0.003	0.721	−0.026		0.011	0.117	−0.907		0.012	0.078	−0.440	
	(0.016)		0.037				8.147		(2.200)		8.183	
School_location2	0.064	0.000***	0.077		−0.066	0.000***	−20.613		−0.048	0.000***	−15.823	
	(0.014)		0.133				−12.629		(1.942)		−8.210	
BMI	−0.003	0.646	−0.004		0.004	0502	−0.324		0.003	0.577	−0.336	
	(0.002)		0.003				0.662		(0.240)		0.604	
Gender	0.048	0.000***	0.057		−0.041	0.000***	−13.362		-0.028	0.000***	−9.787	
	(0.011)		0.099				−7.366		(1.458)		−4.071	
Math anxiety	–	–	–		–	–	–		**−0.287**	**0.000*** **	**−45.748**	
									(0.915)		**−42.163**	

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.
PAOS, the frequency of participation in out-of-school physical activities per week; school location 1, comparison of school location between town and city; school location 2, comparison of school location between rural area and city.
These variables were standardized during data analysis: Math achievement, Math anxiety, Physical activity, Parental support.
The standardized regression coefficients β are presented in this table. The bolded coefficient values are the key results in this mediation model.

0.085 was moderately small. The direct influence to math achievement of the mediation model was with a large effect size $f^2_{Direct-MATH} = 0.261/(1 - 0.261) = 0.353$. The total influence to math achievement of the mediation model was with a medium effect size $f^2_{Total-MATH} = 0.186/(1 - 0.186) = 0.229$.

Moderated Moderated-Mediation Model

Hypothesis 2 pertained to the conditional process model, which featured moderated moderated-mediation effects. The effect of parental support for physical activity and the child's gender on weekly frequency of out-of-school physical activity and mathematics through math anxiety were tested simultaneously (Hayes, 2018). The unstandardized results revealed that neither the three-way interactions of weekly frequency × parental support × gender nor the two-way interactions of weekly frequency × gender were significant, whereas the interactions of weekly frequency × parental support and parental support × gender were significant. The effect of parental support and children's gender on mathematics through math anxiety ($b = -36.239$, $p < 0.001$) accounted for 29% of the variance ($F[11,22497] = 187.202$, $p < 0.001$; **Table 3**). In addition, weekly frequency of out-of-school physical activity had a positive significant effect on mathematics and a negative effect on math anxiety (**Table 3**).

Specifically, the index of the whole moderated moderated-mediation model did not reach the significance level [Index = −0.159 (0.500); LLCI = −1.135; ULCI = 0.820]; however, the indices of the conditional moderated mediation with the parental support variable were significant for both male and female children [The conditional index of male = 1.158 (0.309); LLCI = 0.544; ULCI = 1.763; the conditional index of female = 0.999 (0.393); LLCI = 0.230; ULCI = 1.780]. This indicated that math anxiety played a significant mediating role at different levels of perceived parental support for both daughters and sons.

TABLE 3 | Moderated moderated-mediation model results and regression results for math anxiety as an intermediary variable.

		Outcome						
		M: Math anxiety				Y: Math achievement		
Predictor		***B***	***SE***	***P***		***B***	***SE***	***P***
PAOS	$a_1 \rightarrow$	−0.116	0.009	0.000***	$c' \rightarrow$	3.808	0.738	0.000***
Parental support	$a_2 \rightarrow$	−0.064	0.009	0.000***				
Gender	$a_3 \rightarrow$	0.103	0.013	0.000***				
PAOS × PS	$a_4 \rightarrow$	−0.032	0.008	0.000***				
PAOS × Gender	$a_5 \rightarrow$	−0.008	0.013	0.553				
PS × Gender	$a_6 \rightarrow$	−0.035	0.014	0.010*				
PAOS × PS × Gender	$a_7 \rightarrow$	0.004	0.013	0.735				
SES		−0.167	0.007	0.000***		38.800	0.797	0.000***
BMI		−0.001	0.002	0.772		0.280	0.238	0.239
Town-city		0.003	0.020	0.893		3.962	2.201	0.072
Rural area-city		0.125	0.017	0.000***		−12.039	1.943	0.000***
Math anxiety					$b \rightarrow$	−36.239	0.750	0.000***
	R	0.290		0.000***		0.511		0.000***

Gender	***Z*-score-PS**	**Conditional effect**	***SE***	**LICI**	**ULCI**
Female/daughter	-1	3.053	0.448	2.202	3.969
Female/daughter	0	4.211	0.342	3.553	4.888
Female/daughter	1	5.096	0.426	4.264	5.958
Male/son	-1	3.497	0.564	2.407	4.613
Male/son	0	4.495	0.380	3.761	5.255
Male/son	1	5.259	0.469	4.363	6.209

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.
PAOS, the frequency of participation in out-of-school physical activities per week; parental support, perceived parental support for their children's participation in out-of-school physical activities.
These variables were standardized during data analysis: math achievement, math anxiety, physical activity, parental support.
The unstandardized coefficients B are presented in this table (PROCESS software can only provide standardized regression coefficients for mediation-only models).

Figure 3 illustrates the effect of weekly frequency of out-of-school physical activity on mathematics through math anxiety, which was significant for both boys and girls in terms of parental support. From the overall trend, the anxiety level decreased significantly with the increase of weekly frequency of out-of-school physical activity, and most girls had a higher anxiety level than boys with the same level of parental support. The interaction between boys with low parental support and girls with high parental support was significant. In other words, in the same low weekly frequency situation, girls had higher levels of anxiety than boys; however, with the increase in the frequency of weekly out-of-school physical activity, the anxiety level of girls with high parental support was significantly lower than that of boys with low parental support.

Additionally, **Figure 4** depicts a statistical path diagram for the fourth-grade participants. According to the coefficients B, Eq. (5) can be written in the following equivalent form:

$$\theta_{PAOS \rightarrow anxiety} b = 4.204 + \left(1.160 - 0.145 gender\right) parental\ support + 0.290 gender.$$

The results showed that the mediating effect increased positively with *W* (perceived parental support), regardless of whether *Z* (gender) was 0 (male) or 1 (female). These results are visually reflected in **Figure 5**. The effect size of the moderated moderated-mediation model to math anxiety $f^2_{\text{M-M}-\text{M}-MA} = 0.290^2/(1 - 0.290^2) = 0.082$ was moderately small, while the whole moderated moderated-mediation model had a large effect size to math achievement, $f^2_{\text{M-M}-\text{M}-MATH} = 0.511^2/(1 - 0.511^2) = 0.353$.

DISCUSSION

In this study, a moderated moderated-mediation model was used to explore the association between physical activity and academic performance. Its contributions are three-fold. First, our study verified that out-of-school physical activity can affect mathematics. Second, we found that physical activity influenced mathematics through the mediating role of math anxiety. Finally, we observed that the effect of out-of-school physical activity on math anxiety was contingent on the perceived parental support for their participation in physical activity, regardless of the child's gender.

Out-of-School Physical Activity and Academic Performance

Consistent with our initial hypothesis, the results from our analysis of data from a representative sample of Chinese students

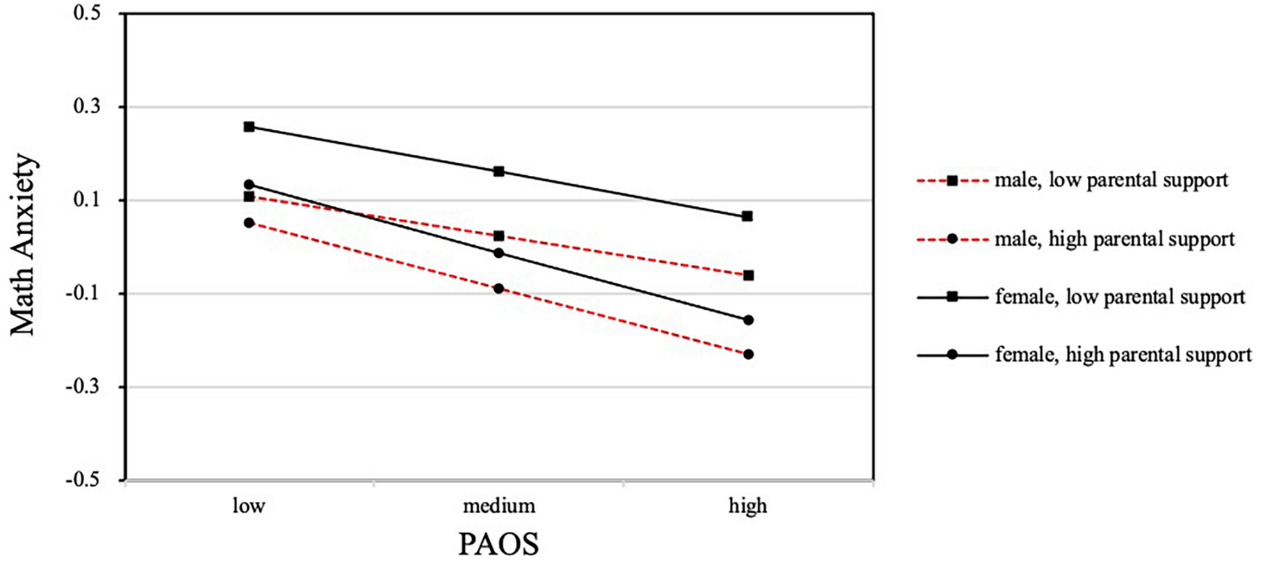

FIGURE 3 | Math anxiety as a function of PAOS, parental support, and children's gender.

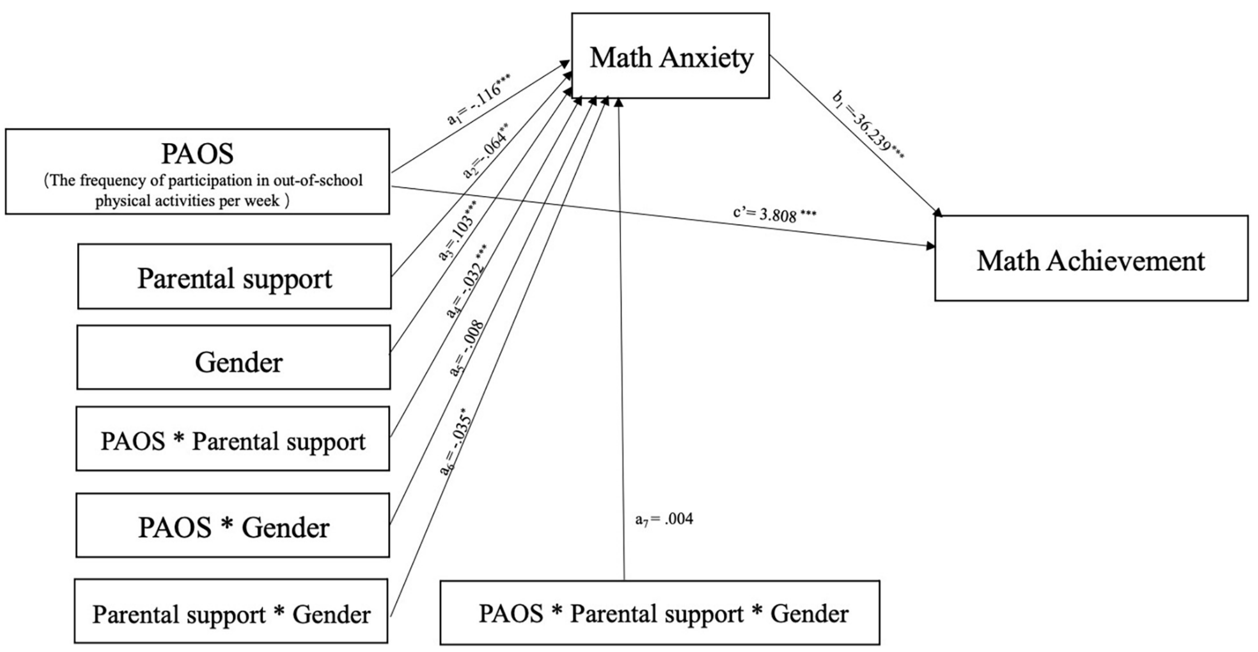

FIGURE 4 | Statistical (path diagram) form of the fourth-grade participants. **p* < 0.05, ***p* < 0.01, ****p* < 0.001.

supported the significant and direct effect of out-of-school physical activity on mathematics and were similar to other studies on such intramural activities (Donnelly et al., 2009; Diamond, 2015). Our results are also consistent with those of other studies that have demonstrated that in-school physical activity positively affects mathematical skills (Fredericks Claude et al., 2006; Davis et al., 2011; Erwin et al., 2012). The effect size of direct influence to math achievement of the mediation model meant that our research provided evidence for the positive impact of physical activity on academic performance from the perspective of physical activity out-of-school.

The positive effect of physical activity on academic performance is supported by the explanation of physiological performance and further verified the executive function hypothesis (Kopp, 2012). Regular exercise and moderate aerobic activity are associated with greater brain volume, improved neurophysiological responses to stimulation, and better levels of growth factors that promote brain tissue growth, neurogenesis,

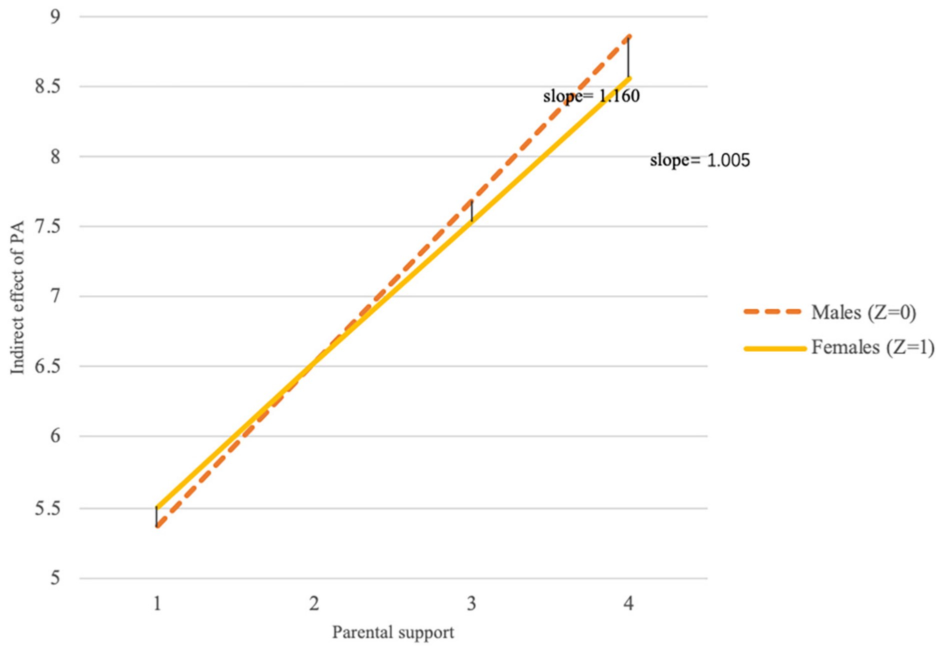

FIGURE 5 | Visual depiction of the indirect effect of PA on mathematics through math anxiety as a function of parental support (W) and gender (Z).

and angiogenesis, with physiological indicators like the flow of blood and oxygen to their brain concerning the effects of exercise on cognitive function (Teferi, 2020). Research confirmed that regular physical activity alters specific brain structures and functions, especially in tests that require more executive function (Miyake et al., 2000; Diamond, 2013), which is a subset of goal-directed cognitive operations underlying perception, memory, and action (Donnelly et al., 2016). Academic performance is strongly associated with neurocognitive improvements, and are closely related to core executive functions (cognitive flexibility, working memory, and inhibition) during brain development (Diamond, 2012; Singh et al., 2012; Álvarez-Bueno et al., 2017). The positive effect of physical activity on executive function has also been demonstrated (Diamond, 2012; van der Niet et al., 2014; Ishihara et al., 2017; de Bruijn et al., 2018). Hence, physical activity may prove to be a simple, yet important, method of enhancing those aspects of children's intelligence, cognition, and academic achievement (Tomporowski et al., 2007). The results of this study validated that out-of-school physical activity is equally effective.

The present study's focus on out-of-school physical activity expands the literature in this area and highlights the role of extramural sports. The impact of physical activity on academic performance and cognitive development is often underestimated, and out-of-school sports are given especially little attention. This is possibly because when researchers initially explored the impact of physical activity from the perspective of academic performance, they have tended to pay more attention to school education and focus on intra-school physical education, ignoring the positive impact of out-of-school physical activity on academic achievement. Compared with physical education in school, out-of-school physical activity is more in line with students' interests, the sports environment and types are more diverse, the exercise time is relatively free, the atmosphere is more relaxed, and its psychological and physical effects cannot be ignored. Combining the previous results on physical activity in schools and the factor of family support, this study informs how physical activity can have a more comprehensive effect on children's mental health, physical health, and academic performance.

Nonetheless, there is still room for improvement regarding the research design of physical activity indicators. On the one hand, the findings of this study were based on large-scale data, and some indicators (physical activity, and parental support for physical activity) were derived from fewer items. The study's replicability and the extension of this conclusion need to be further verified in other studies. On the other hand, almost all studies focus on one aspect of intramural or extramural sports, possibly due to the limitations of research design or practical operation (Donnelly et al., 2016; Álvarez-Bueno et al., 2017; Barbosa et al., 2020). When studying individual differences, in addition to the regular intramural sports curriculum, other intramural sports should be considered, which can make the role of sports in the research more refined.

Further, it is worth emphasizing that the impact of physical activity on other kinds of academic performance is also of concern. Although the subject of mathematics has received the most attention (Barbosa et al., 2020), there are several studies on reading, spelling, language, science, and geography. Most of these studies have also focused on intramural physical education (Sibley and Etnier, 2003; Esteban-Cornejo et al., 2015; de Greeff et al., 2018; Bedard et al., 2019). From the meta-analyses, physical activity had null or small-to-medium positive effects on academic performance, and chronic physical activity showed a moderately positive effect on academic performance, but acute physical activity did not demonstrate benefits (Barbosa et al., 2020). This deserves further attention, whether it is for different disciplines or different forms of physical activity.

Math Anxiety and Its Role in Physical Activity and Academic Performance

Our research provided further evidence for the distraction hypothesis, in which math anxiety can be regarded as similar to other mental health factors, for example, self-concept (Dapp and Roebers, 2019) and self-efficacy (Suchert et al., 2016; Liu et al., 2020), that improve the relationship between physical activity and academic performance as a mediator with the effect size of the proportion of the mediation effect to the total effect, which means that physical activity outside of school can improve math performance to some extent by relieving math anxiety, but not as strongly.

The present study's findings on the positive improvement effect of physical activity on anxiety levels provide further reference and highlight the characteristics of out-of-school physical activity. Systematic meta-analyses from the 1990s previously established a significant and negative correlation between mathematics anxiety and mathematics achievement, although some meta-analyses have recorded inconsistent effects of physical activity on anxiety (Craft and Landers, 1998; Ahn and Fedewa, 2011; Cerrillo-Urbina et al., 2015; Ferreira-Vorkapic et al., 2015). This study's analysis of the effect of out-of-school physical activity is more in line with the impacts on physical and mental health. Off-campus sports activities usually initiate from students' interests and are characterized by more freedom in exercise intensity and duration. It is, thus, conceivable that they could have a positive psychological and physiological effect.

The findings with a medium effect size provide evidence for the conceptual model, which hypothesized that the mechanisms explaining the association between physical activity, cognition and mental health in young people might be neurobiological, psychosocial and/or behavioral, and might be affected by the indicators of physical activity (Lubans et al., 2016; Barth Vedøy et al., 2020). The effects of physical activity on mental health can be explained by physiological indicators, such as cerebral blood flow and arousal levels (Querido and Sheel, 2007), neurotransmitters (Ploughman, 2008), the growth and plasticity of neurons (Hassevoort et al., 2016), and measures of brain function related to executive function (Donnelly and Lambourne, 2011). Results were similar to another study, it showed that increased physical activity levels and fitness can help alleviate or relieve depression, anxiety and stress by improving bone and musculoskeletal function (Eveland-Sayers et al., 2009). And the findings from previous large-scale observational studies also suggest that physical activity participation has a small to moderate effect on preventing and managing the risk of anxiety and depression, which in turn affects academic performance and mental health (Teferi, 2020).

Although the effect of physical activity on anxiety was supported in this study, other mental health factors were not considered or controlled for, which may be a reason behind the weak effect on this aspect. In particular, general and test anxiety, which are closely related to math anxiety, (Hunsley, 1987), were not considered. Since general anxiety is not specific to a situation, its relationship to mathematics performance is less direct than math anxiety (Barlow et al., 1986). Regarding test anxiety, since this assessment was a low-stakes test, the purpose was to monitor the overall levels, and not fed the results back to students. Studies on the relationship between general anxiety and test anxiety with mathematics avoidance behavior showed that, compared with situational measures of test anxiety, mathematics anxiety was associated with higher ability and mathematics avoidance behavior (Dew et al., 1984). Therefore, general anxiety and test anxiety were not controlled in this study. However, the influence of these two on performance cannot be ignored, and it is necessary to obtain supplementary verification in follow-up research.

In addition, evidence suggests that the association between math anxiety and math achievement starts in childhood, and remains significant through adulthood (Hill et al., 2016). As for adolescents and young adults, a large body of research has found small-to-moderate negative correlations between math anxiety and math achievement in middle school, high school, and undergraduate student samples (Hembree, 1990; Ma, 1999). The difference in the magnitude of this relationship at different growth stages needs to be further explored. Moreover, Lagerberg (2005) argued that physical activity cannot guarantee an improvement in mental health because many moderating factors are present. The factors that moderate the relationship between students' math anxiety and achievement include gender, school grade, age, ethnicity, teachers' characteristics, and (low) math ability (Lagerberg, 2005; Barroso et al., 2021). These influencing factors deserve further refinement or combination in subsequent studies.

Moderating Role of Parental Support According to Children's Gender

Notably, parental support for children's out-of-school physical activity had a significant positive effect on reducing anxiety and improving mathematical performance for both boys and girls. The results regarding the interaction between perceived parental support and gender indicated that although the average math anxiety levels among girls with low weekly frequency of out-of-school physical activity were higher than that of boys, as children perceive more support for physical activity from their parents, the anxiety levels of girls with high parental support were significantly lower than those of boys with low parental support. Thus, parents' support for their children's after-school physical activity played a key, positive role in improving their children's mental health and academic performance. Naturally, it will also contribute to their physical health, which deserves more attention from parents and requires schools and relevant education departments to provide corresponding coordination and assistance.

The interaction between gender and weekly frequency of out-of-school physical activity had no significant effect on anxiety, indicating that out-of-school physical activity can improve math anxiety and mathematical performance regardless of gender. Although Hypothesis 2 was not verified, we obtained research results that can be beneficial to improving children's anxiety and academic performance. This means that if parents give support for either their children's physical activity, children can alleviate their anxiety through appropriate physical activities and improve mathematics performance. Therefore, parents should be encouraged to support the moderate-to-vigorous physical activity of their children, and different methods can be considered according to children's gender (Lijuan et al., 2017).

In addition, the significant interaction between parental support and weekly frequency of out-of-school physical activity on anxiety indicated that different levels of parental support for their children's extracurricular physical activity significantly affected children's math anxiety and mathematics. The results showed that the whole moderated moderated-mediation model had a large effect size to math achievement. It can be suggested that within a reasonable range (e.g., once a day), the higher the degree of parental support for their physical activity that children perceive, the more extensive the effect of physical activity on relieving their anxiety, which in turn affects their academic performance. It is recommended that education practitioners and parents can focus on supporting their children's physical activity in different aspects.

Theoretical and Practical Implications

This study has implications for theory and educational practice and application and provides empirical evidence for the positive impact of physical activity on mental health and subject education. First, our research provided further support for the distraction hypothesis, the executive function hypothesis and verified the mediation effect of anxiety. Appropriate levels of physical activity had a significant effect on improving academic performance through the alleviation of anxiety, which supported our initial hypothesis and was consistent with the mediating effect of other psychological variables in relevant previous studies. The significant partial mediation effect of math anxiety further validated this mechanism.

Second, our results provided evidence for the positive effect of physical activity on mathematics academic performance from the specific perspective of after-school physical activity, which has important reference value for enhancing the prioritization of physical activity by education departments. It is not so easy to attract attention to the importance of the effect of out-of-school physical activity, especially among those parents who neglect physical activity or overemphasize academic performance; however, it is worthwhile to help them realize that appropriate physical activity is a good way to benefit both their children's academic performance and physical health. Parents should be made aware of the potential harm of physical and mental problems. Rather than focusing solely on the academic performance of their children or condoning their children to spend too much time on electronic products, parents should try to make changes in their thinking and daily arrangements and support their children as much as possible to participate in physical activities.

Third, the nexus between physical activity and mathematics through math anxiety has crucial implications for policymakers. Governments should emphasize the indispensable role of physical activity, assist schools in formulating feasible physical education and activity plans, and provide corresponding financial and implementational support to reduce the negative effects of overlearning at the national level. Educational departments at different levels can support physical activity in schools according to the actual situation and reasonably increase courses and extracurricular activities in schools, including curricular physical education (PE), integrated physical activity (active breaks or teaching subjects such as math with physically active tasks), and extracurricular physical activity (active recess or lunchtime physical activity).

Fourth, the communication between schools and families should be enhanced, with schools advocating for the value of physical activity to parents. Schools should be encouraged to confirm the positive role of physical activity to parents. While actively organizing and arranging intra-school physical activity, parents should be able to actively and reasonably participate in children's physical activity arrangements. This would allow the effective combination of physical activity both in and out of school, rendering the impact of physical activity on physical and mental health more efficient.

Lastly, to encourage physical activity among children, the environment for physical activities must be engaging, rather than based on strict discipline and an emphasis on skill, otherwise, it may cause children further psychological burden (Lagerberg, 2005). Moreover, while encouraging physical activity, parents should be cautious of over-emphasizing its importance, which would lead to replacing one misunderstanding with another. The special needs, interests, and mental health of children should be taken into consideration; extra training courses should be selected carefully; and compulsory activities must be avoided. Furthermore, policymakers and education executors should strengthen their participation in, and guidance they provide on, the environment, content, and implementation of physical activity in order to obtain more reliable evidence and improve the impact of physical activity on children's physical health, psychological health, and academic performance more effectively.

Limitations

Some limitations of the current study should be mentioned. First, part of the analyzed data was derived from self-reported questionnaires. For children in the fourth grade, it is inevitable that this data would include inaccurate or invalid answers. In follow-up research, more flexible and objective data collection methods should be adopted, such as online check-ins or activity records. Second, the variety of key variables analyzed could be richer. Our study used the frequency of activity as a variable when assessing out-of-school physical activity; however, the type of activity (e.g., aerobic), duration, and dosage can be investigated by future studies on the benefits of physical activity (Petruzzello et al., 1991; Ahn and Fedewa, 2011; Kyan et al., 2019). In addition, in terms of parental support variables, further angles of inquiry could include the supportive behavior of parents, degree of parental participation, and maternal or paternal logistical support (Trost et al., 2003; Davison, 2004; Gustafson and Rhodes, 2006). Third, more diverse experimental designs and a richer composition of participants can be considered in order to compare and supplement the present study's research results. The intervention effects of physical activity on mental health may differ depending on other moderators such as research design (Conn, 2010) and study implementation (Stice et al., 2006), in addition to gender (Kremers et al., 2007; Simen-Kapeu and Veugelers, 2010). In future research, more moderating variables or the comparative study of different groups can be used. Controlling conditions should be more stringent as well (e.g., control for physical activity in other contexts, general anxiety, or test anxiety) to undertake richer and more systematic research on the relationships between physical activity, psychological variables, and other academic achievements.

CONCLUSION

This research examined whether physical activity improves math achievement through the alleviation of math anxiety, with the incorporation of the moderating role of perceived parental support for physical activity and the factor of gender. The results demonstrated that both boys and girls can benefit significantly from parentally supported physical activity, which can alleviate math anxiety and, in turn, improve their academic performance in mathematics. As perceived parental support for physical activity and the frequency of participation in out-of-school physical activities per week increased, the children's anxiety levels and mathematics were significantly affected in a positive direction.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: the dataset is confidential. Further inquiries should be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Collaborative Innovation Center of Assessment Toward Basic Education Quality, Beijing Normal University, Beijing, China. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

TY supervised the quality of the research process and provided financial support. HL supervised the quality of the research process and revised it critically for important intellectual content. JZ designed the study, analyzed the data, and wrote the manuscript. HW provided valuable suggestions for the study design and checked the quality of the research. XW participated in the data analysis and manuscript revision. YW participated in the data analysis and provided suggestions. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.862666/full#supplementary-material

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Effects of Kindergarten, Family Environment, and Physical Activity on Children's Physical Fitness

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To explore the relationship between kindergarten environmental factors, children's physical activity, and physical fitness, this study uses the stratified random sampling method to obtain 4,600 children in relevant kindergartens. The questionnaire survey and children's physical fitness test were completed with the help of parents and kindergarten staff. The exploratory (EFA) and confirmatory (CFA) factor analysis is used to process the obtained database and set the significance level of all indicators $\alpha = 0.05$. The results show that kindergarten environmental factors significantly affect children's physical activity and healthy physical fitness. Children with large play areas in these kindergartens, more sports equipment items, who participate in more than three games per week, of no <40 min of each class, with an appropriate number of classes, and excellent teachers' teaching ability have better physical fitness. Family environmental factors significantly affect children's physical activity and fitness. Children with more family sports equipment items, more peers living nearby, safer playing places, more hands and feet, and parents who are good at sports have better performance in health fitness. Children's physical activity not only directly affects their performance of physical fitness, but also plays a dual intermediary role between kindergarten environment and physical fitness, family environment, and healthy physical fitness.

Keywords: kindergarten environment, family environment, physical activity, healthy physical fitness, mediation, multiple regression

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INTRODUCTION

Early childhood is a relatively stable and rapid development stage, and is the primary stage of future skill development. If we can stimulate the development of children's physical function, it will help to improve their physical activity efficiency (1, 2). Early childhood is also a critical period to learn basic motor skills. Maturity alone cannot be fully developed, but the relevant goals can be achieved through the interaction between individual children and the environment (3). The first environment children are exposed to after birth is the family one. Relevant research shows that family housing form (4–6), socioeconomic status (5, 7), birth order of children (8), education level of children's parents (9), and parents' participation in sports associations (10) can provide important information about the impact of the family environment on children's health and physical development. However, due to the limitation of human resources, scholars have not comprehensively discussed these variables. Scholars tend to focus on three factors: the impact of family sports experience (such as outdoor sports games, running and jumping sports game frequency, etc.) on children's physical fitness (11, 12); the impact of the family physical environment (such as safe sports and game places near the family and the amount of sports equipment in the family) on children's health and physical fitness (13, 14); and the impact of family psychosocial environment (such as the number of siblings, birth order, the number of playmates of the same age, and parents' expectations) on children's health and physical fitness (15–17).

On the other hand, with the rapid development of the economy, the proportion of children from two-wage families is increasing. The enrollment rate of 5-year-old children is almost 100%, and more than half of them are sent to Kindergarten at the age of two (18, 19). Kindergarten is an ideal environment for children to enter learning and grow up in group life formally. It plays a vital role in childhood. From the perspective of dynamic physical education, if children can develop good exercise habits in preschool education, this will impact positively on subsequent healthy growth. Relevant research reports show that kindergarten environmental factors (such as space size, venue equipment, sports games, class methods, etc.) also play an essential role in the development of children's health and physical fitness. The survey found that the space available for sports games in kindergartens in China is generally small, and children's activity space is insufficient (20). Children's sports and game courses are inadequate. The opening rate of weekly physical fitness courses and 1-h outdoor activity courses every day is significantly lower than in Japan. The number of sports and game courses is too large, and teachers waste more time maintaining classroom order, which reduces the teaching quality of sports and game courses (21–23). There are also research reports that show the development of children's health and physical fitness is closely related to the kindergarten environment, the total area of the kindergarten, the amount of sports equipment and equipment items, whether the curriculum content is based on games, and whether children have an annual physical fitness test (24–28).

At present, the lack of physical activity in young children has become a common problem worldwide. In the newly issued guidelines for young children's sports, preschool children must accumulate more than 180 min of various types of physical activities throughout the day, including no <60 min of physical activities of medium and above intensity (29). It can be seen that to meet the requirements of the guide, the impact of family and kindergarten environment on children's physical activity cannot be underestimated. Firstly, children's physiological and cognitive characteristics determine that they need their parents to provide sports experience and information, and sports itself is highly infectious. Children's sports socialization process is affected by parents' sports attitudes. Compared with children without support, children with parental encouragement and support are more likely to participate in various sports games and believe that they have more robust sports performance (30, 31). Secondly, children spend most of their time in kindergartens. Whether the teaching of children's physical education curriculum meets the needs of children, especially whether children can reach the expected level of physical activity every day, is quite sensitive to the impact on the development of their basic motor skills. If children do not participate in sports games for enough time, sedentary time will increase, which is bound to affect their health, physical fitness, and movement development level. In fact, at present, there is a severe shortage of physical activity in children in China. The obesity rate and poor vision detection rate of children aged 3– gradually increase with age (31); the uncoordinated proportion of children's movement development is as high as 42 and 67.3% of children cannot master all kinds of health and physical fitness well (32).

To sum up, children's health and fitness are affected by the kindergarten and family environment, as well as the amount of daily physical activity. Among them, kindergarten curriculum content, teaching methods, class atmosphere, situational arrangement, and learning evaluation all affect health and fitness in a flexible manner. Family sports experience, the physical environment inside and outside the family, and psychosocial environment are more complex and changeable. These multi-level interactive and mixed environmental factors affect the development of children's physical fitness (33). Therefore, it is an important research topic to explore the impact of kindergarten and family environmental factors on children's physical activity and physical fitness, and reveal the causal relationship and influence weight between these variables, so as to cultivate children's good exercise habits. At present, the research of foreign scholars mostly focuses on the investigation of the implementation of sports game curriculum. However, some foreign scholars have extended the detection field to the empirical study of the impact of environmental factors on children's health and physical fitness, the overall research on the relationship between various variables is insufficient. Because of this, this study attempts to explore the causal relationship between kindergarten and family environment, children's physical activity, and healthy physical fitness using quantitative research. It boldly puts forward that physical activity may mediate environmental factors and healthy physical fitness, to provide a more reliable practical basis for promoting the development of children's motor skills and motor performance.

OBJECTS AND METHODS

Respondents

This study selects the parents of children in all kindergartens registered by the Education Bureau of the main metropolitan and non-main metropolitan areas of Chongqing as the survey object. The situation of kindergartens in all districts of Chongqing in 2020 through the preschool education network were sorted, including the main urban areas: Yuzhong District, Jiangbei District, Nan'an District, Yubei District, Beibei District, Jiulongpo District, and Shapingba District. The non-main urban areas included: Yongchuan District, Changshou District, Hechuan District, Jiangjin District, Bishan district, and Jiangjin district. To ensure the representativeness of the sample, this study randomly selected four kindergartens in each section and obtained a total of 52 kindergartens (28 in the main urban area and 24 in the non-main metropolitan area); After the establishment of kindergartens, one kindergarten class aged 4, 5, and 6 was randomly selected from each kindergarten, and a total of 156 classes were obtained (84 in the main urban area and 72 in the nonmain metropolitan area).

Questionnaire Distribution and Recovery

Before the investigation, the members of the research group communicated with the district education bureaus successively, and then negotiated with the heads of the kindergartens after obtaining authorization. Each kindergarten was entrusted to select the client (principal or director) to submit the survey paper to the corresponding parents of children. In total, 4,600 questionnaires were distributed, 4,386 were recovered, and 99 invalid questionnaires (key information variables were not filled in) were eliminated. Finally, 4,287 valid questionnaires were obtained, including 2,311 boys and 1,976 girls, 3,107 public kindergartens and 1,180 private kindergartens, 2,400 in main metropolitan area, and 1,887 in non-main metropolitan area (see **Table 1**).

Research Tools

Questionnaire Design

Based on a large number of documents and combined with the needs of this study, a "questionnaire on kindergarten and family environment and physical activity" is formed through preparation, modification, sorting, and analysis, including:

Contents of Kindergarten Environment Survey: (1) kindergarten attribute, subordinate area, and surrounding area; (2) Number of kindergarten staff; (3) The area and total area of the kindergarten playing field; (4) Sports equipment items in kindergartens; (5) Teaching activities in kindergartens (such as the number of sports game courses implemented every week, the main contents of game courses, the time of implementing game courses each time, and the number of classes implementing sports game courses in each class); (6) Teachers who teach children's sports and game courses in kindergartens; and (7) Implementation of a health fitness test in kindergartens.

The contents of the investigation of children's family environment: (1) Residential type; (2) Home sports equipment project; (3) Whether the sports and game places near the home are safe; (4) Number of siblings in the family; (5) Education level of parents; (6) Whether parents are good at sports; and (7) Number of playmates of the same age near the family.

To calculate children's physical activity, the calculation formula of exercise participation used by Fox (34) is adopted: degree of exercise participation = exercise frequency × (average exercise intensity + exercise duration). The greater the value, the higher the degree of exercise participation, and the subjects were divided into high, medium, and low categories according to the baseline of children's physical activity. The calculation method of exercise duration is: A. exercise time ≤30 min, B. exercise time is 31–40 min, C. exercise time is 41–50 min; D. The exercise time is 51–60 min, and E. the exercise time is ≥61 min (1–5 points are given from a to e, respectively). The calculation method of exercise intensity is, A) not tired at all, B) not tired, C) a little tired, D) very tired, E) very tired (1–5 points from a to e, respectively). The exercise frequency is calculated based on the number of exercise times in a week: A, ≤1 time / week, B, 1–2 times per week, C, 3–4 times per week, D, 5–6 times per week, E, more than six times per week (1–5 points are given from a to e, respectively).

TABLE 1 | The relationship between children's physical activity, health fitness, and personal essential background variables ($N = 4,287$).

		Physical activity				Healthy physical fitness			
		High activity	**Moderate activity**	**Low activity**	**test (x^2;P)**	**High fitness**	**Moderate fitness**	**Low fitness**	**test (x^2;P)**
Gender	Male	808 (35.0%)	1,178 (51.0%)	325 (14.1%)	22.32; 0.000	952 (41.2%)	1,016 (44.0%)	343 (14.8%)	33.0; 0.000
	Female	560 (28.3%)	1,129 (57.1%)	287 (14.5%)		664 (33.6%)	882 (44.6%)	430 (21.8%)	
	Total	1,368 (31.9%)	2,307 (53.8%)	612 (14.3%)		1,616 (37.3%)	1,898 (44.3%)	773 (18.0%)	
Kindergarten attribute	Public kindergarten	991 (31.9%)	1,696 (54.6%)	420 (13.5%)	5.79; 0.055	979 (40.8%)	1,022 (42.6%)	399 (16.6%)	23.37; 0.000
	Private kindergarten	377 (31.9%)	611 (51.8%)	192 (16.3%)		637 (33.8%)	876 (46.4%)	374 (19.8%)	
	Total	1,368 (31.9%)	2,307 (53.8%)	612 (14.3%)		1,616 (37.3%)	1,898 (44.3%)	773 (18.0%)	
Kindergarten location	Downtown urban area	960 (40.0%)	1,080 (45.0%)	360 (15.0%)	192.53; 0.000	1,010 (42.1%)	1,092 (45.5%)	298 (12.4%)	125.03; 0.000
	No downtown	408 (21.6%)	1,227 (65.0%)	252 (13.4%)		606 (32.1%)	806 (42.7%)	475 (25.2%)	
	Total	1,368 (31.9%)	2,307 (53.8%)	612 (14.3%)		1,616 (37.3%)	1,898 (44.3%)	773 (18.0%)	

Health Fitness Measurement of Young Children

The physical fitness of children aged 4 to 6 is mainly measured by the fifth national physique monitoring index system (children's Edition). The contents include:

(1) Walking balance beam (balance capacity); (2) Standing long jump (explosive force); (3) 15 m obstacle running (coordination and agility); (4) Forward bending in sitting posture (flexibility); (5) Continuous jumping with both feet (muscle endurance); and (6) Six test items, including 20 m running (speed), are designed to evaluate children's health and physical fitness. According to the baseline standard of children's health and physical fitness index, the health and physical fitness were divided into three categories: high, medium, and low. To reduce the error, the survey personnel shall discuss before the test, explain the matters that must be required during the test, and strive to standardize the test. The whole test will be completed from May 1 to June 5, 2020. The six test items were tested twice, and the best results were obtained. The testers were composed of 16 postgraduates majoring in physique and health (divided into four groups). To reduce the possibility of test error, the prediction was made in three kindergartens before the formal test, to obtain the reliability among testers (i.e., consistency among testers).

Validity and Reliability

In terms of validity analysis, after the pre-test survey volume was finalized, eight experts in this field were hired to evaluate the meaning expression (correctness and need) of the questionnaire, and provide suggestions on adding, deleting, or merging and other suggestions. After the questionnaire was recovered, the topic sentences and questionnaire structure were modified one by one according to the opinions put forward by experts and scholars. The semantics and sentences were clear, smooth, and complete. Finally, the average validity score of experts was more than 90 points. In terms of reliability analysis, the questionnaire was tested by test-retest reliability. The research group randomly selected three kindergartens in Beibei District and tested them by retest at 3 weeks. The test-retest reliability was 0.93 ($P < 0.05$).

Mathematical Statistics

SPSS 21.0 was used to analyze the data, and crosstabs, correlation, and regression analysis were used to explore the correlation between kindergarten and family environmental factors, children's sports participation, and children's health and physical fitness index, using Amos 21.0 to construct structural equation model and explore the mediating effect of physical activity. Significance level setting of all indicators $\alpha = 0.05$.

RESULTS

Comparison Between Children's Background Information and Their Physical Activity and Fitness

Table 1 shows:

(1) According to the overall situation of the respondents, the proportion of high, medium, and low physical activity was 31.9, 53.8, and 14.3%, respectively. Through crosstabs analysis, it was found that there were significant gender differences in children's physical activity, which was affected by the geographical location of kindergartens (Pearson Chi-Square: $x^2 = 22.32$, 192.53, P = 0.00, 0.00). Among them, the physical activity of male children was generally higher than that of female children (high activity accounts for 35.0 vs. 28.3%), and the physical activity of children in central urban was generally higher than that in non-main urban areas (high activity accounts for 40.0 vs. 21.6%).

(2) The overall situation of children's health and physical fitness was that the proportion of high, medium, and low fitness were 37.3, 44.3, and 18.0%, respectively. Further analysis shows that there were significant gender differences in children's health and physical fitness. At the same time, affected by the attributes and geographical location of kindergartens (Pearson Chi-Square: $x^2 = 33.0$, 23.37, 125.03, $P = 0.00$, 0.00, 0.00), it shows that the health and physical fitness of male children was generally better than that of female (high fitness ratio 41.2 vs. 33.6%). The health and physical fitness of public kindergartens was usually better than that of private kindergartens (high fitness ratio 40.8 vs. 33.8%). The health and physical fitness of kindergartens in central areas was generally better than those in non-main urban areas (high Fitness accounts for 42.1 vs. 32.1%).

Correlation Analysis Between Family, Kindergarten Environment, Children's Physical Activity, and Physical Fitness

Table 2 shows:

(1) There is relative independence between the kindergarten environment and the family environment. The correlation coefficient is very weak, but there is a significant correlation between kindergarten environment and family environmental factors and children's physical activity ($r = 0.38^*$, 0.32^*); Kindergarten environment was significantly correlated with children's "walking balance beam" (0.31*), "standing long jump" (0.32*), "double foot continuous jump" (0.32*), and "20 m run" (0.41**), while the family environment was significantly correlated with children's "15 m obstacle running" (0.27*), "double foot continuous jump" (0.28*), and 20 m run (0.37*).

(2) There is a high correlation between children's physical activity and its six indicators of health and physical fitness, that is, the correlation coefficients between children's physical activity and walking the balance beam, standing long jump, 15 m obstacle running, sitting body flexion, continuous jumping off both feet, and 20 m running are 0.51**, 37*, 0.48**, 0.25*, 0.55**, and 0.39*, respectively. In addition, there is a moderate or high correlation between children's physical fitness indicators (Y_1-Y_6), which provides a basis for the construction of subsequent mixed models.

Analysis of the Impact of Kindergarten and Family Environment and Children's Physical Activity on Their Health and Physical Fitness

To reveal the impact of kindergarten environment, family environment, children's physical activity, and other factors on their health and physical fitness, this study uses multi-classification ordered logistic regression method. The standard

TABLE 2 | Correlation matrix between family and kindergarten environment, children's physical activity, and health fitness indicators.

	X	M	S	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6
X: Kindergarten Environment	1.00								
M: home environment	0.04	1.00							
S: Physical activity	**0.38***	**0.32***	1.00						
Y_1: Walking balance beam (s)	**0.31***	0.05	**0.51****	1.00					
Y_2: Standing long jump (cm)	**0.32***	0.09	**0.37***	**0.32***	1.00				
Y_3: Run around obstacles for 15 m (s)	0.07	**0.27***	**0.48****	**0.25***	**0.24***	1.00			
Y_4: Sitting posture forward flexion (cm)	0.10	0.08	**0.25***	**0.34***	**0.29***	**0.33***	1.00		
Y_5: Continuous jump with both feet (cm))	**0.32***	**0.28***	**0.55****	**0.41****	**0.54****	**0.27***	**0.45****	1.00	
Y_6: 20 m running (s)	**0.41****	**0.37***	**0.39***	**0.30***	**0.21***	**0.33***	**0.52****	**0.41****	1.00

"", "**" represent the significant levels of 0.05 and 0.01, respectively.*

model of odds ratio (OR) is:

$$\ln\left(\frac{\pi_{il}+\ldots+\pi_{ij}}{\pi_{i(j+1)+\ldots\pi_{ij}}}\right)=\alpha_j-(\beta_1X_{i1}+\ldots+\beta_PX_{iP}) \quad (1)$$

(I) Multi classification logistic regression model

The cumulative probability has $P_1 \leq P_1 + P_2 \leq P_1 + P_2 + P_3 \leq \ldots \leq P_1 + P_2 + \ldots P_J = 1$. Therefore, J-1 models can be created for J categories. Each cumulative logistic model is like a general binomial logistic model. If the former J category is merged into one category, it will be merged into another category from (J + 1) to the j.

In this study, according to the baseline standard of children's healthy physical fitness (4 ∼ 5 ∼ 6 years old), walking balance beam (Y_1), standing long jump (Y_2), 15 m obstacle running (Y_3), sitting posture forward flexion (Y_4), double foot continuous jumping (Y_5), and 20 m running (Y_6) are divided into five grades: excellent, good, medium, pass, and fail. The corresponding probabilities are P_1, P_2, P_3, P_4, and P_5 in turn. Obviously, $P_1 + P_2 + P_3 + P_4 + P_5 = 1$. Thus ($Y_1$-$Y_6$), all obey the ordered distribution of 5 classifications. Selecting 13 indicators such as kindergarten environment, family environment and children's physical activity as the influencing variable group, the following four cumulative logistic models can be obtained.

$$\ln\left(\frac{p_1}{p_2+p_3+p_4+p_5}\right)=\alpha_i-(\beta_1X_{i1}+\ldots+\beta_PX_{i\beta}),\ j=1 \quad (2)$$

$$\ln\left(\frac{p_1+p_2}{p_3+p_4+p_5}\right)=\alpha_i-(\beta_1X_{i1}+\ldots+\beta_PX_{i\beta}),\mathrm{j}=2 \quad (3)$$

$$\ln\left(\frac{p_1+p_2p_3}{p_4+p_5}\right)=\alpha_i-(\beta_1X_{i1}+\ldots+\beta_PX_{i\beta}),\ j=3 \quad (4)$$

$$\ln\left(\frac{p_1+p_2p_3+p_4}{p_5}\right)=\alpha_i-(\beta_1X_{i1}+\ldots+\beta_PX_{i\beta}),\ j=4 \quad (5)$$

(II) Four cummulative logistic regression models

Regression model and obtain odds ratio (OR). Generally, for the reference baseline (OR = 1), if OR > 1, it indicates that the influencing factor is favorable for Y. Otherwise, it is negative.

Table 3 shows: (1) The playground area in kindergartens significantly affects children's Y_2, Y_3, and Y_6. The OR value shows that when the area of playgrounds in kindergartens increases from "61–100 m^2" to "≥ 101 m^2", the number of children who significantly improve their physical fitness indexes of explosive power, sensitive coordination, and speed will increase to 1.29, 1.28 and 1.35 times the original number, respectively. The number of sports equipment items in kindergartens significantly affects children Y_1 and Y_3. The OR value shows that when the number of sports equipment items in kindergartens increases from "less than six kinds" to " 16 kinds and above," the number of children who improve their balance ability, sensitivity, and coordination ability will increase to 1.36 and 1.29 times of the original number, respectively. The number of weekly play classes in kindergartens significantly affects Y_1, Y_2, Y_5, and Y_6. The OR value shows that when the number of weekly play classes in kindergartens increases from "2 times/week" to "≥ 3 times/week", the number of children whose balance ability, explosive power, endurance, and speed can be significantly improved will increase to 1.52, 1.47, 1.42, and 1.67 times of the original number, respectively. The length of each game class in kindergarten significantly affects Y_2 and Y_6. The OR value shows that when the time of each game class in kindergarten increases from "<30min / time" to "≥41min / time", the number of children whose explosive power and speed increase significantly will increase to 1.25 and 1.87 times of the original number, respectively. The number of play classes per kindergarten significantly affects Y_2, Y_3, Y_4, Y_5, and Y_6. The OR value shows that when the number of play classes per kindergarten increases from "1 class/time" to "2 classes/time," the number of children who can significantly increase their explosive power, sensitive coordination, flexibility, endurance, and speed will increase to 1.31, 1.24, 1.39, 1.29, and 1.41 times of the original number, respectively, However, when the number of game classes in kindergartens increases from "2 classes/time" to ≥ "3 classes/time," the number of children whose explosive power, sensitivity and coordination, flexibility, endurance, and speed decline significantly will reach 0.74, 0.68, 0.70, 0.81, and 0.64 times of the original number, respectively. The professional ability of game teachers significantly affects Y_1, Y_2, Y_5, and Y_6. The OR value shows that when the professional ability of game teachers is improved from "good ability" to "very good ability," the number of children with a significant increase in balance ability, explosive power, endurance, and speed will increase to 1.32, 1.29, 1.31, and 1.59 times the original number, respectively.

(2) Family sports equipment items significantly affect children's Y_2, Y_3, Y_5, and Y_6. The OR value shows that when the amount of family sports equipment items increases from "6-9 items" to "10 and above," the number of children who can significantly improve their explosive power, sensitivity coordination, endurance, and speed will increase to 1.37, 1.52, 1.62, and 1.40 times the original number, respectively; The safety of sports and game venues near the home significantly affects children Y_1, Y_2, Y_3, Y_5, and Y_6. The OR value shows that when the safety of sports and game venues near the home changes from "not very safe" to "very safe," the number of children whose balance ability, explosive power, sensitivity, coordination, endurance, and speed increase significantly will increase to 1.34, 1.18, 1.23, 1.24, and 1.20 times of the original number, respectively. The number of siblings in the family substantially affects children Y_1, Y_3, Y_5, and Y_6. The OR value shows that when the number of siblings increases from "one person" to "two or more," the number of children with significant increases in balance ability, sensitivity, coordination, endurance, and speed will increase to 1.26, 1.72, 1.39, and 1.52 times the original number, respectively. The father's sports proficiency and ability significantly affect children Y_3 and Y_5. When the father's sports proficiency and ability are improved from "general ability" to "very good," the number of children's sensitive coordination and endurance will increase significantly to 1.32 and 1.30 times the original number, respectively. Mother's Sports proficiency and ability significantly affect children Y_1 and Y_5. When mother's Sports proficiency and ability are improved from "general level" to "very good," the number of children whose balance and endurance are significantly improved will increase to 1.23 and 1.27 times the original number, respectively. The number of playmates of the same age near the family significantly affects children Y_3, Y_5, and Y_6. When the number of playmates of the same age near the family increases from "≤3 person" to "≥5 person," the number of children with a significant increase in sensitivity coordination, endurance, and speed will increase to 1.48, 1.29, and 1.32 times the original number, respectively.

(3) Children's physical activity significantly affects their health and physical fitness in six aspects (balance ability, explosive force, sensitivity and coordination, flexibility, endurance, and speed). When children's physical activity increases by a unit value, the number of children whose balance ability, explosive force, sensitivity coordination, flexibility, endurance, and speed increase significantly will increase to 1.29, 1.22, 1.31, 1.21, 1.33, and 1.20 times the original number, respectively.

Causal Relationship Between Environmental Factors, Physical Activity, and Children's Health and Physical Fitness

Figure 1 is a hypothetical model about the causal relationship between kindergarten and family environment, physical activity, and children's physical fitness. After verification, the model shows:

(1) From the results of absolute fit test: the absolute fit index x^2 / DF of the model is 2.77, and the corresponding probability $p = 0.26 < 0.05$, indicating that the covariance matrix of the hypothetical model is very suitable for the observed data. The AGFI value of the model is 0.94 (> 0.90 is the adaptation), and the RMSEA is 0.048 (generally, RMSEA <0.05 is excellent, and 0.05–0.08 is good). From the value-added adaptation test results, IFI = 0.93 (>0.90 is the adaptation), CFI = 0.97 (>0.90 is the adaptation), and TLI = 0.94 (>0.90 is the adaptation). In short, whether absolute fit or value-added fit test, the hypothetical model of this study has a better fit with the actual data.

(2) The mediating effect of physical activity was discussed and calculated according to bootstrap method (34). In this study, non-parametric percentile bootstrap was used to test the significance of the mediating effect. The original data were sampled 2,000 times and the 95% confidence interval (CI) was estimated. Firstly, it is judged that the indirect effect does not contain 0 in the 95% confidence interval and reaches a significant level, indicating that there is an intermediary effect. At this time, if the direct effect contains 0 in the 95% confidence interval, it means that the direct effect is not significant and is a complete intermediary effect; If the indirect effect and direct effect do not include 0 in the 95% confidence interval, both reach a significant level, and if the total effect does not include 0 in the 95% confidence interval, reaching a significant level, it is a partial intermediary effect.

Through **Figure 1** and **Table 4**, it can be seen that the indirect effect of the kindergarten environment on children's physical fitness is 0.19*, which is very significant. The confidence interval of 0.087–0.364 obviously does not contain zero, while the direct effect of kindergarten environment on children's physical fitness is 0.27*, which is very significant. The confidence interval of 0.106–0.412 obviously does not contain zero. At the same time, the total effect is 0.46*, and the confidence interval of 0.156–0.574 also does not contain zero. This fully affirms that physical activity plays a partial intermediary role between the kindergarten environment and children's physical fitness. Similarly, the indirect effect of family environment on children's physical fitness is 0.15*, which is very significant. The confidence interval of 0.006–0.287 obviously does not contain zero, while the direct effect of family environment on children's physical fitness is 0.21*, which is very significant. The confidence interval of 0.106–0.412 obviously does not contain zero. At the same time, the total effect is 0.36*, and the confidence interval of 0.146–0.502 also does not contain zero, Therefore, it can also be judged that physical activity plays a partial intermediary role between children's family environment and children's physical fitness.

(3) It can be further found from **Figure 1** that the judgment coefficient R^2 of kindergarten environment and family environment on physical activity is 0.38, which shows that 38% of the variation of children's physical activity can be caused by the kindergarten environment and family environment, in which the role of family environment accounts for 14% (from the standardized path coefficient $r = 0.38^*$, $0.38 \times 0.38 = 0.14$), while the kindergarten environment accounts for 24% (from the standardized path coefficient $r = 0.49^*$, $0.49 \times 0.49 = 0.24$). Obviously, the influence of kindergarten environmental factors on physical activity is much higher than that of the family environment. The judgment coefficient R^2 of kindergarten environment, family environment, and physical activity on

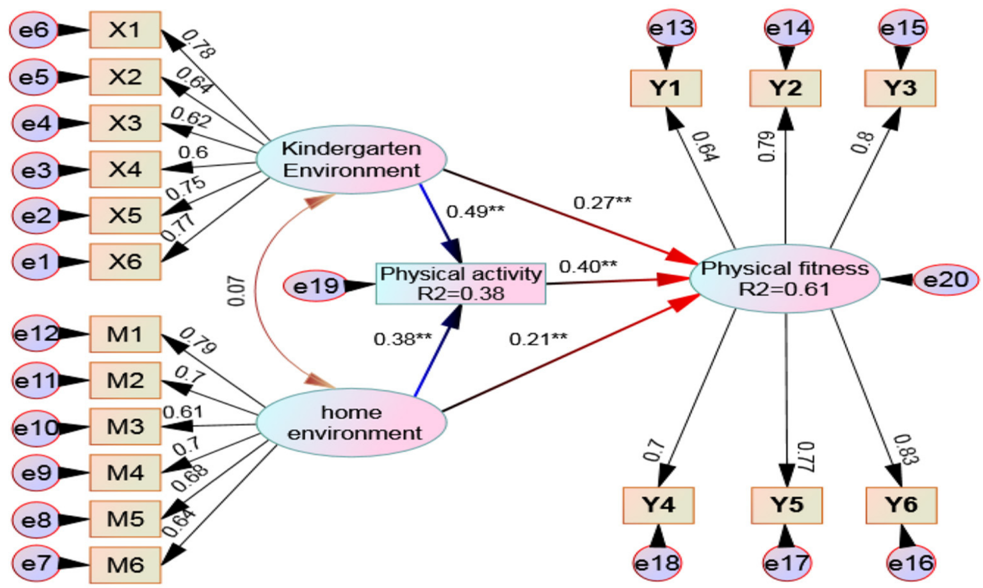

FIGURE 1 | Relationship model between environmental factors, physical activity and children's health and physical fitness. ** means that the path coefficient has reached a very significant level.

children's health and physical fitness is 0.61 (7+4+16+19+15%), which shows that 61% of the variation of children's physical fitness can be caused by five aspects. Among the five influences, the direct explanatory power of kindergarten environment, family environment, and children's physical activity on health fitness was 7% ($0.27 \times 0.27 = 0.07$), 4% ($0.21 \times 0.21 = 0.04$), and 16% ($0.40 \times 0.40 = 0.16$) respectively, while the amount of physical activity bears the dual intermediary force, in which the influence of intermediary I is 19% and that of intermediary II is 15%. It can be seen that the amount of physical activity of young children (1 direct influence + 2 intermediary forces = 0.16 + 0.19 + 0.15 = 50%) plays a decisive role in their health and physical fitness.

DISCUSSION

Impact of Kindergarten Environment on Children's Health and Physical Fitness

This study found that the amount of sports equipment, the area of game venues, the number of game classes per week, and the number of classes per game class in kindergartens were all related to children's health and physical fitness. From the perspective of the area of kindergarten play space, when the area increases from <60 m^2 to more than 101 m^2, children's physical fitness indicators such as explosive power, sensitivity, coordination, and speed are significantly improved. Nathan et al. (35) found that, when the kindergarten game space is relatively reduced and the number of group games decreases, children's aggressive behavior shows a significant increase. Although the research results do not demonstrate that the kindergarten game space area has a positive effect on improving children's health and physical fitness, they do prove the importance of the kindergarten game space area. This study found that when the number of sports equipment items in kindergartens increased from less than ten categories to more than 16 categories, children's health and physical fitness, such as balance ability, sensitivity, and coordination, were significantly improved. This result has been supported by relevant studies (32, 36). The interview further confirmed that the diversity and convenience of sports equipment in kindergartens (such as floor mats, balance beams, large-scale climbing, and other equipment) could not only provide more training opportunities for children's body movements, but also contribute to the improvement of children's health and physical fitness. This study found that weekly sports and game classes in kindergartens can significantly affect children's healthy physical fitness. When the number of classes is increased from 2 times/week to more than 3 times/week, children's balance ability, explosive power, endurance, and speed can be significantly improved. In addition, the length of each game class is also very critical. When the course length is increased from <30min/time to ≥41 min/time, children's ability in explosive power and speed is significantly improved. It can be seen that more than three game classes per week and ≥40 min of game time per class are guaranteed, which is beneficial to promote the physical fitness of children. It is also consistent with the "333 plan" advocated by the newly issued children's sports Guide (3 times a week, 30 min each time, and 130 beats/ min). The latest survey shows that (18, 31) the frequency of sports games in kindergartens in China is mostly ≤2 times/week, and the time is <30 min / time. This phenomenon must attract the attention of relevant departments.

In addition, from the teaching methods of children's game courses, this study found a "turning point" phenomenon in the impact of the number of classes in each class on children's

TABLE 3 | Statistical table of logistic regression analysis of the impact of family and kindergarten environment and children's physical activity on their Healthy physical fitness.

	Y_1 Balance ability			Y_2 Explosive force			Y_3 Sensitivity and coordination			Y_4 flexibility			Y_5 endurance			Y_6 speed		
	OR	t	p	OR	t	p	OR	t	p	OR	t	p	OR	t	p	OR	t	p
X_1 ≤60 m² (baseline)	1.00	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
61–100 m²	1.03	0.69		1.09	1.24		1.11	1.89		0.94	0.81		0.93	0.92		1.10	1.55	
≥101 m²	1.07	0.85		**1.29**	3.17	*	**1.28**	3.52	*	1.07	1.33		1.03	1.30		**1.35**	4.09	*
X_2 ≤9附(baseline)	1.00	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
10–15 kinds	**1.21**	2.96	*	0.90	1.26		1.17	1.89		0.97	1.09		1.02	0.92		1.10	0.88	
≥16 kinds	**1.36**	3.61	*	1.13	1.84		**1.29**	3.17	*	1.10	1.48		1.012	1.08		0.97	1.03	
X_3 1 time/week (baseline)	1.00	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
2 times/week	**1.47**	12.47	***	1.06	1.53		1.03	0.96		0.97	0.87		0.90	0.63		**1.43**	9.18	***
≥3 times/week	**1.52**	13.5	***	**1.47**	15.3	***	1.14	1.83		1.06	1.29		**1.42**	8.91	**	**1.67**	18.2	***
X_4 ≤30 min/time (baseline)	1.00	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
31–40 min/time	1.04	1.28		1.09	1.47		0.93	0.85		1.06	1.54		0.89	0.97		1.15	1.89	
≥41 min/time	1.08	1.39		**1.25**	3.29	*	1.02	1.23		1.15	1.81		1.07	1.52		**1.87**	19.2	***
X_5 1 class/time (baseline)	1.00	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
2 classes/time	1.05	1.25		**1.31**	8.75	***	**1.24**	4.26	*	**1.39**	6.25	**	**1.29**	4.12	**	**1.41**	5.09	**
≥3 classes/time	1.10	1.47		**0.7444**	−9.1	***	**0.68**	−5.09	*	**0.70**	−8.21	**	**0.81**	−5.27	**	**0.64**	−7.01	**
X_6 General ability (baseline 基比)	1.00	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Better ability	1.08	0.92		1.13	1.79		0.97	1.22		1.11	1.58		1.10	0.96		1.14	1.77	
Excellent ability	**1.32**	3.960	*	**1.29**	3.25	*	1.05	1.43		1.09	1.90		**1.31**	3.58	*	**1.59**	9.2	***
M_1 ≤5 items (baseline)	1.00	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
6–9 items	1.09	1.57		**1.23**	5.66	*	1.15	2.21		0.97	0.71		**1.33**	6.19	**	**1.27**	402	*
More ten items	1.122	1.69		**1.37**	6.01	*	**1.52**	12.4	**	1.08	1.11		**1.62**	15.3	***	**1.40**	6.51	**
M_2 Not very safe (baseline 比)	1.00	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Very safe	**1.34**	4.56	*	**1.18**	2.77	*	**1.23**	3.25	*	0.94	0.81		**1.24**	3.25	*	**1.20**	3.51	*
M_3 One person (baseline)	1.00	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
More than two people	**1.26**	4.03	*	1.22	3.17	*	**1.72**	12.4	***	1.06	1.77		**1.39**	5.89	**	**1.52**	5.87	**
M_4 Not good at (baseline)	1.00	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Commonly	1.04	1.25		0.98	0.88		**1.29**	7.51	**	1.06	1.49		**1.24**	4.02	*	1.06 1.14	1.15	
Be good at	1.11	1.34		1.06	1.44		**1.32**	6.04	**	1.13	1.19		**1.30**	4.33	*	1.14	1.66	
M_5 Not good at (baseline)	1.00	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Commonly	**1.19**	3.22	*	1.05	1.02		1.04	1.50		0.96	0.87		**1.18**	2.81	*	0.93	0.82	
Be good at	**1.23**	2.98	*	0.99	0.95		1.07	1.42		1.10	1.45		**1.27**	3.24	*	1.05	1.32	
M_6 ≤2 person (baseline)	1.00	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
3–4 person	1.02	1.54		0.94	0.95		**1.32**	5.87	**	0.91	0.97		1.12	1.99		**1.26**	3.78	*
Five persons and above	1.08	1.26		0.99	1.26		**1.48**	6.99	**	1.01	1.23		**1.29**	3.21	*	**1.32**	4.06	*
S Physical activity	**1.29**	3.25	*	**1.22**	2.84	*	**1.31**	4.02	*	**1.219**	2.81	*	**1.33**	4.26	*	**1.20**	3.02	*
R^2/F/P	0.30/18.29/**			0.37/29.25/**			0.41/34.17/**			0.17/4.89/*			0.48/87.89/***			0.51/97.12/***		

X1, Kindergarten play area; X2, Kindergarten sports equipment project; X3, Number of game classes per week in kindergarten; X4, The kindergarten arranges time for each game class; X5, Kindergarten class level of each game class; X6, Professional ability of game teachers; M1, Home sports equipment project; M2, Safety of playground near home; M3, Number of different siblings; M4, Father is good at sports and ability; M5, Mother's good at sports and ability; M6, Number of playmates of the same age near the family; S, Children's physical activity; Y1, Walking balance beam (s); Y2, Standing long jump (cm); Y3, Run around obstacles for 15 m(s); Y4, Sitting posture forward flexion (cm); Y5, Continuous jumping with both feet (cm); Y6, 20 m running(s).

** and ** represent significant levels of 0.05 and 0.01 respectively.*

physical fitness. Compared with the effect of a single class, if two classes were jointly implemented in each Game class, the results showed that children's explosive power, sensitivity and coordination, flexibility, endurance, and speed could be significantly improved. If more than three classes were jointly implemented in each Game class, then the children's explosive power, sensitivity and coordination, flexibility, endurance, and speed decreased significantly. The reason may be that more than three classes are in the same Game class, and the excessive number of children will significantly increase the

TABLE 4 | Analysis of the mediating effect of physical activity on the relationship between environmental factors and health and physical fitness.

Intermediary model I: Kindergarten Environment → Physical activity → Healthy physical fitness			Intermediary model II: home environment → Physical activity → Healthy physical fitness		
	Standardization coefficient	95% confidence interval		Standardization coefficient	95% confidence interval
Indirect effect: Kindergarten Environment → Physical activity → Healthy physical fitness	0.19*	0.087–0.364	Indirect effect: home environment → Physical activity → Healthy physical fitness	0.15*	0.006–0.287
Direct effect: Kindergarten Environment → Healthy physical fitness	0.27*	0.106–0.412	Direct effect: home environment → Healthy physical fitness	0.21*	0.109–0.368
Total effect: Kindergarten Environment → Healthy physical fitness	0.46*	0.156–0.574	Total effect: home environment → Healthy physical fitness	0.36*	0.146–0.502

Direct effect, indirect effect and total effect are directly derived from Amos.

difficulty of management, which means that more time is spent on maintaining order, and the time spent on game training decreases. Sport injuries increase at the same time. However, the implementation of sports game courses in a single class is not conducive to children's better sports performance, which seems to imply that they have plenty of game activity time. Still, the number of classes is too small or the class size is too small, which is not conducive to improving children's physical fitness. So, how many classes are needed to jointly implement the game class, or how many teachers are needed in each class, which is more conducive to improving children's physical fitness? What is the causal relationship and possible mechanism between these variables? Finally, the professional ability of game teachers is also worth considering. The study found that if the professional ability of kindergarten sports game teachers is improved to a higher level, children's balance ability, explosive power, endurance, and speed can be significantly improved. Because there are few reports on this research at home and abroad, studies such as that by Tong Tiantian pointed out that (37) kindergarten teachers concurrently serve as sports game course instructors, which will increase children's sports injury rate due to a lack of professional sports cognition. Therefore, from a long-term perspective, it is necessary to carry out systematic study and training for preschool teachers, especially in combination with the experience sharing of actual teachers, to improve teachers' confidence and professional ability in sports game teaching.

Influence of Family Environment on Children's Healthy Physical Fitness

From the impact of family environmental factors, the number of family sports equipment items has a significant positive effect on children's explosive power, sensitivity and coordination, endurance, and speed, which is consistent with the research of Cong et al. (35) on Japanese children. In addition, Kim and Park (37) found that the convenience and diversity of family sports equipment are conducive to increasing children's engagement in sports games and have positive benefits for improving children's physical fitness, which further supports the findings of this study. This study found that the safety of sports and game venues near the family significantly affected children's balance ability, explosive power, sensitivity and coordination, endurance, and speed, which is also consistent with some previous studies (38, 39). It is believed that children living in communities with old and damaged game facilities near the home have a significant increase in their aimless wandering time, frequent inappropriate events, and significantly poor performance of healthy physical fitness.

From the perspective of the internal environmental structure of the family, this study found that when the number of siblings in the family increases by "1 person," children's balance ability, sensitivity and coordination, endurance, and speed will increase significantly, which is also supported by previous relevant literature; that is, children with more siblings will perform better in health and physical fitness (40). The interview results show that living in a large family with more siblings can create a fun environment, providing more learning and imitation opportunities for each other, which helps to improve children's health and physical fitness. But there are also inconsistent reports. Scholars found that the balance ability of the first child is significantly better than that of the second and third (41). The study also found that the number of playmates of the same age near the family also has a great impact on children's sensitivity, coordination, endurance, and speed. This result is consistent with the research of sughara (42) and Martzog et al. (43). The latter believes that many leisure activities of today's children are occupied by arts or cultural learning arranged by their parents. There are fewer and fewer opportunities to gather more than 3–5 peers to implement games jointly, and children's healthy physical fitness naturally shows a downward trend. Finally, the father's exercise proficiency significantly affects children's sensitivity, coordination, and endurance, while the mother's exercise proficiency significantly affects children's balance ability and endurance. These findings are consistent with the research results of Hoffmann et al. (44). Therefore, some experts questioned (45, 46) whether children's physical activity, health fitness, and health status are affected by hereditary genes. Parents who are good at sports may bring hereditary genes to children.

Therefore, how much influence do environmental factors have? The exploration of these problems is very challenging.

Physical Activity as a Dual Intermediary Between Environmental Factors and Physical Fitness

Effects of Kindergarten and Family Environment on Physical Activity

Previous studies believe that habitual physical activity is a critical factor in developing cognitive ability in early childhood, and a sufficient physical activity environment will significantly accelerate the formation of children's displacement motor skills (47–49). The impact of kindergarten and the family environment on children's physical activity has become a hot topic in children's sports activity research (50). This study found that the multiple regression coefficients (judgment coefficient) R^2 of the kindergarten environment and family environment on children's physical activity was 0.38, and the influence of the kindergarten environment on children's physical activity (24%) was significantly greater than that of the family environment (14%).

The influence of the kindergarten environment on children's physical activity was supported by many previous research results. Pate et al. (51) found that the amount of physical activity of children in kindergartens with different characteristics varies greatly, which may be related to the software and hardware facilities and relevant policies and implementation of kindergartens. Zhang et al. (52) found that children in kindergartens with a supportive environment engaged in medium and high-intensity activities significantly more than those in kindergartens with poor supportive environment. Brown et al. (53) pointed out that the outdoor activity environment of kindergartens (open space, fixed game equipment, balls and equipment, toy wheels, drama props) and teachers' participation enthusiasm significantly affect children's physical activity. Schulman et al. compared (54) 285 American schools and found that the larger the kindergarten area, the higher the students' physical activity and the better the performance of fitness. McCurdy et al. found (55) that the amount and intensity of children's physical activities are affected by the venues, venue facilities, green space area, environmental characteristics, and diversity in the campus. Xin Rou (56) found through telemetry that schools with open surface morphology (such as outdoor walkways), playgrounds, and lawn areas account for a relatively high proportion, and the physical activity of students in these schools is increased. However, there is an apparent lack of research on children's game class week frequency, duration, class number, and teachers' Sports proficiency on children's physical activity. Follow- up research should strengthen the discussion in this regard.

Similarly, the effect of the family environment on children's physical activity has also been supported by many previous studies. Suen et al. (57) found that parents' educational background, parents' restrictions on their children's walking or cycling, and parents' rules on their children's sedentary time are negatively correlated with their children's moderate and high-intensity physical activity after class. Family encouragement, social support, and parents' support for children's play were positively associated with children's physical activity on weekends. Jerstad (58) shows that the distance between individual family and leisure facilities significantly affects children's physical activity, and the frequency of leisure facility use decreases sharply with the increase of length. Frank (59) found that there are more leisure and entertainment facilities, parks, amusement parks, shopping malls, and other facilities near the family, and children's regular walking behavior is better. Hobbs et al. (60) found that after controlling for personal background variables, the closer to the park green space or leisure facilities, the higher the chance of visiting and the greater the amount of physical activity. Another study found that (35) the higher the safety of the environment near the home, the higher the frequency of family physical activity participation, and the greater the amount of physical activity. In short, domestic scholars have little research on the impact of family environmental factors on children's physical activity. Foreign scholars pay more attention to teenagers and middle-aged and elder people, especially the effect of different siblings and the number of playmates of the same age near the family on children's physical activity. This research should be strengthened in the future.

Dual Mediating Effect of Physical Activity

This study proposed a mixed structure model diagram between the kindergarten and family environment, physical activity, and children's health and physical fitness, which was adopted after two correction rounds. According to the bootstrap method, it is confirmed that the mediating effect of physical activity is established. The study found that the three variables of kindergarten environment, family environment, and physical activity have a very significant impact on children's health and physical fitness. From the perspective of direct influence, the amount of physical activity is the largest (16%), the kindergarten environment is second (7%), and the family environment is the most minor (4%). What is more noteworthy is that the amount of physical activity not only mediates the kindergarten environment and physical fitness (19%), but also mediates the family environment and physical fitness (15%). In other words, the amount of physical activity plays a dual mediating role of 34%, plus the direct influence of 16%, which has a cumulative force of 50%, which shows the impact of children's physical activity on their physical fitness. This finding has also been supported by many previous scholars. There is a dynamic correlation between the amount of physical activity and the development level of children's motor skills. This correlation may be relatively weak in the early stage of individual life, but it will continue to increase with age (61). The amount of physical activity in childhood is an essential determinant of the development of motor skills and the improvement of healthy physical fitness level. The acquisition and accumulation of children's various exploratory sports experiences need a sufficient amount of activity stimulation. At the same time, an adequate amount of physical activity is conducive to stimulating children's willingness and motivation to participate in sports activities, and then has a positive effect on the level of healthy physical fitness (38). Although the research on the relationship between children's physical activity and their physical fitness has been widely concerned and valued by the academic community, the research on the relationship between them has always lacked sufficient longitudinal research support. There are often dynamic changes between children's physical development, organ function improvement, and basic motor skill development, which determines that the relationship between children's daily physical activity and healthy physical fitness (balance, flexibility, speed, endurance, etc.) is also dynamic. Therefore, the research conclusion will show distinct age and gender characteristics. In the future, more longitudinal studies on the impact of children's physical activity on physical fitness are needed to reveal its impact mechanism fully.

CONCLUSION

There are significant gender differences in children's physical activity and health fitness. It is significantly affected by the kindergarten environment and family environment, in which the influence of the kindergarten environment is considerably bigger than that of the family environment. Children's physical fitness can be directly affected by the kindergarten environment, family environment, and physical activity, in which the effect of physical activity is the most significant, the kindergarten environment is the second most, and the family environment is the smallest. The dual intermediary role of physical activity is established. It not only mediates the kindergarten environment and physical fitness, but also mediates the family environment and physical fitness. Therefore, the impact of physical activity on children's physical fitness plays a decisive role.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of School of Physical Education, Southwest University (Approval No.: swu-ty202105).

AUTHOR CONTRIBUTIONS

WH was mainly responsible for the design of the paper, the preparation of the questionnaire, and participated in the writing of the paper. JL was mainly engaged in the distribution of the questionnaire and data processing and analysis. YC provided decision-making and financial support for this study. All authors contributed to the article and approved the submitted version.

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Associations Between Gross Motor Coordination and Executive Functions: Considering the Sex Difference in Chinese Middle-Aged School Children

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Considering that motor and cognitive processes are intertwined and inhibit or help each other throughout life and that primary school age is one of the most critical stages of children's cognitive and motor development, this study aimed to investigate the relationship between executive functions and gross motor skills in Chinese children aged 9–10 years, as well as gender differences. The flanker task, the 1-back task, the more-odd shifting task, and the test of gross motor coordination (Körperkoordinationtest für Kinder) were used to collect data on executive functions and gross motor coordination. The results were as follows. First, there was a weak association between gross motor coordination and the inhibition reaction time in the congruent test and the reaction time of working memory ($r = -0.181$ to -0.233), but no association was found between gross motor coordination and cognitive flexibility. Second, a weak-to-moderate correlation was presented between the move sideways test and the inhibition reaction time in the congruent test and the reaction time in the refreshing test of the working memory ($r = -0.211$ to -0.330). Finally, gender influenced on the relationship between gross motor coordination and the reaction time of both inhibition ($\beta_{Gender} = -0.153$, $p < 0.05$) and working memory ($\beta_{Gender} = -0.345$, $p < 0.01$). To conclude, our results suggest that children with better motor coordination skills require less reaction time, especially girls, and this association was more substantial than in boys. The finding supports the current assertion that there are commonalities between gross motor coordination and cognitive control by showing the relationship between gross motor coordination and complex cognitive processes (executive function) in preadolescent children.

Keywords: gross motor coordination, executive functions, children, working memory, inhibition function

INTRODUCTION

Gross motor coordination (GMC) represents the involvement of large body muscles in balance, limb, and trunk movements (Chaves et al., 2016). It is a complex trait that integrates internal neurological and neuromotor processes (Keogh and Sugden, 1985), and its manifold expression is generally explained in terms of additive genetic effects, as well as their interaction with environmental factors (Chaves et al., 2016). Well-developed GMC goes hand-in-hand with higher levels of complex movement and sport-specific skills, which are essential for developing higher levels of cognitive function (Irene and Vander-Fels, 2015). Executive functions (EFs) are cognitive processes that influence actions, ideas, and emotions from top to bottom (Zelazo and Carlson, 2012) and include attentional or cognitive flexibility, working memory, and inhibitory control, which enable individuals to plan, organize, and solve problems, as well as to manage their impulses (Best and Miller, 2010). It is also known as complex cognitive functions (i.e., higher-level cognitive processes that control and regulate complex cognitive processes) (Su et al., 2021). Low GMC levels were shown to be related to complex cognitive functions and language development in children and adolescents (Houwen et al., 2016). Additionally, more and more scholars encourage starting from the "exercise benefits intelligence" theory hypothesis, which states that motor and cognitive skills are intertwined and inhibit or help each other throughout life (Piaget and Cook, 1952; Payne and Labban, 2017). Therefore, GMC is not only an important aspect of children's motor development but also of their cognitive growth.

In recent years, the impact of exercise on children's EF has been the focus of international scholars. A growing body of research has explored the benefits of short-term (Chang et al., 2012; Vera and Emi, 2016), long-term (Ludyga et al., 2018; Liu et al., 2020), and a variety of traditional physical activities (Egger et al., 2018; Gu et al., 2021) on children's EF (Verburgh et al., 2014). Recently, within the preadolescent age range, several meta-analyses have shown that enhanced cognitive functioning as a result of physical activity is most obvious in EFs (Verburgh et al., 2014; Liu et al., 2020) and attention (Greeff et al., 2017).

Several underlying mechanisms might explain the effects of physical activity on EF. From a psychophysiological perspective, acute physical activity can cause an increase in neurotransmitters (e.g., epinephrine, dopamine, brain-derived neurotrophic factors), which are thought to enhance EF processes (Dishman et al., 2006; Roig et al., 2013). Additionally, relevant brain research has also verified the positive effect of physical activity on individual cognitive processes, which can improve EF and attention in adolescents. Physical activity promotes strong self-regulation ability and goal-oriented behavior, enabling adolescents to effectively plan, manage, and implement multiple tasks, and enhances their ability to adapt to the external environment (Vandenbroucke et al., 2018). These findings provide more scientific evidence for the role of exercise in complex and advanced cognitive development in children.

For years, different views have been expressed about the relationship between GMC and EF in children and adolescents. Rigoli, Piek, Kane, and Oosterlan reported positive associations of motor coordination (MC) with working memory and inhibitory control in children aged 12–16 years and found that GMC and EF presented a linear association (beta $= 0.29$, $p < 0.05$) (Rigoli et al., 2012). Carlos, Luz, and Luis showed that 9–11-year-old children with high MC have better cognitive performance and found a moderate correlation between gross motor [Körperkoordinationtest für Kinder (KTK)] coordination and EF (CAS) (Carlos et al., 2014). However, Livesey et al. (2006) showed that gross motor skills (MABC) in children aged 5–6 years were only weakly related to response inhibition (Stroop and stop-signal task). Unfortunately, these studies did not consider the expected effects of MC on EF in linear regression. However, the current literature has indicated the relationship between motor skills (MOBAK-5) and working memory in children aged 10–12 years, and no relationship has been found in inhibition control and motor skills and in switching tests and any type of motor skills (Ludyga et al., 2019). In contrast, another recent study demonstrated that among the components of EFs (BRIEF), inhibition, working memory, planning/organizing, and organization had a significant relationship with gross motor skills (TGMD-2) in children aged 8–10 years, with success rates of 48, 39, 25, and 43%, respectively, and found locomotor and EF presented a linear association [beta $= 0.56$, $p < 0.01$; (Athirezaie et al., 2022)]. This laid the foundation for the research hypothesis to test the regression relationship between GMC and EF.

Findings from these previous studies on the relationship between EF and gross motor skills have not been unified. It is possible that the GMC assessment tools of these studies, including refined motor skills (MABC, TGMD), led to different results. Moreover, EF varies greatly in adjacent age groups of children, and there is a lack of research on the relationship between EF and GMC in children at certain ages. Therefore, the relationship between GMC and EF in children needs to be further explored, especially in the single age group of children aged 9–10 years. To the best of our knowledge, the relationship between GMC and EF in Chinese children has not been investigated. This may be related to the lack of development of assessment tools for GMC in Chinese children and adolescents. Therefore, we adopted the KTK, which is an overall dynamic coordination assessment for children and adolescents aged 5–14 years, which has been adopted by researchers worldwide (Vandorpe et al., 2011). Moreover, the accuracy and reaction time of the EF in this test are remarkable. Some studies have confirmed that MC has different correlations with reaction time and EF accuracy (Xu and Yan, 1999), but previous studies do not finely distinguish the behavioral data of EF. Therefore, it was necessary for this study to explore the potential relationship between EF accuracy, reaction time, and GMC based on previous studies. Furthermore, previous studies have shown that there is no gender difference in children's EF (Welsh et al., 1991), but other studies have found that white boys respond faster than white girls, black boys, and black girls when they complete the go/no-go task (Brocki and Bohlin, 2004). The GMC of different genders also has certain differences (Moreira et al., 2019), so it seems that the effects of gender on EF and GMC also need to be considered.

Based on the above, our study has three objectives, namely, (1) to determine the GMC and EF of children aged 9–10 years in China; (2) explore the correlation between GMC and EF in children aged 9–10 years; and (3) study gender and body mass index (BMI) differences in the relationship of GMC and EF. Hopefully, our study can enrich the empirical research on the correlation between children's GMC and EF.

RESEARCH METHOD

Participants

As the forerunner of the integrated reform of physical education in China, Shanghai has a strong representation in China. Participants were recruited from two public primary schools in Shanghai by convenience sampling, L and N. It was found that the assessment standards of P.E. lessons from the two public schools in 2019 and 2020 were consistent with the overall standards of all schools in Shanghai, and there was no statistically significant difference between the two public schools mentioned above, which meant that the research samples reflected the overall situation of primary schools in Shanghai.

The research samples (n) included 364 healthy children aged 9–10 years (the percentage of girls: 46.1%) (average age: 9.55 ± 0.92 years). Data for another six children were excluded because of reported motor impairment ($n = 2$) or absence on test days ($n = 4$). The Gpower3.1 statistical software was utilized to analyze obtained data. The study first supposed effect size = 0.50, $\alpha = 0.05$, and statistical test power = 0.90, then presented the minimum sample size as 290. Given the 20% inefficiency rate caused by MC and invalid measurement of EF, the final sample size was 364.

Several points should be clarified. (1) All children participated in the study of their own accord, and only when parents provided written consent and children themselves verbally agreed to participate in this study. (2) All the children were sighted or obtained corrected visual acuity, and no neuromuscular disease was found. (3) The participants enjoyed normal development of intelligence without mental or learning disabilities as assessed by their teachers. (4) All procedures complied with the Declaration of Helsinki. (5) The study was authorized by the Institutional Review Board of the local Education Department (102772021RT072), which takes responsibility for evaluating the research conducted in schools.

Research Tools and Procedures

Procedures

All participants were tested separately in quiet rooms at their respective institutions. From September to November 2020, 364 children aged 9–10 years were tested for GMC and EF. The testers consisted of 22 graduate students (education major, second-year graduate students) who familiarized themselves with children's motor skills, test procedures, and standard language by watching relevant test videos, and pre-tested 40 non-tested children. During the pretest, testers gave oral guidance and demonstrations as required. Finally, an experienced and well-trained experiment leader evaluated the testers' performances. The evaluation included three parts, namely, oral guidance, demonstration, and test procedures. Moreover, as the KTK tool is an outcome assessment tool, the assessment was conducted by three researchers. Two researchers separately conducted field tests. When there was disagreement between the two researchers, a third researcher evaluated the original video to reach a consensus.

Two stages were involved in the test, namely, (1) measurement of gross motion coordination from September to October 2020 and (2) measurements of EF were scheduled between 12:45 p.m. and 13:15 p.m. and took place in groups of 20 in a school classroom in November 2020.

Children's GMC (KTK Tool)

The KTK assessment tool of GMC was adopted in this study. Schilling, a German scholar, revised it for the second time in 2007 and reported that the KTK reliability coefficients of a single test ranged from 0.80 to 0.96; the coefficient of the total battery was 0.97 (Vandorpe et al., 2011). The reliabilities in this study (intraclass correlations) varied between 0.753 and 0.782 per dimension (Song, 2020), which was higher than the internal consistency pass line (0.7) set by Nunnally (Nunally, 1978; Hair et al., 1995; Wu, 2003), and retested reliability varied between 0.832 and 0.961. The KTK consists of four subtests lasting for 15–20 min for each participant. Details are presented as follows.

(1) Jumping sideways (JS). The jump side task consists of a field (60 × 100 cm) framed by sidelines and divided into two halves by a center line. Participants were required to complete as many sideways jumps as possible, with feet together, over a wooden slat (two trials, each for 15 s). A child's jump on one of the lines was not counted. Ultimately, we added up the number of jumps for both trials. Notably, these jumps were performed using two legs.
(2) Moving sideways (MS). Participants were required to move across the floor for 20 s using two wooden platforms (e.g., cross the first board, reach the second board, move the first board, and step on the second board), and participants had two opportunities. To ensure that children moved sideways, two 50-cm-long boundaries were added. Ultimately, we added up the number of jumps for both trials.
(3) Hopping for height (HH). Participants hopped on one leg over an increasing number of 5 cm foam blocks to a maximum of 12 blocks. Participants began hopping 1.5 m away from the foam blocks, hopped up to and over the foam block, and completed a further two hops for the trial to be deemed successful. Three trials were given for each height, with 3, 2, or 1 point(s) given for a successful performance during the first, second, or third trial, respectively.
(4) Walking backward (WB). In this task, children were instructed to walk backward along three balance beams with differences in width (3 m length; 5 cm height; 6, 4.5, and 3 cm widths). A maximum of 24 steps (8 per trial) was counted for each balance beam, which comprised a maximum of 72 steps (24 steps × 3 beams) for this test. The number of successful steps on each beam was calculated.

The original score for overall MC was calculated by adding the original scores of the four subtests into a formula. Based on guidance for the latest edition of the KTK in 2007, the original score of overall MC was converted according to the reference [motor quotient (MQ)] of specific age and gender, hence obtaining the MQ (Hair et al., 1995; Wu, 2003; Vandorpe et al., 2011). Records with scores significantly deviating from the standard were verified, and tests missed by participants were conducted at another time.

Executive Function

Our study adopted the measurement tool of children's EF (validity > 0.85) developed by Chen Aiguo et al. in 2011 (Zhang et al., 2017). Participants were seated in front of a laptop (with 80 cm distance between participants) and completed computer-based versions of flexibility, working memory, and inhibitory control exercises, which were administered with the E-Prime software 1.1 (Psychology Software Tools, Pittsburgh, USA).

The flanker task was employed to assess inhibitory function, including congruent and incongruent trials. A congruent test consisted of a horizontal array with the same five letters, such as LLLLL or FFFFF, whereas an incongruent test consisted of a horizontal array of five letters with different middle letters, such as LLFLL or FFLFF. In inhibition tasks, participants were required to press F or L with their left or right index finger according to the middle letters that appeared in the trial. Pressing the wrong button or failing to react within the specified time was considered an incorrect reaction. Participants were asked to perform 12 pre-trials and then complete two modes with 48 trials. Each mode had an interval of 1 min. Tests, both congruent and incongruent, were conducted in a random order with equal probability in each group. The duration was about 6 min for two modes. A smaller score for reaction times or higher accuracy meant better inhibition ability.

The 1-back task was employed to assess working memory, which included a series of rapidly changing letters (B, D, L, Y, O) presented at the center of the computer screen for 2 s with an interval of 3 s. Participants carefully observed each letter and determined whether it was the same letter as the one that had appeared before the two trials. If so, they pressed the "F" key; if not, they pressed the "L" key. Identical and different letters each accounted for 50%. Pressing the wrong button or failing to react within 1.5 s was considered an incorrect reaction. The trial consisted of two stages every 25 times. A shorter reaction time indicated better working memory, and higher accuracy meant refreshing ability.

The more-odd-shifting task was employed to assess cognitive flexibility. A number appeared in the center of the computer screen every 2 s, and the participants were asked to make judgments of the presented numbers (1–9). The task consisted of three sections, namely, (a) "big or small" – a black number was presented on the screen. If the number presented was smaller than 5, they pressed the "F" key; otherwise, they pressed the "L" key. (b) "Odd or even" – a green number was presented on the screen. If the number presented was even, they pressed the "L" key; otherwise, they pressed the "F" key. (c) This section contained type A and B tests. Participants were asked to press the "F" or "L" key to indicate whether the black numbers were greater than 5 and whether the green numbers were odd or even. The trial was divided into six sections with the sequence of "abccba." Segments A and B did not need to be switched, each presenting 16 times. Segment C was switched 32 times, including 16 switch processes. A pretest was conducted 8 times for segments A and B and 16 times for segment C the first time. The test results measured the difference in reaction time between the switching condition (the average of segment C) and the non-switching condition (the average of segments A and B). Smaller differences and higher accuracy signified better cognitive flexibility.

BMI Test

The BMI test requires subjects to use the Ogilvy Health electronic body mass and height meter (Sengkang Jiaye HK6800 children's version; the unit is accurate to 0.01 kg and 0.01 cm) in the state of underwear and bare feet, and the obtained data are passed through BMI = kg/m^2 to calculate the BMI value for each child.

Statistical Analysis

The t-test was performed on the subjects' gross motor scores and EF to test for gender differences. Using the Pearson product-moment correlation coefficient and two-tailed $p < 0.05$ was considered statistically significant for a difference. Correlations were calculated between subjects' GMC and inhibition, working memory, and cognitive flexibility. Finally, by controlling for gender variables, linear regression analysis was performed with gross motor scores as independent variables, EF total scores and inhibition, working memory, and cognitive flexibility as dependent variables.

Before analysis, the normal distribution, linearity, and homogeneity of variance were verified by an independent-samples t-test using a histogram, P-P plot, and scatter plot (Tabachnick and Fidell, 2014), and the test level was $p = 0.05$. According to Cohen's classification, the correlation (r) was divided into weak ($r = 0.10$), moderate ($r = 0.30$), and high ($r = 0.50$), whereas effect size (R^2) was classified as weak effect (1–8%), moderate effect (9–24%), and strong effect (≥25%).

RESULTS

Descriptive Statistics of Children's GMC and EF

The descriptive statistics of GMC and EF with gender differences are shown in **Table 1**. Before analysis, we used the histogram to perform the normality test, the histogram tends to be normally distributed, and the distribution curve is centered. The average of motor quotient for GMC was 84.56 (12.95). In terms of gender-based differences in GMC, boys outperformed girls in jumping sideways and hopping for height ($p < 0.05$). In walking backward and moving sideways, girls were better than boys, and there were also statistical differences ($p < 0.05$).

In terms of the EF, in the inhibition task, boys surpassed girls in reaction time in the congruent/incongruent tests and accuracy rate in the incongruent test, while girls outperformed in the reaction time in the congruent test and accuracy rate in the congruent test. Among them, statistical significance was found in the reaction time in the congruent tests ($p < 0.05$). In the refreshing test, the 1-back reaction time and accuracy of girls were better than those of boys with respective statistical significance ($p < 0.01$). As for cognitive flexibility, girls surpassed boys in accuracy in the switching and big-small/odd-even tests, both with statistical significance ($p < 0.05$).

TABLE 1 | Descriptive statistics of gross motor coordination and executive function of children aged 9–10 years.

Variables	Boys (n = 196)	Girls (n = 168)	Total (n = 364)	Gender difference (T)	Gender difference (p)
BMI	18.98 (3.63)	16.91 (2.82)	17.98 (3.42)	−1.38	0.003[2)]
Gross motor coordination					
MQ	86.45 (15.56)	82.17 (12.97)	84.56 (12.95)	−2.94	0.027[1)]
WB	38.25 (5.43)	44.95 (9.64)	39.96 (7.87)	−4.41	0.016[1)]
HH	35.58 (4.56)	29.17 (2.97)	30.21 (2.49)	−0.340	0.030[1)]
JS	45.54 (13.78)	38.94 (13.20)	41.66 (13.55)	−0.146	0.046[1)]
MS	11.47 (3.05)	15.81 (3.26)	13.40 (3.28)	3.09	0.005[2)]
GMC	127.18 (34.95)	121.71 (17.79)	123.93 (32.08)	−1.46	0.145
Executive function					
Inhibition					
Reaction time of incongruent test	611.18 (95.28)	622.44 (86.05)	616.38 (91.19)	1.07	0.234
Reaction time of congruent test	630.28 (146.25)	609.08 (96.43)	620.49 ± 126.02	−3.78	0.000[2)]
Accuracy of incongruent test	0.83 (0.16)	0.81 (0.14)	0.82 (0.16)	−1.61	0.109
Accuracy of congruent test	0.84 (0.15)	0.88 (0.09)	0.86 (0.12)	1.42	0.156
Working memory					
Reaction Time of Refreshing Test	926.89 (159.03)	864.32 (160.21)	889.35 (178.91)	−4.17	0.010[1)]
Accuracy of Refreshing Test	0.75 (0.21)	0.88 (0.11)	0.77 (0.21)	2.57	0.005[2)]
Cognitive flexibility					
Reaction time of big–small/Odd–even test	829.89 (191.74)	807.01 (155.14)	819.33 (175.93)	−1.24	0.220
Reaction time of switching test	976.15 (137.28)	1231.54 (298.17)	1113.67 (269.59)	10.21	0.000[2)]
Accuracy of big–small/ odd–even test	0.52 (0.15)	0.73 (0.19)	0.77 (0.17)	2.72	0.047[1)]
Accuracy of switching test	0.55 (0.17)	0.61 (0.29)	0.57 (0.18)	2.45	0.015[1)]

1) $p < 0.05$; 2) $p < 0.01$. MQ, motor quotient; WB, walking backward; HH, hopping for height; JS, jumping sideways; MS, moving sideways; GMC, gross motor coordination.

Correlation Between GMC and EFs

By drawing a scatter plot, it is intuitively judged that there is a linear relationship between the two, and by drawing a standardized residual scatter plot and a histogram and P-P plot with a standard curve, we believe that the residual variance is a homogeneous and approximately normal distribution. Correlation analysis (**Table 2**) showed a significantly weak correlation between MQ and inhibition reaction time and working memory reaction time ($r = -0.181$, $p < 0.01$; $r = -0.232$,$p < 0.01$). However, there was no significant correlation between the MQ and the accuracy of inhibition and working memory as well as cognitive flexibility ($p > 0.05$). In terms of inhibiting task response time, there was a statistically significant weak correlation between WB, MS, and congruent test response time for the total sample ($r = -0.168$ to-0.221, $p < 0.01$), while WB, MS, and MQ were statistically different and weak correlated with incongruent test response time for girls ($r = -0.148$ to -0.182, $p < 0.05$). In terms of accuracy, the JS enjoyed a significantly weak correlation with accuracy in the incongruent test ($r = 0.136$, $p < 0.05$), and the MS of girls had a remarkably weak correlation with accuracy in the incongruent test ($r = 0.129$, $p < 0.05$). In working memory, the MS of the whole sample was significantly and moderately correlated with the reaction time ($r = -0.330$, $p < 0.01$). Girls' WB was significantly different and weakly correlated with reaction time ($r = -0.215$, $p < 0.01$), and accuracy was statistically different and weakly correlated ($r = 0.134$, $p < 0.05$). There was a significant weak correlation between MS and working memory accuracy of girls ($r = 0.181$, $p < 0.01$). In addition, there was a statistically different and weak correlation between WB and accuracy in the girls' cognitive flexibility ($r = 0.183$, $p < 0.05$) and a statistically different and weak correlation between JS and cognitive flexibility reaction time in the girls ($r = -0.148$, $p < 0.05$).

In summary, MQ and MS in children aged 9–10 years, there was a weak-to-moderate correlation with inhibition of control consistency reaction time, and reaction time of working memory. To further explore the effect of gross movement on inhibitory control and working memory, we took the reaction time in the congruent test of inhibitory function and the reaction time in the refreshing test of working memory as dependent variables (**Table 3**), multiple linear regression analysis was performed with gender and BMI as independent variables, MQ, or MS.

The MS had a weak and predictive effect on the reaction time in the congruent test ($R^2_{adj} = 0.042$, $p < 0.05$) of inhibitory control. Specifically, for each unit change in the MS, the reaction time in the congruent test changed by −0.281 standard deviation. The MQ had a weak and predictive effect on reaction time in the congruent test ($R^2_{adj} = 0.030$, $p < 0.05$). Specifically, for every unit change in the MQ, reaction time in the congruent test changed by −0.258 standard deviations. Furthermore, gender had a significant influence on the reaction time in the congruent test of inhibitory control ($\beta = -0.153$, $p < 0.05$). The MS had a moderate and predictive effect on the reaction time in the refreshing test of working memory ($R^2_{adj} = 0.106$, $p < 0.01$),

TABLE 2 | Correlation between gross motor coordination and executive functions of children aged 9–10 years.

Test	Gender	Inhibition				Cognitive flexibility				Working memory	
		Reaction time of incongruent test	Reaction time of congruent test	Accuracy of incongruent test	Accuracy of congruent test	Reaction time of big–small/odd–even test	Reaction time of switching test	Accuracy of big–small/odd–even test	Accuracy of switching test	Reaction time of refreshing test	Accuracy of refreshing test
WB	Boys	−0.124	−0.159[1)]	0.078	0.12	0.036	−0.132	−0.068	−0.042	−0.026	−0.016
	Girls	−0.153[1)]	−0.185[2)]	0.006	0.038	−0.077	−0.096	0.079	0.183[1)]	−0.215[2)]	0.134[1)]
	Total	−0.113	−0.168[1)]	0.017	0.099	−0.039	−0.103	0.050	0.068	−0.108	0.036
HH	Boys	0.024	−0.074	0.058	0.112	−0.02	−0.068	−0.047	−0.062	−0.070	0.097
	Girls	−0.069	−0.009	−0.023	−0.007	0.016	−0.068	−0.102	0.054	−0.036	0.026
	Total	−0.013	−0.056	0.003	0.077	−0.013	−0.134	−0.076	0.029	−0.038	0.087
JS	Boys	−0.006	−0.049	0.108	0.059	−0.045	−0.084	−0.114	−0.126	−0.012	−0.025
	Girls	−0.034	−0.166[1)]	0.147[1)]	0.072	−0.073	−0.148[1)]	−0.085	−0.009	−0.134	0.033
	Total	−0.016	−0.09	0.136[1)]	0.064	−0.057	−0.094	−0.108	−0.066	−0.05	0.004
MS	Boys	−0.106	−0.181[1)]	0.051	0.09	0.007	−0.064	0.009	0.098	−0.271[2)]	0.047
	Girls	−0.182[1)]	−0.252[2)]	0.062	0.129[1)]	−0.05	−0.118	−0.044	−0.058	−0.354[2)]	0.181[2)]
	Total	−0.133	−0.211[2)]	0.038	0.115	−0.031	−0.099	0.043	0.067	−0.330[2)]	0.088
MQ	Boys	−0.105	−0.155[1)]	0.118	0.068	0.050	−0.011	−0.126	0.075	−0.186[2)]	0.033
	Girls	−0.148[1)]	−0.195[2)]	0.078	0.121	0.020	−0.080	0.102	0.030	−0.288[2)]	0.063
	Total	−0.116	−0.181[2)]	0.105	0.082	0.041	−0.055	−0.098	0.054	−0.233[2)]	0.045

1) $p < 0.05$; (2) $p < 0.01$. MQ, motor quotient; WB, walking backward; HH, hopping for height; JS, jumping sideways; MS, moving sideways.

TABLE 3 | Regression analysis of the correlation between gross motor coordination and executive functions of children aged 9–10 years.

Task	Dependent variable	Variable	*B*	Standard error	*β*	*t*	*p*	VIF	*R*	R^2	R^2_{adj}	*F*
Inhibition	Reaction time of congruent test	MS	−0.558	0.379	−0.281	2.731	0.010[1)]	1.043	0.211	0.045	0.042	$F_{(3,361)} = 12.541$, $p < 0.05^*$
		Gender	−1.494	0.120	−0.153	2.115	0.024[1)]	2.096				
		BMI	0.020	0.683	0.021	0.055	0.178	2.053				
											D–W value	2.190
	Reaction time of congruent test	MQ	−0.893	0.463	−0.258	1.877	0.044[1)]	1.215	0.186	0.035	0.030	$F_{(3,361)} = 9.013$, $p < 0.05^*$
		Gender	−0.782	0.095	−0.187	1.561	0.155	1.808				
		BMI	−0.588	0.014	−0.069	1.120	0.178	2.348				
											D–W value	2.032
Working memory	Reaction time of refreshing test	MS	−0.872	0.520	−0.330	4.569	0.001[2)]	1.466	0.331	0.109	0.106	$F_{(3,361)} = 25.923$, $p < 0.01^{**}$
		Gender	0.521	0.866	−0.345	5.544	0.000[2)]	2.224				
		BMI	−0.216	0.480	−0.097	2.160	0.016[1)]	1.528				
											D–W value	1.789
	Reaction time of refreshing test	MQ	−0.427	0.647	−0.233[2)]	4.123	0.001[2)]	1.938	0.225	0.051	0.049	$F_{(3,361)} = 19.427$, $p < 0.01^{**}$
		Gender	−0.253	0.476	−0.201[2)]	1.943	0.020[1)]	2.175				
		BMI	−0.031	0.637	−0.081	0.055	0.297	1.250				
											D–W value	2.251

(1) p < 0.05; (2) p < 0.01.

that is, for every unit change in the MS, the reaction time in the refreshing test changed by −0.330 standard deviations. The MS had a stronger predictive effect on the reaction time in the working memory refresh test. In addition, the MQ had a weak and predictive effect on the reaction time in the refreshing test of working memory ($R^2_{adj} = 0.049$, $p < 0.01$), that is, for every unit change in the MQ, the reaction time in the refreshing test changed by −0.233 standard deviations. Moreover, gender and BMI explained 10.6% of the variation in reaction time in the refreshing test ($F_{(3,361)} = 25.923$, $p < 0.01$), gender, and BMI ($\beta_{\text{Gender}} = -0.345$, $p < 0.01$; $\beta_{\text{BMI}} = -0.097$, $p < 0.05$) became the best variables to negatively predict the reaction time in the refreshing test.

DISCUSSION

The first goal of this study was to analyze the GMC and EF of children aged 9–10 years in China. According to descriptive statistics, the MQ of Chinese children aged 9–10 years [83.56 (12.95)] was lower than that of Australian children [90.60 (16.50)] and Belgian children [96.40 (13.40)] (Bardid et al., 2015), indicating that Chinese children have weaker GMC ability. The reason for this may be that Chinese children completed the KTK test more carefully, performed the test tasks too seriously, paid more attention to the completion of the test, and ignored the continuity of the skills (e.g., with the addition of two 50 cm long boundaries, children will pay more careful attention to these constraints).

The scores for EF were similar to the statistics in the published studies on EF in Chinese children (Chen et al., 2015) because children's EF remains stable around the age of 10. This result was also supported by neuropsychological research (James, 1996). The result demonstrated that girls outperformed boys in the inhibition reaction time in the congruent test, reaction time and accuracy of working memory, accuracy in the big-small/odd-even tests and cognitive flexibility, while boys surpassed girls in the switching test. A possible explanation is that the subtests of inhibition and working memory tasks focused on simple reaction time, which is shorter in girls after the age of 9 than in boys (Li and Luo, 2012). Thus, girls between the ages of 9 and 10 performed better than boys in inhibition and refreshing tasks. On the contrary, the subtests of switching were dominated by the choice reaction time. Because of gender differences in reaction types based on different characteristics, boys generally have faster choice reaction times (Li and Luo, 2012), while girls may prefer to make cautious decisions, which also leads to higher accuracy.

The second goal of this study was to analyze the relationship between GMC and EF. In working memory, we found moderate associations between reaction time in the refreshing test and the MC (−0.33), and weak associations between reaction time in the refreshing test and the MQ (−0.23). Furthermore, in inhibition, we found weak associations between reaction time in the congruent test and the MC (−0.21) and MQ (−0.18). These results were weaker than the results reported by Davis et al. (2012) and Rigoli et al. (2012). Both studies used older children and standardized quantitative and qualitative measures for motor proficiency. It is worth emphasizing that Carlos et al. (2014) used standard cognitive assessment tools, and Ludyga et al. (2019) and our study used EF assessment tools, which are more focused on EF. Ludyga et al. (2019) evaluated children aged 10–12 years in Switzerland and found an association of (−0.31) between motor skills (MOBAK-5) and working memory.

Notably, differences in the measures used to assess EF and gross motor skills are common (e.g., MOBAK-5 aims to evaluate the quality of movement, which is process-oriented compared with the KTK, while MABC selects children with severe motor difficulties), which may account for the heterogeneity of results because of differences between product (e.g., KTK) and process-oriented (e.g., MOBAK-5) results. Additionally, there are many types of EF assessment tools. In this study, we focused on cognitive ability, and a recent study has targeted EF assessments (e.g., flanker task, go/no-go). Furthermore, we found that children with high quantitative MQ scores performed better in working memory tests. Some studies have also linked working memory performance to aerobic fitness rather than to motor competences (Raine et al., 2013; Marchetti et al., 2015). As fitness was not assessed in this study, it remains unclear whether this variable mediated the correlation between gross motor skills and working memory updating.

After controlling for variables such as gender and BMI through regression analysis, it was found that the MS and MQ contributed 10.6 and 4.9%, respectively, to the reaction time in the refreshing test. The MS and MQ contributed 4.2 and 3.0%, respectively, to the inhibition reaction time in the congruent test. This indicated that compared with the WB, HH, and JS, the MS had a better predictive effect on EF. This may be related to the action characteristics of the MS, which emphasized cooperation of upper and lower limbs space orientation and balance. Moreover, the sensitivity of the individual may also be improved through good body posture adjustment, and the lower limbs, trunk, and upper limbs form an efficient and coordinated dynamic chain that promotes rapid changes in movement and direction. Therefore, when children completed the MS, they needed to map the given password and the actions they needed to perform, and according to the password change, new schemas were extracted to which they must respond accurately and quickly, which challenges their working memory and inhibition. In addition, the WB had a certain weak correlation with the reaction time in the congruent test of the inhibition. This was because when children performed the WB tasks, they could pay enough attention to the balance beam, which reflected the inhibition of the response. However, the HH belonged to the dimension of whole-body coordination. Although single-leg hopping required coordination between swinging and supporting the legs, since it was a one-time jump, it did not require high sustained attention. Completing the JS required a focus on strength and endurance. Although this skill involved physical coordination, children use it frequently in daily life, and for them, the task is relatively simple and therefore not significant. This may be related to what we found earlier, that the internal consistency of the KTK assessment tool for Chinese children was not high, and that there were differences in the measurement focus of these four items.

Coincidentally, in a recent study that included the KTK assessment tool and EF, Maurer (2019) pointed out that the performance of simple and difficult GMC tasks had differential effects with EF (Maurer, 2019). Given the non-association between the easy gross motor tasks (JS, HH) and EFs, we assume that the required GMC movements were not completely automated. Children in this age group have probably reached a point of skill development at which the EFs are no longer substantially required to perform the tasks (Carlson et al., 2013). Therefore, the EFs were likely to be minimally involved during the performance of the easy gross motor tasks (JS, HH), leading to their weak and non-significant association with EFs. The reason is that subtests such as the HH and JS are simple and are often used in P.E. classes, so the participants' high proficiency in these MC tasks leads to the weakening of the automatic reaction of EF. Therefore, gross motor skills must constantly change the context of the task. Only in the context of dynamic movement do individuals need inhibitory responses (Alesi et al., 2016).

The mechanisms underlying the association between gross motor skills and EF are still a matter of an ongoing debate (Irene and Vander-Fels, 2015). Current literature has shown that children with high motor competences are more effective in guiding the preparation of complex MC structures (involving working memory operations) than those with low motor competences (Ludyga et al., 2018). In addition, previous studies have found a specific relationship between visuospatial memory and certain aspects of MC (Piek et al., 2008; Rigoli et al., 2012). It has been speculated that the MC of early gross motor skills is related to the development of later working memory abilities, and it has been speculated that these specific associations may be partly determined by a common cerebellar mechanism. In addition, previous studies have also offered explanations from the perspective of neural mechanisms; that is, the participation of neural pre-activation mechanisms is high, and motor skills with complex background environments can not only promote children's physiological arousal but also cause cognitive activation to a greater extent (Diamond, 2000). The ability to pre-activate neural networks related to cognition is reflected in the cognitive requirements of gross motor skills themselves. When gross motor tasks are difficult, novel, unmastered or practiced, varied rather than fixed, they must be focused rather than automated and require quick reflexes and responses so attention will be specifically activated, which can promote increased activity in the cerebellum and prefrontal regions.

No correlation existed between GMC and cognitive flexibility, but it does not mean that people can ignore the positive impact of GMC on cognitive flexibility. No correlation may be related to differences in the underlying neural processes of inhibition, working memory, and cognitive flexibility. Cognitive flexibility is a complex task, which requires participants to switch between operations and mental sets when performing complex tasks in addition to the inherent inhibition requirements, motor skills with higher complexity require a higher correlation between MC and cognitive flexibility (Cui et al., 2019). Cognitive flexibility has a longer development process than other EFs, and improvements in cognitive flexibility throughout childhood are delayed as was shown in other studies; 13-year-old children still have not reached the level of adults (Davidson et al., 2006). To date, similar to the results of this research, the studies mentioned above have reported either no correlation between these variables (Rigoli et al., 2012; Ludyga et al., 2019) or a weak correlation between cognitive flexibility and gross motor skills (Roebers and Kauer, 2009).

Regarding the third goal of our study, the results indicated that gender exerts influence on the relationship between GMC and the reaction times of both inhibition and working memory. In the evaluation of EF, girls were better than boys in inhibition (reaction time in the congruent test) and working memory (reaction time in the refreshing test, accuracy in the refreshing test). This may be related to the gender differences in individual cognitive ability and brain development. The overall development of boys is later than that of girls. The gender differences in the cognitive development of 9-year-old children may stem from the development of individual physiological maturity and brain structure. In addition, the development of gross motor skills for 9–10 years old showed gender differences. Boys developed better in strength and physical skills, while girls developed better in physical coordination skills. Some methodological issues limited the interpretation of the present results. The present findings were based on a cross-sectional investigation, so causality could not be inferred.

In general, many factors cause differences between MC and EF. There remain flaws in this study, namely, (1) participants only included children aged 9–10 years in primary school. Differences in study stage, age, mental conditions, and socioeconomic backgrounds may have had an impact on the correlation of MC and EF, which deserves further research. (2) This study only considered the simple transmission mechanism of GMC and EF. In fact, there may be mediating effects and moderating effects of multiple variables concerning people's mental processes, so future research should include more mediators, including self-efficacy and self-regulation ability, to reflect the complex transmission process between GMC and EF. (3) As cross-sectional research, this study could not provide further information on the directional relationship between motor and cognitive areas. In the future, longitudinal studies on related topics should be conducted to provide more empirical evidence for the benefits of exercise for children's cognitive development.

CONCLUSION

By investigating the primary relationship between the GMC and EF of children aged 9–10 years in China, compared with cognitive flexibility and inhibitory control, GMC had a better-than-expected effect on working memory.

We found that children with better MC skills require less reaction time of working memory, especially girls, and this association was more substantial than in boys. MS was the most effective for EFs among the GMC. It is hoped that this study will demonstrate the benefit of improving gross motor skills in promoting the EF of children aged 9–10 years and provide a reference for relevant departments to formulate sound strategies for encouraging physical exercise for children and adolescents.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of the Shanghai University of Sport. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

SL, S-TC, and YC contributed to the conception and design of the study. SL and S-TC organized the database and performed the statistical analysis. S-TC and YC contributed to manuscript revision, read, and approved the submitted version. All authors contributed to the article and approved the submitted version.

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The Impact of the COVID-19 Pandemic on the Physical Fitness of Primary School Students in China Based on the Bronfenbrenner Ecological Theory

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After the outbreak of the COVID-19 pandemic, nation lockdown became an effective way to isolate the spread of the virus. Schools were postponed, students had to stay at home and opportunities for physical activity amongst school children were severely affected. This research sought to determine the impact of the pandemic on the physical fitness of primary school students. In total, 1,235 students from grades one to five in a primary school in Beijing took part in this research. Using the Chinese National Student Physical Fitness Standard as a guide, the students were subjected to BMI, vital capacity, 50 m sprint, sit and reach, timed rope-skipping, timed sit-ups, and 50m × 8 shuttle run measurements. These tests were administered once before and once after the lockdown period. The results showed that the overall physical fitness of the participants was better after the lockdown [p = 0.000, r = −0.14, 95% CI (−0.219, −0.061)]. Specifically, vital capacity, sit and reach, timed rope-skipping and timed sit-ups had improved after the lockdown. Meanwhile, 50m × 8 shuttle run dropped slightly but not significantly whereas 50 m sprint dropped sharply after the lockdown. The proportion of overweight and obese students increased, but the difference before and after the lockdown was small. It appeared that during the pandemic, through the intervention of many comprehensive factors, home-based fitness was normalized and promoted the healthy development of students.

Keywords: children, coronavirus, exercise, fitness assessments, fitness tests, physical education

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INTRODUCTION

In late 2019, the emergence of a novel human coronavirus, Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), triggered a global COVID-19 pandemic (Schmidt et al., 2020) and posed a health threat of unknown magnitude worldwide (Chen et al., 2020a). Due to the easy spread of the virus and the emergence of new variants, no effective medication has been found to eliminate the virus completely. Instead, lockdown was an effective way to interrupt the transmission chain and control the pandemic. Lockdown was first implemented in Wuhan on January 23, 2020, in China. As the epidemic continued, all provinces, municipalities, and autonomous regions had activated the Level I response to major public health emergencies on January 29, 2020 (IFENG, 2020), which is the highest level of response to major public health emergencies (The Central People's Government of the People's Republic of China, 2006; IFENG, 2020). Lockdown or strict control measures were implemented across the country, which included imposing a lockdown on the infected area, restricting or stopping fairs, gatherings, and theater performances, shutting down work and businesses, and implementing closed community management, with residents disallowed to leave their homes, and home services were provided, including home delivery and home treatment by medical staff (The Central People's Government of the People's Republic of China, 2006). The lockdown was not lifted until the regions downgraded their Level I response to Level II or more lower-level accordance with the public health emergency level criteria based on the control of the epidemic (Tianjin Daily, 2020). In terms of schools, for the safety of students and to prevent the spread of the virus on campus grounds, and the February 19–June 16, 2020, semester was scheduled to home-based online classes (Minstry of Education of the People's Republic of China, 2020a). As the outbreak was brought under control, students were able to re-enter the classroom for the new semester on September 1, 2020, and resume their regular studies.

In facing the COVID-19 pandemic, what impact did the lockdown have on students' health? On the one hand, students could not go out of the house freely and could not walk to the park or playground for exercise, which reduced the time for physical activities but increased the screen time for watching TV or playing with cell phones, which will inevitably bring adverse effects to students' health (Carroll et al., 2020; Cuschieri and Grech, 2020; Pietrobelli et al., 2020). In addition, for active students, staying at home for a long time might affect students' mental health and cause problems such as lonely, restless, anxiety, or uneasy (Adıbelli and Sümen, 2020; Duan et al., 2020; Francisco et al., 2020). As physical fitness was considered a powerful marker of health in children (Ortega et al., 2008), that will subsequently determine health in adulthood (Malina, 2001; Ding and Jiang, 2020), it is growing in significance to everyday life (American College of Sports Medicine, 2013). Physical fitness was reported to be essential for performing school assignments and meeting home responsibilities, with enough energy for sport and alternative leisure activities (Corbin et al., 2014). Furthermore, fitness can help build a stronger immune system to guard against viral and bacterial infections (Corbin et al., 2012). On the contrary, low fitness level was associated with negatively impacting health outcomes, such as obesity, heart disease, impaired skeletal health, and poor quality of life (De Miguel-Etayo et al., 2014). Physical fitness was found to be affected by genetic factors, but also by physical activities (Bouchard et al., 2012; Takken and Hulzebos, 2013), and only regular physical activity could achieve optimal physical fitness (Corbin et al., 2012). There were also studies showing that maintaining regular physical activity habits was a key strategy for mental health, which could help regulate mood (Kaur et al., 2020; Maugeri et al., 2020). Therefore, during the special period, it was very necessary to continue to carry out physical activities at home.

Therefore, this study sought to determine the rank distribution of physical fitness indicators of primary school children and to compare the fitness levels of students before and after the lockdown, The interpretation of the results was conducted according to Bronfenbrenner (1977) ecological theory, which explained that throughout the life span, an individual was embedded in multiple environments, such as the family, school, and social environments. **Figure 1** outlines the different environmental factors in each level of the Ecological Theory Framework, providing a useful theoretical framework that focuses on the major factors affecting children's development (Bronfenbrenner, 1979; Sallis et al., 2008; Browne et al., 2021; Lopez et al., 2021; Teran-Escobar et al., 2021; Stienwandt et al., 2022). The findings of this study will provide a reference value for similar public health emergencies in the future.

MATERIALS AND METHODS

Participants

A primary school in Beijing, China, was invited to participate in the study. Prior to the lockdown, 1,428 children in this school underwent the physical fitness assessments. Following the lockdown, a total of 1,235 students again underwent the physical fitness assessments, and were included in the final sample (638 boys and 597 girls). The remaining 193 children whose evaluation were previously recorded, were promoted to middle school and were excluded from the study. All students read the Participant Information Form, and their parents or guardian signed the informed consent form. This study was conducted according to

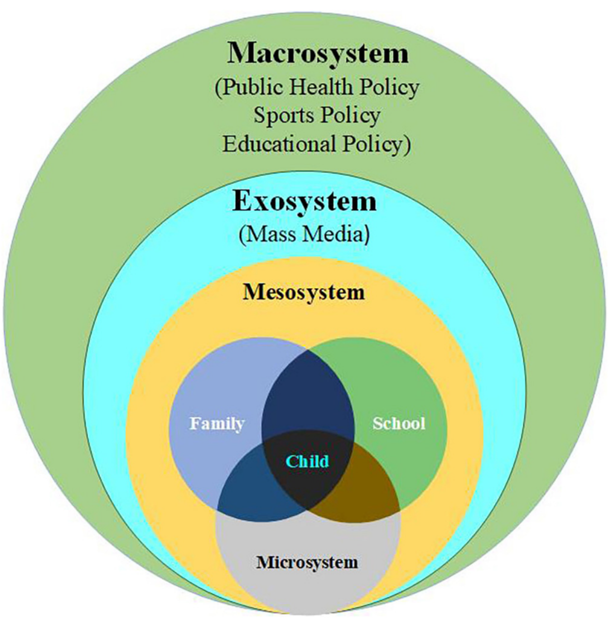

FIGURE 1 | Bronfenbrenner's ecological model. Image reproduced with minor modifications from Bennett and Grimley (2001), with permission from Elsevier (License number 5334520439220).

the procedures as approved by the University of Malaya Research Ethics Committee (UM.TNC2/UMREC – 667).

Procedures

There were two data collection sessions, one before lockdown (October 2019) and one after lockdown (October 2020). All CNSPFS tests were administered during normal school hours according to standard operating protocols by five trained physical education (PE) teachers.

Before the assessment, the researcher explained each test and demonstrated each test technique. Participants were allowed one practice trial for each test. The researchers tested the subjects in accordance with the test protocol and requirements. At the end of all tests, direct scores were obtained for each of the seven tests and raw data were input into a central spreadsheet.

Measures

The most current fitness assessment requirements and standards in China, the 2014 revised Chinese National Student Physical Fitness Standard (CNSPFS) battery (Ministry of Education of the People's Republic of China, 2014), was used to assess the physical fitness of participants. The CNSPFS was tailor-made for children of different grades, that is, different test standards were used for different grades and genders (Zhu et al., 2017). The testing battery is a common testing battery that has been widely used to evaluate children's physical fitness in China.

This battery consisted of a standardized test, that involved a total of seven fitness indicators, which are Body Mass Index (BMI), vital capacity (VC) of the lung, 50 m sprint, sit and reach, timed rope-skipping, timed sit-ups, and 50 m × 8 shuttle run (Zhu et al., 2017), covering areas of body mass index, aerobic capacity, speed, flexibility, and abdominal strength. Children's overall physical fitness performance was categorized, per CNSPFS standards, as excellent, good, pass, or fail (Ministry of Education of the People's Republic of China, 2014).

BMI

A portable instrument (GMCS-IV; Jianmin, Beijing, China) was used to measure the height and weight of the students and to obtain the BMI, which was calculated by taking a person's weight and dividing by their height squared. During testing, the subject stood on the bottom plate of the equipment with bare feet, back to the upright posture, with the head upright, the torso naturally straight, the upper limbs naturally drooping, the heels close together, and the toes 60 degrees apart. After 2–3 s, the measurement result was displayed on the LCD, and the voice broadcast prompt was synchronized. All participating children from Grades 1–6 were assessed for this measure.

Vital Capacity

The vital capacity (VC) was assessed by using a spirometer (GMCS-IV; Jianmin, Beijing, China), which is a device that measures the maximum amount of air that can be fully exhaled from the lung after a maximum inhalation. During the test, the participant stood in front of the instrument, installed the disposable mouthpiece on the side of the air inlet push tube, and held the handle of the instrument firmly. Participants were asked to bring the mouthpiece close to their mouth, take a deep breath, and blow at a moderately uniform speed until they stopped blowing. Participants were not allowed to stop breathing during the process or inhale twice during the test. Each participant was tested twice and the maximum value taken. All participating children from Grades 1–6 were assessed for this measure.

50 m Sprint

To assess speed in this test, in addition to the 50-m straight race track, a starting flag, a whistle and a stopwatch were also needed. Participant started from a stationary standing position with one foot in front of the other and the front foot must be behind the starting line. Once the participant was ready and motionless, the starter gave the instructions "set" then blew whistle and waved the starting flag to provide the signal to the finish line timekeeper to start timing. After hearing the whistle, participants had to run across the finish line at the fastest speed. The timekeeper stopped timing at the same time. Two trials were allowed, and the best time was recorded to the nearest two decimal places. All participating children from Grades 1–6 were assessed for this measure.

Sit and Reach

Flexibility was measured using the sit and reach test which was carried out by a seat forward flexion tester (GMCS-IV; Jianmin, Beijing, China). During the test, the participant sat on the flat ground with legs straight and legs flat against the test longitudinal plate. The legs were about 10–15 cm apart. The upper body was bent forward. Participants took the test twice with the best score recorded in centimeters (cm), to the nearest one decimal place. All participating children from Grades 1–6 were assessed for this measure.

Timed Rope-Skipping

To test children's coordination and muscle endurance, a rope-skipping test was conducted requiring them to land on both feet after they got off their feet. Participants were instructed to skip continuously for 1 min after they were given the appropriate length of ropes. The tester counted and recorded the number of rope-skipping. All participating children from Grades 1–6 were assessed for this measure.

Timed Sit-Up

Abdominal muscle strength and endurance was measured using a 1-min sit-up test. Participants were divided into pairs. One participant lied on their back with their legs slightly apart, their knees bent at a 90-degree angle, and held the head with hands close to ears while the other partner held down the ankle joint to secure the lower limb. During the performance, participants had to elevate their trunks to the point where the elbows made contact with their thighs, then lowered their shoulders back to the mat to resume the starting position. When given the "start" signal, the tester began the stopwatch and recorded the number of times of completed sit-ups within 1 min. This measure was assessed only for primary school children from Grades 3–6.

50m × 8 Shuttle Run

Cardiovascular endurance was tested using 50 m × 8 shuttle run test. During this test, participants needed to run back and forth eight times along a straight track line between 2 poles set 50 m apart. Participants were asked to run at their maximum speed and, at the end of the track line, turn around at a pole in a counter- clockwise direction, and run back to the starting line. A stopwatch was used in the test, and time was recorded to the nearest second. This measure was assessed only for primary school children from Grades 5–6.

Data Analyses

The raw results of all tests were first calculated using grade- and sex-specific weights defined by the 2014 revised CNSPFS (Ministry of Education of the People's Republic of China, 2014), and weighted scores were subsequently categorized into the categories of excellent (defined as having scores of 90), good (scores 80–89), pass (scores 60–79), or fail (scores <60).

Descriptive statistics were used to analyze all tests, with means and standard deviations (SD) reported. Moreover, the scores ranked distribution [n (%)] were reported for each PF outcome to compare the number of the subjects who fell within the established standards of the test items. McNemar–Bowker Test was used to test for differences in the distribution between the two time points. Kolmogorov–Smirnov test was used to identify normality, and all assumptions for Non-parametric Wilcoxon test were met when making before and after lockdown comparisons. An effect size, r, was calculated using the conversion formula (Morgan et al., 2019), with effect size > 0.5 considered as large, >0.3 as medium, and >0.1 as small (Cohen, 1988).

Statistical significance was set at $p < 0.05$, and all analyses were performed using SPSS Statistics for Windows version 25.0.

RESULTS

Rank Distribution of BMI and Physical Fitness

For BMI rank distribution, overweight and obese students increased after the lockdown compared to before the lockdown. Obesity increased by 0.8% while overweight increased by 2.6% between the two time periods.

Correspondingly, underweight and normal students reduced after the lockdown compared to below the lockdown, Underweight reduced by 1.2% while normal reduced by 2.2% between the two time periods. The breakdown for BMI rank distribution before and after the lockdown are shown in **Table 1**.

TABLE 1 | BMI rank distribution.

Indicator	Year	Underweight	Normal	Overweight	Obesity
		(*n* and %)	(*n* and %)	(*n* and %)	(*n* and %)
BMI	2019	46 (3.7)	913 (73.9)	159 (12.9)	117 (9.5)
BMI	2020	31 (2.5)	885 (71.7)	192 (15.5)	127 (10.3)

For Physical Fitness indicators, **Table 2** and **Figure 2** provide information about the changes in the rank distribution before and after the lockdown. The results show that VC, timed rope-skipping and timed sit-ups indicators had all increased in the proportions of excellent rank, while the proportions of other ranks had all decreased after the lockdown. In terms of sit and reach, although the proportions of excellent and good rank had also increased, the fail rate had also increased after the lockdown. Similarly, the comparison results of the 50 m × 8 shuttle run index showed that the proportions of excellent had increased, however, the proportions of good and fail ranks had decreased after the lockdown. Conversely, for the 50 m sprint, the indicator showed that the proportions of excellent and good ranks had decreased, while the proportion of pass and fail ranks had increased after the lockdown.

Comparison of Scores Before and After Lockdown

Normality of data was assessed using the Kolmogorov–Smirnov test. It was revealed that the data for all seven test indicators were not normally distributed ($p < 0.05$). Subsequently, the Wilcoxon signed ranks test, a non-parametric paired difference test, was selected to compare the performance of students before and after lockdown.

As shown in **Table 3**, the total results of the participants show that 41.13% of the 1235 students had lower scores after the lockdown, with the greatest decrease in the scores of 50 m and 50 m × 8 shuttle run, corresponding to 58.14 and 47.43%; 51.50% of the students had better results after the lockdown; 7.37% of the students had no changes. This difference indicated that the physical fitness of the students had significantly increased to a certain extent after the lockdown, with $z = -4.743$, $p = 0.000$, $r = -0.14$, a small effect size according to Cohen (1988).

With the exception of 50 m × 8 shuttle run, the difference between the scores before and after the lockdown for BMI, VC, 50 m sprint, sit and reach, timed rope-skipping, and timed sit-up were all statistically significant. BMI (z = −2.118, $p = 0.034$, $r = -0.06$) and 50m sprint (z = −12.209, $p = 0.000$, $r = -0.35$) had decreased, with small and medium effect sizes respectively. Conversely, timed sit-ups ($z = -5.339$, $p = 0.000$, $r = -0.21$) had increased with a small to medium effect size, both sit and reach ($z = -8.456$, $p = 0.000$, $r = -0.24$) and timed rope skipping ($z = -9.658$, $p = 0.000$, $r = -0.28$) increased with small to medium effect sizes. VC ($z = -16.117$, $p = 0.000$, $r = -0.46$) had increased with medium to large effect sizes. Scores of 50 m × 8 shuttle run before and after the lockdown were not significantly different, $z = -0.656$, $p = 0.512 > 0.05$, $r = -0.04$, and decreased with a small effect size.

DISCUSSION

This study sought to determine the rank distribution of physical fitness indicators of primary school children and to compare their fitness levels before and after the lockdown. For rank distribution, the proportion of overweight and obese students increased after the lockdown compared to before the lockdown.

TABLE 2 | The physical fitness rank distribution.

Indicator	Year	Excellent	Good	Pass	Fail	Sum P&F (*n* and %)
		(*n* and %)	(*n* and %)	(*n* and %)	(*n* and %)	
VC	2019	525 (42.51)	325 (26.32)	383 (31.01)	2 (0.16)	385 (31.17)
	2020	754 (61.05)	295 (23.89)	186 (15.06)	0 (0.00)	186 (15.06)
50m sprint	2019	232 (18.79)	232 (18.79)	722 (58.46)	49 (3.97)	771 (62.43)
	2020	154 (12.47)	180 (14.57)	804 (65.10)	97 (7.85)	901 (72.95)
Sit and reach	2019	396 (32.06)	287 (23.24)	542 (43.89)	10 (0.81)	552 (44.7)
	2020	472 (38.22)	339 (27.45)	406 (32.87)	18 (1.46)	424 (34.33)
Timed rope-skipping	2019	687 (55.63)	192 (15.55)	350 (28.34)	6 (0.49)	356 (28.83)
	2020	846 (68.50)	153 (12.39)	233 (18.87)	3 (0.24)	236 (19.11)
Timed sit-ups	2019	256 (38.04)	175 (26.00)	239 (35.51)	3 (0.45)	242 (35.96)
	2020	326 (48.44)	158 (23.48)	187 (27.79)	2 (0.30)	189 (28.09)
50m×8 shuttle run	2019	67 (26.48)	58 (22.92)	114 (45.06)	14 (5.53)	128 (50.59)
	2020	74 (29.25)	40 (15.81)	132 (52.17)	7 (2.77)	139 (54.94)

Sum P&F means summary of Pass and Fail.

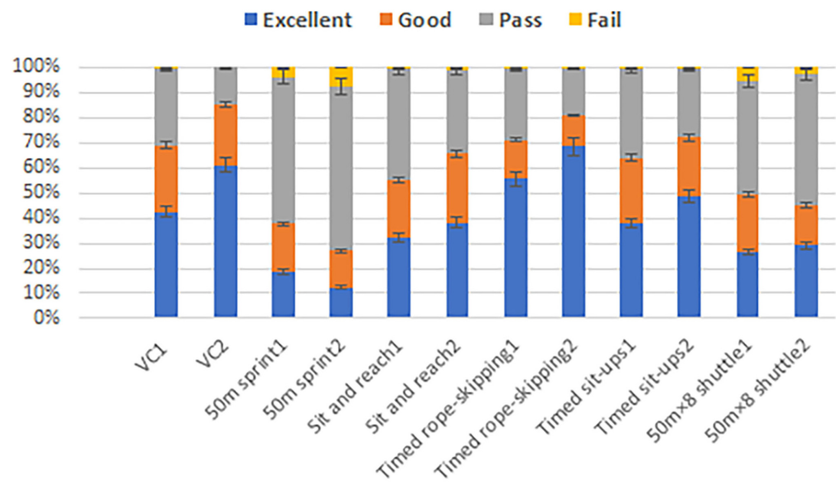

FIGURE 2 | Physical fitness rank distribution before and after the lockdown. 1-2019; 2-2020.

TABLE 3 | Wilcoxon signed ranks test for all CNSPFS tests.

Indicator	Before	After	Rank score (after-before)				Z	Asymp. Sig. (2-tailed)	R	95%CI
	Mean ± SD	Mean ± SD	Negative ranks (%)	Positive ranks (%)	Ties (%)	N				
Total score	84.21 ± 7.50	84.95 ± 7.90	41.13	51.50	7.37	1,235	−4.743	0.000	−0.14	(−0.219, −0.061)
BMI	92.89 ± 12.95	92.28 ± 13.31	12.47	9.23	78.30	1,235	−2.118	0.034	−0.06	(−0.139, 0.019)
VC	85.35 ± 11.17	90.67 ± 10.06	18.54	53.20	28.26	1,235	−16.117	0.000	−0.46	(−0.540, −0.380)
50 m sprint	76.21 ± 16.07	72.13 ± 17.43	58.14	26.72	15.14	1,235	−12.209	0.000	−0.35	(−0.429, −0.271)
Sit and reach	81.95 ± 11.62	83.75 ± 13.03	27.13	46.80	26.07	1,235	−8.456	0.000	−0.24	(−0.319, −0.161)
Timed rope-skipping	88.11 ± 12.49	91.43 ± 11.12	23.97	40.81	35.22	1,235	−9.658	0.000	−0.28	(−0.359, −0.201)
Timed sit-ups	84.64 ± 11.26	86.86 ± 11.27	29.57	45.62	24.81	673	−5.339	0.000	−0.21	(−0.317, −0.103)
50 m × 8 shuttles run	78.60 ± 16.19	78.49 ± 14.92	47.43	39.13	13.44	253	−0.656	0.512	−0.04	(−0.214, 0.134)

As for the remaining physical fitness indicators, except for the 50 m sprint, all other indicators had increased in proportions of excellent rank, with a majority accompanied by decreased in fail ranks. Notably, the 50 m sprint had decreased in the excellent and good ranks, and increased in the pass and failure ranks. As for comparisons between the physical fitness scores, the overall results after the lockdown were better than those before the lockdown. The results of the specific tests show that, except for BMI, 50 m sprint, and 50 m × 8 shuttle run scores, other test results had improved. Among the decreasing indicators, the difference in BMI before and after was statistically significant, but the magnitude was small. As for the 50 m × 8 shuttle run, there was a drop but it was not statistically significant. Only the 50 m sprint had a large significant decline. It appeared that the negative impact of the lockdown period on the physical fitness of the students was mainly concentrated on the speed quality of running.

The results of this study indicated that there were improvements in some physical fitness indicators, in contrast to previous studies (Ito et al., 2021; Pombo et al., 2021; Jarnig et al., 2022), in which the results showed that the lockdown had negative impact on the physical fitness of the children. In the longitudinal study of the impact of mitigation measures concerning COVID-19 on the health and well-being of primary school students, it was found that the closures of schools and sports facilities resulted in the adverse combination of increased BMI and decreased physical fitness (Jarnig et al., 2022). Pombo et al. (2021) reported that less physical activity, a sedentary lifestyle, and more screen time were the reasons for the decline in physical fitness after the lockdown. To explain why this study found significant increases instead of decreases in physical fitness after lockdown, the Bronfenbrenner Ecology Theory appeared to be a probable and suitable model to be used for the main points of discussion. According to the Bronfenbrenner Ecology Theory, macrosystems include the public health system and educational policy (Lenhoff and Pogodzinski, 2018), which influence child development primarily through their association with family-and school-level factors (Su, 2012).

Macrosystem Level

The first-level public health emergency response was activated across China following the outbreak of the COVID-19 pandemic in December 2019 due to the strong spread, unpredictability, and serious harm of the COVID-19. Lockdown policy was implemented, large-scale events had been cancelled or postponed, opening of schools were postponed, and people had reduced their outings to stay at home to minimize cross-infection and cut off the spread of the virus to the greatest extent (Li and Liu, 2020; Liu et al., 2020). Staying at home for a long time without going out, sitting for a long time, playing with mobile phones, and lying down for a long time had become a living condition for most people during the pandemic prevention and control period (Zhuang, 2020). In the face of this situation, on January 30, 2020, the General Administration of Sport of China issued a notice on promoting scientific home-based fitness methods, requiring local sports departments to introduce simple, scientific, and effective home-based fitness methods based on local conditions to guide people to start a healthy home-based lifestyle (General Office of the General Administration of Sport of China, 2020). Later on February 12 and 16, the Ministry of Education of the People's Republic of China issued a Notice on Work Arrangements titled "Suspension of Classes without Suspension of Learning" during the postponement of the start of primary and secondary schools and another Notice for parents of primary and middle school students in China as a guide for children's home study and life during the pandemic, requiring schools and parents to guide students to arrange indoor physical exercises to enhance students' physical fitness and ensure maintenance of their health (Minstry of Education of the Peop's Republic of China, 2020b; Minstry of Education of the People's Republic of China, 2020a). These policies had indirectly promoted the health of children.

Exosystem Level

At the Exosystem level, the mass media became an essential tool for combating COVID-19, which offered a unified platform for all public health communications, comprehensive healthcare education guidelines, and robust social distancing strategies while still maintaining social connections (Anwar et al., 2020).

Various information about "home-based fitness" was disseminated on social media platforms, including informational and motivational persuasive sports health information (Huang et al., 2020). For example, General Administration of Sport of China (General Office of the General Administration of Sport of China, 2020), the relevant local sports departments used the Internet, TV, radio, and other media resources to widely publicize the importance of home fitness, and made people more aware of the benefits of physical exercise for physical health, that proper physical exercise can not only improve physical functions but also enhance immunity (Nieman, 2000; Leandro et al., 2007; da Silveira et al., 2021). Social media also provides sports health prescriptions, cloud competitions, and cloud activities organization and planning which had greatly stimulated the participation and creativity of sports participants in the "cloud" and promoted national fitness through competitions, punch cards, and relays (Huang et al., 2020).

In addition, the most important impact on children was mass media, such as DingTalk and MOOC, which provided online educational videos (Guo et al., 2014; Ai and Huang, 2021), had maintained the original teaching plan disrupted by the pandemic, and restored normal teaching order by providing online education platforms for schools and families (T. Chen et al., 2020b).

Mesosystem and Microsystem Level

For children, whether the school and family setting at Microsystem level, or the relationship between family and school at the Mesosystem level, all these relationships affected children's health and played the most direct role in helping them cope with the pandemic.

In order to make up for the lack of exercise time and promote the normal growth and development of children during the pandemic, the Ministry of Education of the People's Republic of China had proposed that "Suspension of Class without Suspension of Learning" (Minstry of Education of the People's Republic of China, 2020a). Hence all schools practiced online guidance to allow students to learn and participate in physical exercises at home, and conveyed through the network platform, home-based physical exercise videos for students to watch and learn, and improve the effectiveness of their exercise. At the same time, the schools had established an effective evaluation and monitoring system by using software such as DingTalk's "Physical Fitness Training Every Day", and WeChat to perform physical check-in tasks for students (Xiang et al., 2020).

On the family side, parents began to understand the value of exercise, which is that regular exercise of sufficient intensity could be used as an auxiliary tool to strengthen and prepare the immune system for COVID-19 (da Silveira et al., 2021). Parents encouraged their child to participate in more sports activities (De La Haye et al., 2014) and increased the consumption of exercise equipment which affected children's physical activity behaviors (Sirard et al., 2010). For example, at the beginning of the COVID-19 outbreak, sales of treadmills increased by 173.3% on a year-on-year ratio.

In the context of school and family relationships, home-school cooperation had become an important force to ensure the effectiveness of online physical education (Shu and Xia, 2020). As professionals, PE teachers provided parents with professional education guidance through online videos and articles related to the value, function, content, methods, and experience of home parent-child exercise. This was carried out with the help of online platforms such as class QQ groups and WeChat groups. Parents also provided in-PE learning assistance and after-PE exercise feedback for PE teachers' online teaching. Through the interaction between teachers and parents, an educational synergy was finally formed, which played a positive role in the growth and development of students (Hu et al., 2020; Shu and Xia, 2020).

Using the Bronfenbrenner Ecological Theory as the focus of discussion, it was possible to conclude that the overall physical fitness of the students before and after the lockdown showed an upward trend, which was achieved through the various efforts of the public health policies, mass media, parents, and schools. However, due to the objective reality of home exercise, running activities for endurance and speed have shown a downward trend. The main reason was that home-based exercise venues were mostly in narrow venues such as living rooms, bedrooms, and corridors, and the scope of activities related to running endurance and speed was limited. It appeared that the choices of home-based exercise programs for children were possible mainly for the development of strength, flexibility, coordination rather than speed and endurance (Xu, 2020; Zagalaz-Sánchez et al., 2021). Future research should investigate how to improve sprint performance and endurance in the home environment. As for the changes of BMI scores, studies had shown that the lockdown had led to unhealthy nutrition in some people, such as excessive intake of snacks and sweets, and eating in response to boredom which easily led to conditions of overweight or obesity (Rundle et al., 2020; Deschasaux-Tanguy et al., 2021; Jenssen et al., 2021). However, due to home-based fitness which helped students to consume parts of energy and get rid of fat production, there was only a small difference in the status of overweight and obesity before and after the lockdown. A limitation of this study was the lack of indicators such as students' daily exercise time and intensity, and parents' ages, parents' educational level, and parents' exercise habits, which might impact students' physical fitness results (Rossi et al., 2021).

CONCLUSION

The results of this study showed that students' physical health was effectively intervened during the lockdown period. Under the combination of efforts at all levels of the ecological model to guide the students to include home-based fitness into everyday life and to promote students' individual health behavior, students' physical health was maintained during the pandemic.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Malaya Research Ethics Committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

HL conceptualized the research, collected and analyzed data, and drafted the manuscript. JC supervised the research, interpreted the data, and reviewed the manuscript. Both authors contributed to the article and approved the submitted version.

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Shaping Future Directions for Breakdance Teaching

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This article reports on the evolution of breakdance. Given the inclusion of breakdancing in the 2024 Olympic Games in Paris, France, scholars have generated substantial international research related to breakdance teaching in recent years. However, few researchers have focused on the impact of formal formative assessment on breakdance teachers' teaching and students' learning. We wish to contribute to the quality of breakdance teaching and learning by identifying the positive impact of recent research on formative assessment on student learning and designing a formal formative assessment task related to breakdance. This article lays out a framework of formal formative assessment tasks and identifies the positive impact of formative assessment on dance education. Although our work is far from perfect, it does provide a general methodological framework for assessing breakdance students' abilities in formal educational settings.

Keywords: breakdance, formative assessment, Olympics, rubric/graded scoring key, hip-hop culture

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INTRODUCTION

Breaking is the oldest known hip-hop style of dance. It is believed to have originated in the Bronx, New York, in the 1970s (Yang et al., 2022). In the following sections of this article, we thoughtfully chose the term "breakdancing" in order to make this art form easily and clearly conveyed to the general public. We believe this is a reasonable step to promote the culture of "breaking."

As a key element of hip-hop culture, breakdancing has triggered a domino effect (Li and Vexler, 2019). This effect has propelled it to spread widely around the world. According to research, more than one million people in France participate in breakdance, with around 11 international breakdancing events and 560 national breakdance events each year (Shapiro, 2004). In China, breakdance is one type of street dance. In 2013, China Hip Hop Union Committee (CHUC) was founded by the Chinese Dancers Association, which allowed the art form to be recognized by the professional dance system and gained support from the government (CHUC, 2020). According to CHUC (2020) data, 32 street dance alliances have been founded in China's 32 provinces (autonomous region, municipality, and special administrative region), with about 8000 street dance institutions in alliances, over three million street dance employees, and over 10 million street dance lovers nationwide. Notably, in 2019, the annual value of production of China's street dance-related industries has reached RMB 50 billion (7.5 billion USD; CHUC, 2020).

Breakdance is so attractive that even the Olympics wish to include it in their list of events. In 2020, breakdancing became an official Olympic sport. In an effort to attract young people who may not follow some of the traditional sports, the International Olympic Committee (IOC) has officially added the form of street dance to the medal events program for the 2024 Summer Olympics in Paris (IOC, 2021). In addition, breakdance is included in the Olympics which will accelerate its spread around the world. According to research, breakdancing is included in the Olympics which will increase its social attention (Tai et al., 2022), inspire the interest of national governments to support, and promote breakdance (Chang and Lee, 2022), parents will support and encourage their children to learn breakdancing in dance schools (Yang et al., 2022), and new employment opportunities will be created for practitioners (Li and Vexler, 2019). Breakdance is far more beneficial and potent than we might imagine. In China, some universities have introduced breakdancing as an item on their college entrance exams (Li and Vexler, 2019). This certainly gives art students who love breakdancing a new opportunity to pursue higher education.

Given the inclusion of this dance form in the 2024 Olympic Games in Paris, France, scholars subsequently generated a substantial body of international research related to breakdance teaching (Shimizu and Okada, 2018; Vexler, 2020; Gunn, 2021; Dodds, 2022; Tai et al., 2022; Yang et al., 2022), for example, the relationship between deliberate practice theory and breakdance movement proficiency (Shimizu and Okada, 2018) and how the process of learning breakdance reflects dancers' personal identity (Dodds, 2022). In fact, there is a tendency for researchers to be eager to seek an innovative teaching and learning strategy to help students learn breakdance effectively. Recognizing the importance of improving breakdance teaching methods, in early 2021, we conducted an investigation and discussed what teachers could do to help breakdancing students learn more effectively. The result of that discussion was a call to action that appeared in *Frontiers in Education* (Yang et al., 2022). Again, we wish to contribute to the quality of breakdance teaching and learning by identifying the positive impact of recent research on formative assessment on student learning and designing a formal formative assessment task related to breakdance.

Formative assessment use in dance education has gained increasing importance in making many types of decisions from school improvement to classroom and instructional decision-making. We present this overview based on the following three studies:

- According to Andrade et al. (2015), formative assessments can effectively promote and motivate students to learn dance and even attract students to participate in the classroom.
- According to Overby et al. (2013), formative assessments can help teachers and school administrators identify changes and improvements needed for the future development of the school by observing student responses.
- According to Harding (2012), formative assessments contribute to the reinforcement of dance teachers' personal values, supporting student leadership roles among their peers, and allowing dance teachers and students to participate in an ever-evolving loop of feedback that is multidirectional.

Such assessment becomes formative assessment when the evidence is actually used to adapt teaching work to meet learning needs (Duckor and Holmberg, 2019b). This means that assessors and teachers must gather evidence about the adequacy of students' responses to assessment items to help teachers adapt their teaching work. It would be interesting to see if evidence exists that addresses the adequacy of student responses to assessment items in formative assessment articles related to breakdance. The present article attempts to identify gaps in formative assessment tasks related to breakdance and to design what we believe are assessment tasks that effectively identify the competency level of breakdance students. The assessment tasks include assessment items, constructing maps, and judgment-based rubrics.

MATERIALS AND METHODS

This article has collected formative assessment tasks related to breakdance from the EBSCO and Web of Science databases. We did not explicitly use the word "breakdance" to search because researchers may focus on related aspects of breakdance such as hip-hop dance (Vasil, 2020), but do not use the word breakdance. However, the articles searched must have included the process of formative assessment task design relevant to breakdance. The following inclusion criteria included (1) written in English, (2) peer-reviewed articles, (3) related to breakdance, and (4) articles (or supplemental materials) must include items or criteria related to assessment skills. To ensure our review was appropriately justified, we used Messick's six aspects of validity to validate formative assessments related to breakdancing (Messick, 1995). These six aspects include:

- Content relevance (to what extent is the assessment content relevant to the domain of the construct measured).
- Substantive (what is the empirical evidence that the students are actually engaged in the processes that are intended by the assessment).
- Structural (how faithful is the scoring structure of the assessment to the structure of the construct domain measured by the assessment).
- Generalizability (to what extent do score properties, interpretations, and test criterion relationships generalize to and across population groups, settings, and tasks).
- External (to what extent are the assessment items/tasks relevant to the criterion).
- Consequential (what are the actual and potential consequences of using the scores).

RESULTS

Only two of approximately 25 publications reviewed in the full text were considered to meet the previously stated inclusion criteria (Foley, 2016; Vasil, 2020). Despite early breakdancing educator Foley explicitly calling for students to learn breakdance at the earliest possible age (Foley, 2016), scholarship on formal formative assessments related to breaking has not followed this trend. This phenomenon may hinder teachers from improving the learning of breakdance students. Based on the articles by Foley (2016) and Li and Vexler (2019), we summarize the following three possible reasons:

- For some street styles, historical documents might be difficult to find because they have been lost or were never created in the first place. Thus, this phenomenon may hinder the design of formal formative assessment items, such as match and multiple-choice items.
- Some media companies use breakdancing to spread misinformation for the purpose of advancing their own agendas. The motives for spreading misinformation are many, including self-promotion and attracting attention as part of a business model. This misinformation has led to ambiguous understandings of the concepts of breakdancing, breaking and popular dance, and street dance among the general public. For this reason, we have chosen to use the term "breakdancing" in this article so that it can be more easily searched by the general public and researchers who are not aware of this art form.
- Debate over the status of breakdancing as an Art or Sport continues. At the extremes, some believe breakdancing is a sport. At the other extreme, others think breakdancing is an art. According to the characteristics of an art form and the philosophy of hip-hop culture, no dancer can be called "the best in the world." Notice that the hip-hop art emphasizes that no dancer can be called the best probably conflicts with summative assessment's purpose for grading, placement, and classification of students (Dixson and Worrell, 2016). If scholars do not fully understand the blurred relationship between formative assessment, summative assessment, and the characteristics of hip-hop art, then this will hinder the design of assessment tasks.

REVIEW ASSESSMENT TASKS RELATED TO BREAKDANCE

This section will focus specifically on the breakdancing assessment items, criteria, and preparation for students before the assessment. Again, space limitations make an extended discussion of these findings impractical. Interested readers are therefore referred to other relevant sources (Foley, 2016; Vasil, 2020; Sato and Hopper, 2021).

- According to Messick's six aspects of validity, Vasil's assessment task was a low-stakes and formative assessment (Vasil, 2020). The results of the assessment were used in a proposal for bringing pop culture into the arts-integrated curriculum. A summative assessment will be conducted at the end of the course, and students will perform a breakdance show. Through three music lessons and three art lessons, students avoid, to some extent, unexpected reactions to the assessment items (Messick, 1995). For example, students will not be confused about the assessment items.
- Vasil's assessment task also follows, to an extent, the six equity themes proposed by Rasooli et al. (2018).

1. A harmless and constructive classroom environment: Students are explicitly told not to use the second video as learning material (the video has swearing).
2. Transparency, consistency, and justification: Students are provided with courses related to assessment skills.
3. In collaborative activities, students can share their thoughts and ideas and support each other.
4. Avoidance of score pollution: Evidence was obtained through collecting students' artwork and informal ways (teacher observation). Although no explicit scoring guidelines were provided, the criteria provided in the supplemental materials were sufficient to support teachers' judgments about student performance.
5. From the pictures provided in Vasil's article, the space for learning dance may be too narrow. This may not meet the principle that students are given the quality resources needed for assessment.
6. Accommodations: Evidence indicates that students were actively engaged in the assessment process and that no students had unexpected reactions to the assessment.

- Based on the six best recommendations from Mehrens et al. (1998) on preparing students for performance assessments, reviewed below.

1. Determine that the interpretation from student performance is only relevant to the specific task.
2. Teachers did not provide additional guidance to any students prior to the assessment.
3. Students were not confused about the dance performance and drawing items, and teachers provided guidance related to the skills.
4. No evidence that assessment criteria were delivered to students.
5. Students were given small bags filled with leftover materials from art class and were told to create something new (the transferability of assessment skills and knowledge).
6. Students' artwork was displayed in the hallway for all to view, supporting students to self-assess.

So far, we have reviewed the assessment tasks related to breakdancing. Despite some limitations, especially related to the preparation prior to the assessment, these items are sufficient to be used for the first report of breakdance students' performance abilities, provided this is not the only assessment that contributes to the report. In addition, we found that existing items on formative and summative assessments are insufficiently designed to cover topics related to breakdancing. When these items are used to assess students, this potentially leads to constructed underrepresentation and affects the reliability of the assessment results (Messick, 1995). In fact, we are certainly not the first to notice this imbalance, but little has been done to address it. We believe that if this article is to be truly helpful to breakdance teachers who continue to face teaching dilemmas, we need to attempt to design a set of formal formative assessment tasks that are directly related to breakdancing. We consider this a reasonable initial step toward a more elaborate intellectual endeavor in the future.

ASSESSMENT TASK DESIGN

This section will design a formal formative assessment task related to breakdancing. This is a low-stakes formative assessment task. The assessment is suitable for breakdancing students age eight and up. Breakdancing teachers can use it to assess their students in the following four capabilities: (1) view breakdancing competition videos to analyze dance movement combinations for level features, (2) execute breakdancing movements' level features, (3) outline breakdancing history level features, and (4) identify breakdancing terms level features.

The results of the assessment will inform the following decisions: (1) assist breakdancing teachers in improving their teaching strategies, (2) identify breakdancing students' ability levels and provide formative feedback, (3) breakdancing teachers can use the assessment results to determine students' position on the construct map and provide targeted guidance to students (See **Figure 1**; Wilson, 2009; Duckor and Holmberg, 2019a), and (4) the results of the assessment will be discussed at meetings with parents to inform student status.

Some potential constraints on the use of this assessment include: (1) We cannot completely eliminate construct-irrelevant variances during the assessment process because there is always some randomness. As noted by Haladyna and Downing (2004), "we never know the size of random error for any examinee" (p.18). For example, some students may be in a bad mood or distracted during the test, which leads to lost scores on some items, but this does not mean that the student has not mastered the skills assessed. Another example is that some students do not get scores on some items that are too easy, but getting scores on some items that are too difficult, does not mean that the student has mastered the high-level skills as well. Although there may be some randomness during the assessment process, we need to do our best to minimize irrelevant construct variance. (2) Recommendations for minimizing construct-irrelevant variance include the following: (i) the implementation of the assessment needs to follow the six equity themes mentioned in the previous section (Rasooli et al., 2018) and the best recommendations for preparation before the assessment (Mehrens et al., 1998), (ii) a spacious dance classroom, (iii) ensuring the assessment equipment is not damaged (sound, VCR, mirror, and lighting), and (iv) teachers should also provide appropriate protective gear when students are breakdancing.

Ways to record assessment results include: (1) Students' test scores will be recorded in a notebook by the breakdancing teacher. (2) Scoring guides are provided for each construct item (short answer item and cloze). (3) The recorded scores will be added to an Excel sheet for technical review. (4) At the end of the assessment, teachers should store student's sample responses effectively to facilitate feedback to students and to support students to self-assess.

The results in the data will be interpreted as follows: (1) As a formative assessment, one of its purposes is to help teachers identify students' zone of proximal development (ZPD) during teaching and learning and to provide targeted guidance to students. As defined by Vygotsky and Cole (1978), the child's zone of proximal development (ZPD) is "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined under adult guidance or in collaboration with more capable peers" (p.86). For example, some breakdancing students may have excellent performance skills, but they may not be aware of the history of breakdance, so teachers can use the assessment results to target delivery to these students with knowledge related to breakdance. (2) Breakdancing gets Olympic status to debut at Paris Games in 2024. When breakdancing studio teachers consider choosing who would be better able to represent their studio in the dance competition, they can also use the results of the assessment to determine who would be a better choice.

Item Description

Due to the limited space of the article, it is impractical to describe all items. Thus, we chose short-answer items, multiple-choice, and cloze items as examples to describe. Items types are diverse and to some extent avoid constructing under-representation (Messick, 1994, 1995). A multiple-choice item is designed to assess the learner's ability to identify the origin and beginning of breakdancing. Multiple-choice items are designed according to the following principles proposed by Haladyna et al. (2002): (1) avoid trick items, (2) simple vocabulary, (3) format vertically rather than horizontally, (4) put the central idea in the stem, (5) avoid negative language, (6) logical option distribution, (7) consistent grammar and structure, and (8) avoid the "none of the above" option.

Cloze items are designed to assess whether the student adequately understands the role of each movement in breakdancing. The design of the fill-in-the-blank items was inspired by Taylor (1956) study that "subjects are asked to close up the gaps in the passages by guessing the identities of the missing words and writing their guesses in the corresponding blanks" (p.43).

The short answer item assesses whether students understand the principles of hip-hop. It requires students to construct their own responses (Rademakers et al., 2005). Responses are presented in multiple words and phrases. The short answer is considered an important item to improve the reliability of the assessment because it can better distinguish between well-prepared students and marginalized students (Fenderson et al., 1997).

In addition, to avoid irrelevant construct variance impacting the reliability of the assessment results, we have done our best to minimize irrelevant construct variance. These efforts include: (1) We collected numerous peer-reviewed articles related to

		Mapping of items and judgement-based rubric criteria to construct levels				
		Objective item numbers	**Criteria numbers**			
Level4	Students at this level can determine if the way of executing movements follows the norm based on distinguishing between different movements. They can also organize evidence in breakdancing historical descriptions into evidence for and against the origins of breakdancing in the 1970s based on explaining the reasons for the twentieth century breakdancing spread around the world. In watching breakdancing competition videos, they can infer principles of breakdancing movement combinations from the video examples. They have plenty of expressive ability to incorporate emotion into breakdance pieces based on using dance movements combined with musical beats.		**1.4**	**2.4**	**3.4**	**4.4**
Level3	Students at this level can distinguish the differences between moves based on an explanation of the definition of breakdancing terms and explain the causes of twentieth century breakdancing's spread around the world. They can also write a short summary of the types of breakdancing moves presented in the video and show the moves from top rock and footwork.	Short answer (written)Skill/knowledge/attitude assessed:Summarize the characteristics of the movements and the history of breakdance.	**1.3**	**2.3**	**3.3**	**4.2**
Level2	Students at this level can explain the definition of breakdancing terms and compare historical breakdancing events to contemporary situations. They can also give examples of various breakdancing moves used in different types of competitions through videos and show movements from top rock.	Cloze item Skill/knowledge/attitude assessed:Identify the functions of different movements of breakdance	**1.2**	**2.2**	**3.1**	**4.1**
Level1	Students at this level can describe terms related to breakdancing and judge the origin time of breakdancing.	Multiple-choice item Skill/knowledge/attitude assessed:Outline the historical background of breakdance	**1.1**	**2.1**		

FIGURE 1 | Student Capability Progress Level Map.

breakdancing to determine the origin of breakdancing. For example, some scholars believe that the origin of breakdancing can be dated back to the 1970s (Forman, 2002; Osumare, 2002; Foley, 2016; Langnes and Fasting, 2016), while others believe that the origin of breakdancing can be traced back much earlier to the 1960s (Bode Bakker and Nuijten, 2018). Due to the controversial origin of breakdancing, the option format was designed as time intervals. (3) For clarity and readability, each option is of a similar length. (4) Providing judgment-based assessment rubric (see **Table 1**). According to the rules of rubrics proposed by Wolf and Stevens (2007) and Brookhart (2018), the assessment rubric will be reviewed in three iterations.

- First iteration: Ensures that rubrics reflect the quality of the breakdancing student's cognitive and movement learning, with indicators ordered in terms of increasing proficiency, and using clear and easily understood language avoids ambiguous language.
- Second iteration: Be written so that students can verify their own performance and ensure that defined by a set of quality indicators that display a continuous level of growth.
- Third iteration: Ensure that the criteria match the construct map to help breakdancing teachers identify student position in the construct map (see **Figure 1**).

Although this is a low-stakes formative assessment task, this process will help design a high-stakes formative assessment task in the future. As mentioned in the introduction, breakdancing has been included in the entrance test program.

Multiple-Choice Item

Which of the following is the original date of breakdancing? (Choose an option).

A: Breakdancing originated in the United States between the 1940s and 1950s.
B: Breakdancing originated in the United States between the 1960s and 1970s.
C: Breakdancing originated in the United States between the 1980s and 1990s.
D: Breakdancing originated in the United States between the 2000s and 2010s.
Correct response: **B.**

Cloze (Constructed Response)

Breakdancers have many standing steps, such as those known as two-step and Indian-step, which can be categorized as________ (1). In breakdancing, the role of _______ (2) is to connect other dance elements together. _________ (3) refers to movements in which dancers use their _________ (4) and feet to support themselves on the floor; it can also be referred to as shuffle. ________ (5) is a category of street dance, it was announced by the International Olympic Committee to be included in the 2024 Olympic Games in Paris, France.

Scoring Guide

Top rock.
Transition.
Footwork.
Hands.
Breaking/b-boying/breakdance/breakdancing.
Words are considered correct if the spelling is close enough to allow the assessor to recognize the words.

Short Answer (Written)

What are the five principles of hip-hop?
Sample correct response:
Peace, unity, love, having fun, and knowledge.

Scoring Guide

1 point for acknowledging that peace and love are principles of hip-hop.
1 point for acknowledging that unity, having fun, and knowledge as hip-hop principles.

CONCLUSION

This article describes the current state of breakdancing. In an effort to attract young people who may not follow some of the traditional sports, the International Olympic Committee (IOC) has officially added the form of street dance to the medal events program for the 2024 Summer Olympics in Paris. In the field of teaching assessment, although early breakdancing educator Foley has explicitly called for students to learn breakdance at the earliest possible age, scholarship on formal formative assessments related to breakdance has not followed this trend. This phenomenon may hinder teachers from improving the learning of breakdance students. We summarized possible reasons for this phenomenon to occur. These reasons include: (i) For some street styles, historical documents might be difficult to find because they have been lost, (ii) some media companies use breakdance to spread misinformation for the purpose of advancing their own agendas, and (iii) debate over the status of breakdancing as an Art or Sport continues. One interesting find is that hip-hop art emphasizes that "no dancer can be called the best," which probably conflicts with summative assessment's purpose for grading, placement, and classification of students. Thus, this article claims that if teachers do not sufficiently understand the characteristics of hip-hop culture, then this phenomenon will hinder the design of assessment tasks. Finally, we believe that if this article is to be truly helpful to breakdance teachers who are facing teaching dilemmas, then we need to try to design a formative assessment task. This task is only tentative. We hope that this task will open more research and discussion on formal formative assessment items related to breakdance among scholars in different disciplines. With future research, scholars can help breakdance teachers become more aware of their teaching strategies, which may depend on how teachers perceive students' test performance.

TABLE 1 | Judgment-based assessment rubric.

1. Identify breakdance movement terms (Indicative behavior criteria):
   - 1.0. Insufficient evidence
   - 1.1. Describe breakdance movement terms
   - 1.2. Explain the definition of breakdance movement terms
   - 1.3. Distinguish the differences between movements based on explaining the definitions of breakdance movement terms
   - 1.4. Determine if the way of execution of movements follows the norms based on distinguishing the differences between movements
2. Construct meaning from breakdance history, including oral and written communication (Indicative behavior criteria):
   - 2.0. Insufficient evidence
   - 2.1. Judging the origin time of breakdance
   - 2.2. Compare historical breakdance events to contemporary situations
   - 2.3. Explain the causes of the twentieth-century breakdance spread around the world
   - 2.4. Organizing evidence in breakdance historical descriptions into evidence for and against the origin of breakdancing in the 1970s, based on explaining the causes of the twentieth-century breakdance's spread around the world
3. Provide personal insights by watching breakdance videos (Indicative behavior criteria):
   - 3.0. Insufficient evidence
   - 3.1. Give examples of various breakdance movements used in different types of competitions by watching the video
   - 3.2. Classify observed or described cases of breakdance works
   - 3.3. Write a short summary of the types of breakdance moves presented in a video
   - 3.4. Infer principles of breakdance movement combinations from the video examples
4. Showing breakdance movements in the dance studio (Indicative behavior criteria):
   - 4.0. Insufficient evidence
   - 4.1. Shows the top rock movements in breakdance
   - 4.2. Using top rock movements in breakdance combined with footwork movements
   - 4.3. Following the beat of the music based on using a combination of the top rock and transition movements in breakdance
   - 4.4. Incorporate emotions into breakdance pieces based on using dance movements combined with musical beats

AUTHOR'S NOTE

MW is an associate professor with decades of experience in guiding postgraduate student teams on topics related to international sports phenomena. NY is an associate professor with decades of experience in guiding postgraduate students on topics of teaching methods and educational assessment. ZY is a postgraduate with over 15 years of breakdancing experience and over 10 years of experience as a teacher. YB is a postgraduate with 10 years of dance experience and 5 years of English translation experience. YC is a postgraduate in dance, focusing on the effects of dance therapy on young people's well-being. CW is a postgraduate in education, focusing on creativity in arts education, and in this article. NW is a postgraduate in education and her research interests focus on data literacy and science literacy.

AUTHOR CONTRIBUTIONS

CW collected and organized the literature. NW reviewed the assessment criteria. All authors contributed to the article and approved the submitted version.

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On 4 December 2020, the International Olympic Committee (IOC) confirmed the inclusion of Breakdance in the Paris 2024 Olympic Games program. A new era has landed! We wish to thank all the young and old B-Boys and B-Girls worldwide, especially the veterans who created this dance because hip-hop has always been all our hopes and dreams. We wish to express gratitude to the editors and reviewers of this journal for their much assistance in the publication of this article. Again, many thanks to all the readers interested in learning about this dance we call "breaking." Peace and love!

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STUDY PROTOCOL
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The Effect of Mindfulness Yoga in Children With School Refusal: A Study Protocol for an Exploratory, Cluster-Randomized, Open, Standard Care-Controlled, Multicenter Clinical Trial

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Background: School refusal occurs in about 1–2% of young people. Anxiety and depression are considered to be the most common emotional difficulties for children who do not attend school. However, at present, no definitive treatment has been established for school refusal, although interventions such as cognitive behavioral therapy have been used. This paper reports a protocol for a cluster-randomized controlled trial of a mindfulness yoga intervention for children with school refusal.

Methods: This study is a multicenter, exploratory, open cluster-randomized controlled trial. This study will recruit children aged 10–15 years with school refusal. After a 2-week baseline, participants for each cluster will be randomly assigned to one of two groups: with or without mindfulness yoga for 4 weeks. Mindfulness yoga will be created for schoolchildren for this protocol and distributed to the participants on DVD. The primary outcome is anxiety among children with school refusal using the Spence Children's Anxiety Scale-Children.

Discussion: For this study, we developed a mindfulness yoga program and protocol, and examine whether mindfulness yoga can improve anxiety in children with school refusal. Our mindfulness yoga program was developed based on the opinions of children of the same age, and is a program that children can continue to do every day without getting bored. In this way, we believe that we can contribute to the smooth implementation of support to reduce the anxiety of children with school refusal, and to the reduction of the number of children who refuse to go to school.

Keywords: children, school refusal, anxiety, mindfulness yoga, a cluster-randomized controlled trial

HIGHLIGHTS

- We have developed a mindfulness yoga program that children can do at home alone.
- This is the first randomized control study of a yoga intervention for children with school refusal.
- We will conduct a cluster-randomized trial to avoid children influencing each other in the facility.

INTRODUCTION

School attendance is a basic ability that is important for children and adolescents. School refusal is a psychosocial problem characterized by difficulty attending school, and in many cases, substantial absence from school (1). In addition, school refusal has been shown to affect learning and achievement negatively and to place youth at risk for early school dropout (2, 3). School refusal occurs in about 1–2% of young people (4). Children with school attendance problems are also likely to have emotional difficulties (5). Anxiety and depression are considered the most common emotional difficulties for children who do not attend school (6, 7). In addition, Hochadel et al. (8) reported that there was a definite relationship between sleep problems and school refusal.

In Japan, school refusal is defined by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) as "students who are absent from school more than 30 days a year due to some psychological, emotional, physical, or social factors or background that prevents them from attending or wanting to attend school, excluding those who are absent due to illness or financial reasons." The number of Japanese children with school refusal has increased every year since 2012, with the highest number recorded in 2020. A survey by MEXT reported that 0.83% of elementary school students and 3.94% of junior high school students were absent from school for a long period of time (9). Possible reasons for school refusal among elementary school students include anxiety and other emotional turmoil (36.1%), apathy (23.0%), and problems with the parent–child relationship (19.1%), whereas those among junior high school students include emotional turmoil such as anxiety (28.1%), apathy (26.7%), and problems related to friendships, excluding bullying (15.4%). In addition, the proportion who report "disruption of the rhythm of life" is on the rise. Thus, anxiety and apathy (except for bullying and friendships) are the main reasons for more than 50% of school refusal cases.

While various interventions have been used to treat school refusal (e.g., psychodynamic treatment, family therapy, medication), cognitive behavioral therapy (CBT) is the most commonly studied. CBT typically involves treatment components such as psychoeducation, relaxation training, cognitive restructuring, graded exposure, and social skills training (10). However, few randomized controlled trials (RCTs) assessing the effectiveness of CBT have been reported, and its efficacy is only partial (4).

Mindfulness is defined as paying total attention to the present moment with a non-judgmental awareness of the inner and/or outer experiences (11). Originally derived from Eastern traditions and Buddhist psychology, mindfulness can be cultivated by various techniques (12, 13). Formally, it is trained by meditation practices such as sitting meditation or physical movements such as yoga. These techniques help steady the mind and train its attentional capacity while increasing its breadth of focus. In several meta-analyses, mindfulness-based interventions have proven to be effective in treating clinical and stress-related problems and disorders in various disease groups (14–16).

Yoga is one of the *ṣaḍdarśanas* of Indian philosophy and is said to have a history of 5,000 years (17). The word "yoga" comes from the Sanskrit words for "integration" and "connection," and aims to harmonize the mind and body, allowing a connection to be felt between oneself and one's surroundings. The Sanskrit word for "health," "*swasthya*," is derived from two Sanskrit words, "*swa*," meaning "self," and "*stha*," meaning "stay."(18). In other words, to be healthy is to stay in oneself, and the connection between being who you are and being healthy is expressed in ancient languages.

It is reported that 300 million people practice yoga across the globe (19). The 2012 and 2017 National Health Interview Survey reported that yoga was the most commonly practiced complementary health approach among US adults, and that the use of yoga and meditation during the past 12 months increased from 2012 to 2017 among US children aged 4-17 years (20, 21). Yoga is considered to be easy to practice for children and adults of all ages. Yoga has also been shown to be effective in improving self-esteem, emotional well-being, positive emotions, and self-regulation in adolescents (22). In several meta-analyses, yoga interventions have been proven to be effective for treating fatigue, pain, hypertension, and type II diabetes (23–26). The intentional combination of mindfulness and yoga can be powerful, resulting in increased stress tolerance and sleep quality and reduced psychological distress and chronic pain intensity (27–29).

McCall et al. reported in a systematic review that mindfulness yoga appears most effective for reducing symptoms in anxiety, depression, and pain (30). Mindfulness yoga interventions have been shown to improve sleep quality significantly among female teachers with chronic insomnia working in primary schools (31, 32). In addition, older adults with insomnia who engaged in mindfulness yoga classes twice a week for 12 weeks had better sleep quality, efficiency, latency, and duration than the control group (33).

For children, mindfulness yoga interventions have been reported to reduce stress levels (34), improve coping with anxiety and anger (35), and increase attention span (36). In a systematic review, nearly all studies indicated reduced anxiety among children and adolescents (age 3–18 years) after a mindfulness yoga intervention (37). Another systematic review recently reported that mindfulness yoga generally leads to some reductions in anxiety and depression in children and adolescents (38).

However, to our knowledge, there is a paucity of research on safe and effective therapeutic interventions for anxiety associated with school refusal. The main purpose of this study is to examine whether a mindfulness yoga intervention can improve anxiety in children with school refusal. In addition, we will examine whether this intervention can improve depressed mood, sleep rhythm, and activity levels. By conducting mindfulness yoga intervention, we will verify the usefulness and effectiveness of a safe and reliable alternative treatment for alleviating anxiety and depression in children with school refusal.

METHODS

Study Design

This study is a multicenter, exploratory, open cluster-randomized controlled trial. A multicenter study was set up because the background of school refusal in children may be influenced by community characteristics. The study will consist of two groups: a mindfulness yoga group and a non-mindfulness yoga group, and the participants will clearly be aware of the treatment. Because of the potential for children within a facility to influence each other, we decided to conduct a cluster-randomized trial with the same intervention within the facility. Ideally, in an open trial, the primary outcome should be an objective measure. However, since the most standard measure of anxiety among children is a self-administered questionnaire, it must be subjective. Therefore, objective evaluation items were set as secondary evaluation items. We believe that this will ensure the evaluation of effectiveness.

Mindfulness Yoga Program Development

This mindfulness yoga program aims to provide a space and time for children to be able to exist "as they are" to create the psychological place they seek. This mindfulness yoga program is a 4-week program that is done alone at home by watching a mindfulness yoga program video, and the space required for the mindfulness yoga is the size of about a normal exercise mat. Initially, 9 children were given the opportunity to experience the mindfulness yoga program. Feedback was received from the children about the mindfulness yoga program in terms of their time and ability to continue. To make it easier for the participants to continue, one program was set at 20 min or less and the program content changed every week. In the first session, the participants will watch a video in front of the researcher and do the first program. The researcher will instruct them on points such as how to breathe and how to relax. After distribution, the students will be asked to follow the instructions in the video to practice mindfulness yoga (**Supplementary Figures 1A–E**). Students will also be asked to keep a daily mindfulness yoga diary (**Supplementary Figures 2A–D**) to track their practice.

The program DVD is structured with the following points in mind:

1. The program encourages participants to explore their senses and feelings to focus on the state of mindfulness with a non-judgmental awareness of the inner and/or outer experiences, rather than to "do it well" or otherwise perfect the performance.
2. The program starts at a low intensity so that it can be implemented by children with school refusal with low activity intensity. The three major asanas and balance poses of yoga were incorporated by moving the limbs extensively, and the whole body is moved to compensate for the lack of activity.
3. Simple movements that can be safely performed by one person and humming breathing to encourage vocalization were incorporated.

Interventions

The study schedule is shown in **Figure 1**. Group A (Standard care + mindfulness yoga intervention group): After obtaining a 2-week baseline of activity and other data, the participants will perform mindfulness yoga for 28 days. The mindfulness yoga session will be conducted according to a video recording of the instructions. At the time of distribution of the mindfulness yoga video, the participants will perform mindfulness yoga along with the mindfulness yoga video to ensure that the researcher understands the purpose of the activity. After the end of the intervention period, the percentage of days in school will be tracked for 8 weeks. Group B (standard treatment group): After obtaining a 2-week baseline of activity and other data, the participants will continue to measure their activity and other data for 4 weeks. The progress of the percentage of days in school will be followed for another 8 weeks.

Both groups will fill out an activity record sheet for the first 14 weeks of the study and wear an actigraph. Both groups will receive 30 min of supportive psychotherapy at the start date and at 2, 6, and 14 weeks, as well as lifestyle coaching on rhythm of life using the activity record sheet. The results of intelligence and psychological tests will be used to provide feedback on innovations to be aware of in daily life and social relationships. Standard care includes self-monitoring and 30-min counseling sessions.

Patients who have been visiting a medical institution or psychological consultation office for treatment prior to participating in the study, or who are attending an alternative school, will continue to receive treatment and consultation, and will not, in principle, change their medication or treatment during the study period. If the treatment is changed during the study period, the details of the change shall be communicated to the person in charge for confirmation in the medication notebook or information form. The participants in the control group will be given the chance to receive the mindfulness yoga program after the completion of this study.

Participants

The study participants will be children in Japan with school refusal aged 10–15 years old who are absent from school for 30 days or more per year. This study was approved by the ethical review board of Kagoshima University (IRB No: 190263). It is estimated that the study dates would be from 23 April 2020 to 31 March 2025. Study recruitment will be done through posters and other means. We will provide explanations using the consent explanatory document and consent forms, and written consent will be obtained from all participants and their guardians.

Inclusion Criteria

1. Children who have been absent from school for 30 days or more per year and who meet MEXT's definition of school refusal

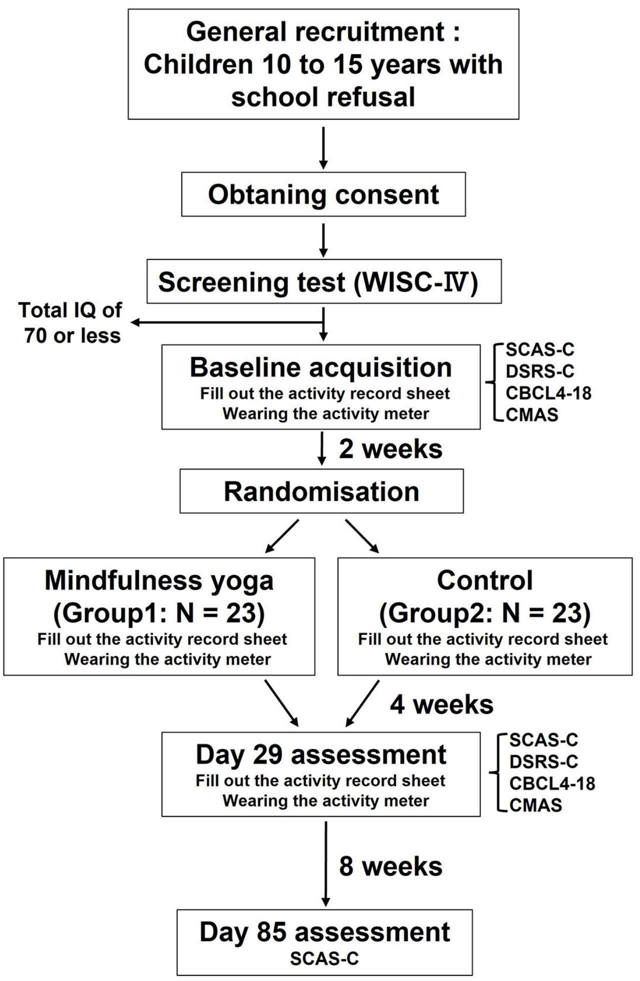

FIGURE 1 | Flowchart of the study schedule. WISC-IV, Wechsler Intelligence Scale for Children, Fourth Edition; SCAS-C, Spence Children's Anxiety Scale–Children; DSRS-C, Depression Self Rating Scale for Children; CBCL-4–18, Child Behavior Checklist for ages 4–18; CMAS, Children's Manifest Anxiety Scale.

2. Children aged 10–16 years at the time of obtaining consent
3. Children with no continuous mindfulness yoga experience or experience deemed equivalent to mindfulness yoga by the physician in charge for a period of 1 year prior to the date of the examination

Exclusion Criteria

1. Children with a total intelligence quotient (IQ) of 70 or less according to the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV)
2. Children who will be age 16 years or older during the research period
3. Children judged by the physician in charge to be inappropriate for inclusion in this study because of the heavy physical and mental burden of being a participant in this research
4. Children with a history of wrist-cutting or attempted suicide
5. Children judged to have the potential for self-injury or other harm
6. Children judged to require an immediate social response, such as those exposed to abuse or bullying
7. Children who have a change in their commuting environment such as graduation, advancement to higher education, or withdrawal from school within the research period
8. Children with a history of schizophrenia, paranoid disorder, depression with thoughts of death, etc., for which the physician in charge has determined that specialized treatment is necessary
9. Children deemed inappropriate by the principal investigator, etc.

Screening Test

The WISC-IV, which is the most widely used intelligence battery in clinical practice, will be conducted as a screening test to assess the general cognitive abilities (IQ) of the children (39). Scaled scores will be derived from index scores in accordance with normative data based on the child's age and gender [mean = 100, standard deviation (SD) = 15].

Randomization

Cluster randomization will be conducted with facilities as clusters. A block randomization method with two strata will be used: "free schools" and "facilities other than free schools." The allocation ratio will be 1:1.

Primary Outcome Measures

We set the Spence Children's Anxiety Scale-Children (SCAS-C) as of the 29th day after the start of the intervention as the primary outcome measure, based on previous studies (40–42). The SCAS-C is a test based on the Diagnostic and Statistical Manual of Mental Disorders, fourth edition, text revision, that assesses anxiety in children using six subscales: separation anxiety disorder, social anxiety disorder, obsessive–compulsive disorder, panic disorder, generalized anxiety disorder, and traumatic fear (localized phobia). The SCAS-C was designed to assess anxiety in school-age children, as it has been suggested that anxiety is associated with school non-attendance in Japan (43).

Secondary Outcome Measures

1. Percentage of school days
   As one of the objective indicators of behavioral change in school refusal, we set the percentage of school days from the day after the start of intervention until the 29th day and from the 30th to 85th days.
2. Average daily activity
3. Behavioral cycle
4. Sleep cycle
5. Average sleep efficiency
   The amount of activity was set for the purpose of improving the accuracy of the measurement and objectively capturing changes in the amount of activity as it is thought that the rhythm of life is disrupted because of school refusal, which may affect the amount of activity. In addition, as it is thought

that the disruption of the daily rhythm caused by school refusal also affects sleep, the sleep cycle and sleep efficiency were established for the purpose of objective measurement. All participants will be asked to fill out an activity record sheet (**Supplementary Figure 3**) to determine their activity level, life/sleep rhythm and school attendance. In addition, they will be asked to wear a sleep analyzer (Sleep-Sign-Act, version 2.0; Kissei Comtec, Nagano, Japan), which has been used in a number of previous studies, including those with children (44–46), to measure objective activity levels and sleep quality.

6. Body temperature
7. Systolic blood pressure
8. Diastolic blood pressure
9. Number of pulsed beats
10. Height and weight
11. Body mass index
    Body temperature, blood pressure (systolic and diastolic), pulse, height and weight (only at the beginning), and body mass index were set to measure the physical effects of mindfulness yoga.
12. Depression Self Rating Scale for Children (DSRS-C)
    The DSRS-C is composed of 18 question items in plain language and is widely used to measure children's depressive symptoms (47). The total possible scores ranges from 0 to 36. A higher total score (>16) reflects a greater risk of clinical depression. Murata et al. modified a Japanese version of the DSRS-C, and have demonstrated its satisfactory reliability and validity. In addition, the DSRS-C was established because it has been suggested to be a powerful tool for understanding children's mentalities and has high discriminative accuracy as a screening test (48).
13. Child Behavior Checklist for ages 4–18 (CBCL-4-18)
    The CBCL-4-18 was developed by Achenbach (49) as an objective assessment tool to assess the behavioral and emotional characteristics of children. It is completed by parents and consists of approximately 100 competence items (e.g., daily activities, relationships with friends and parents, academic performance) and problematic behavior. Itani et al. modified a Japanese version of the CBCL-4-18 (50).
14. Children's Manifest Anxiety Scale (CMAS)
    The CMAS is a validated scale used to assess anxiety disorders in children. It is composed of 53 items, and possible scores range from 0 to 42 (51). Sakamoto et al. modified a Japanese version of the CMAS and have demonstrated its satisfactory reliability and validity (52).

Sample Size Calculation

The intracluster correlation coefficient (ICC) ρ examined in a previous study, a randomized controlled trial of CBT for anxiety disorders in children, ranged from 0.12 to 0.22, so we assumed that the ICC in this study would be 0.17, the median of previous studies.

A pilot study was conducted in Japan to evaluate the efficacy of CBT in children with anxiety disorders using the Japanese version of the SCAS-C, and the results were as follows.

	Before treatment	After treatment
CBT ($n = 31$)	38.8 ± 13.7	24.7 ± 12.5
Control ($n = 31$)	37.4 ± 14.9	38.5 ± 20.9

Considering that mindfulness yoga therapy in this study will have the same effect as CBT, we estimated the mean post-treatment SCAS-C score to be 24.7 in the mindfulness yoga therapy group and 38.5 in the control group (53), and calculated the population variance from the weighted mean, considering that the variances of the CBT and control groups would be equal (54).

$$s^2 = \frac{(31-1)\cdot 12.5^2 + (31-1)\cdot 20.9^2}{31+31-2} = 17.2^2$$

The SD for this study was conservatively estimated at 17.2. Assuming a one-sided significance level of 10% and a power of 80%, the number of subjects was calculated to be 30. Since this is a cluster-randomized trial, the required number of subjects (Ncluster) for a cluster-randomized trial is $Ncluser = N\cdot(1+(r-1)\cdot\rho)$, where N is the sample size designed for a normal RCT. If the average number of subjects per center were three and the ICC ρ 0.17, $Ncluser = 30\cdot(1+(3-1)\cdot 0.17) = 40.2$. The required number of subjects was therefore 46, considering a dropout rate of 10% (55).

Statistical Analysis

Analysis Set

Statistical analysis will be performed for the following analysis sets.

Full Analysis Set

All participants, excluding those who were treated in serious violation of ethical guidelines and those whose data for the primary outcome were absent, will be considered the FAS.

Safety Analysis Set

The population for which standard treatment is administered will be defined as the SAS.

Per Protocol Set

The population consisting of participants who are included in the FAS and do not meet the following conditions will be defined as the PPS.

- Participants who do not meet the inclusion criteria specified for this study or who violate the exclusion criteria
- Significant deviations from the research protocol
- Participants who had not practiced yoga for more than 20 days

Analysis Items and Contents

Summary statistics refer to the number of cases, mean, SD, median, minimum, and maximum values.

Breakdown of Participants

The following tabulations will be made for the enrolled examples:

1. The number of included and excluded participants in the FAS, PPS, and SAS will be tabulated by treatment group and shown in a flowchart. For the excluded participants, a breakdown of the reasons for exclusion will be tabulated.
2. Completed and discontinued participants will be tabulated. For the discontinued participants, a breakdown of the reasons for discontinuation will be tabulated.

Summary Between Treatment Groups

Participant backgrounds will be tabulated by treatment group for each FAS. Summary statistics will be presented for continuous data, and frequencies and proportions (%) for categorical data.

Status of Mindfulness Yoga Practice

Summary statistics will be calculated for the SAS regarding the number of days and percentage of mindfulness yoga performed.

Analysis of the Primary Outcome

The following analysis will be conducted for the FAS. In addition, the same analysis will be conducted for the PPS as a sensitivity analysis to confirm the robustness of the results:

1. A linear mixed effect model will be conducted for the SCAS-C with baseline values and stratification factor (free school/non-free school facility) as covariates, with each facility as a random effect. Statistical testing will use a one-sided significance level of 10%. If the one-sided p-value is <0.1, the null hypothesis will be rejected, and we will proceed to a pivotal study, judging that efficacy of mindfulness yoga treatment has been confirmed.
2. The ICC will be calculated.
3. Summary statistics for the SCAS-C and its change by group and time point (baseline, Day 29, and Day 85) will be shown.
4. The mean and SD of the SCAS-C values will be plotted.

Data Management

The study data will be collected and stored within the REDCap system, which is a web-based, secure, and HIPAA-compliant research management platform. REDCap fully supports several research processes for subject scheduling, subject randomization, data entry and management, as well as data safety monitoring and adverse event reporting. A particular advantage of REDCap is that it leaves a complete audit trail. In addition, the input person is immediately notified if fields are missing and/or out of range values are entered. However, in the case of a loss of Internet access, backup paper copies will be provided, which would then be subsequently entered into REDCap.

Enrolled participants will be identified and queried using REDCap, and no name or other information that would allow a third party to identify a participant directly will be entered into the study database. The data sets stored on a PC will be encrypted and a password will be set to prevent third parties from using the files. Participant identification will be done by numbers or symbols, and the correspondence between these and information that can easily identify the individual (e.g., name, address) to a third party will not be stored in the data set. A list of the correspondence between the information that can be easily identified by a third party (e.g., name, address) shall be stored in a lockable cabinet, etc., (personal information manager: MA).

Monitoring

The principal investigator will have the institution conduct monitoring to confirm that this research is being conducted properly. In principle, the monitoring report will be submitted once a year.

Adverse Events

There are no known health or safety risks associated with participation in the described study, and the risk of adverse events is low. Data monitoring will be monitored by the safety monitoring committee. Any minor or major events associated with the intervention or usual care groups will be monitored throughout the duration of the 1-week program. The chief investigators, MA and HA, will review any adverse events or unintended effects detected.

Patient and Public Involvement

1. In order to develop this yoga program, we asked children between the ages of 10 and 15 for their opinions on whether the program content and time would allow them to continue every day.
2. In preparing the informed assent document, we asked children between the ages of 10 and 15 for their opinions on whether they could read the text and whether the content was easy to understand.
3. Citizen members participated in the ethical review board of Kagoshima University and exchanged opinions.

DISCUSSION

For this study, we developed a mindfulness yoga program and protocol, and examine whether mindfulness yoga can improve anxiety in children with school refusal. Our mindfulness yoga program was developed based on the opinions of children of the same age, and is a program that children can continue to do every day without getting bored.

This study has several strengths. First, it is a new yoga program that combines mindfulness and yoga. Second, this is incorporation of cluster randomization, in which schools and affiliations are randomized as clusters. Third, the content of mindfulness yoga program and time designed as sustained without burden by incorporating children's opinions in the study design. Fourth, because it is a video-based intervention, it can be used in a variety of settings, the ability to implement mindfulness yoga in schools and homes without being limited by geographical factors, since the video-based intervention allows mindfulness yoga to be implemented without direct instructor contact.

The study also has several limitations. First, the analysis design does not include social backgrounds that may contribute to truancy, such as parent-child relationships, economic problems, and friendships. Second, the study does not include developmental disabilities other than intellectual disabilities as the exclusion criteria. Third, the seasonal variation of school refusal was not considered in the intervention design or data collection.

To our knowledge, little research on mindfulness-yoga intervention for children with school refusal has been conducted. Our proposed study is the first RCT intervention for the children with school refusal to be implemented. If this study shows positive results, it will be possible to recommend that mindfulness yoga be implemented with similar strategies with other children and beyond. In addition, the use of mindfulness yoga programs that can be implemented at home or at school may promote cooperation between the fields of medicine and education, and provide comprehensive and integrated support for school children. In this way, we believe that we can contribute to the smooth implementation of support to reduce the anxiety of children with school refusal, and to the reduction of the number of children who refuse to go to school.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Kagoshima University (IRB No: 190263).

AUTHOR CONTRIBUTIONS

MA, TM, SA, TO, KM, and AA were responsible for the initial protocol drafting and design. HA, SK, KM, HS, TY, and YN contributed to preliminary searches used to develop the rationale and background of the study. TF and KO built the REDCap system for this study. HW, MH, and KF advised on methods design and statistical analysis techniques that could be used. All authors contributed and approved this final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.881303/full#supplementary-material

Supplementary Figure 1A | Contents of the first day of the first week of the program.

Supplementary Figure 1B | Contents of days 2 through 7 of the first week of the program.

Supplementary Figure 1C | Contents of days 8 through 14 of the second week of the program.

Supplementary Figure 1D | Contents of days 15 through 21 of the third week of the program.

Supplementary Figure 1E | Contents of days 15 through 21 of the fourth week of the program.

Supplementary Figure 2A | Contents of the diary of the first week.

Supplementary Figure 2B | Contents of the diary of the second week.

Supplementary Figure 2C | Contents of the diary of the third week.

Supplementary Figure 2D | Contents of the diary of the fourth week.

Supplementary Figure 3 | An activity record sheet.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Effects of a blended classroom-based intervention on aerobic fitness, motor skills, inhibition, and daytime sleepiness among Hong Kong children

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In response to the all-round development of primary school children, this study aimed to evaluate the effectiveness of a blended intervention program on children's health-related outcomes of aerobic fitness, motor skills, inhibition and daytime sleepiness in classroom settings. Three experimental conditions include: (1) the "Stand + Move" group combining sit-stand desks and physical activity (PA) recess, (2) "Move" group with PA recess only, and (3) Control group (CG; normal class schedule). A total of 64 primary school children (37.5% girls and 62.5% boys, M [SD] = 9.6 [0.61], BMI mean = 17.0 ± 3.0) participated in all assessments, including aerobic fitness, motor skills, inhibitory control, and daytime sleepiness. The baseline data collection starts from January 2019, with the intervention lasting for 13 weeks and followed by post-intervention and follow up tests conducted in July and October 2019. There was a significant interaction effect on aerobic fitness [$F_{(2,76)} = 10.62$, $p < 0.001$, $\eta^2 = 0.22$] after the intervention period, whereas no significant interaction was observed for other variables. Significant main effects were observed in aerobic fitness (pre − post: −11.75 and −7.22) for both experimental groups, with the blended group showing greater improvements immediately post the test, while motor skills only showed a significant increase at the three-month follow-up, with the greatest increase in the blended group (pre-follow-up: −2.50). For inhibition control and daytime sleepiness, better improvements were shown for the experimental groups than for the control group. The blended designed intervention, by incorporating multiple components as an innovative strategy to reconstruct children's traditional classroom environment in Hong Kong, has demonstrated improved physical and psychological development of school children.

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KEYWORDS

physical literacy, sit-stand desk, children, primary school, motor skill, sleep, inhibition

Introduction

A traditional classroom environment tends to encourage prolonged sitting and a sedentary lifestyle in schoolchildren (1). In some countries, evidence shows that over 63% of class time per school day is considered sedentary (2), and the reported sitting time has been as high as 10 h/day (3). In Hong Kong, children spend up to 32.3% of their waking time sitting, with their prolonged sitting time being approximately 4.9 h/school day (4). Previous studies found that excessive sitting was negatively associated with cardio-metabolic health risk markers, including obesity, metabolic syndrome, high blood pressure and cholesterol in children (5, 6). Moreover, this continues throughout childhood into adolescence and adulthood (7). According to recommendations, schools should facilitate at least 60 min moderate-to-vigorous physical activity (MVPA) for children, through a comprehensive approach incorporating both activities during class, recess, and before-and-after school (8). The movement guidelines for children and youth have especially been emphasized with respect to optimal health by combining physical activity (PA), restricted sedentary behavior, and adequate sleep as three co-developmental behaviors related to a balance of movement behaviors within a 24-hour period (9). The comprehensive approach also emphasized the development of children's physical literacy (8), as this encourages an embodiment encompassing "the motivation, confidence, physical competence, knowledge, and understanding to value and take responsibility for engagement in physical activities for life" (10, 11). Therefore, it is important to promote classroom-based interactions to prevent prolonged sitting and enhance adequate PA as a novel strategy to foster a healthy lifestyle in children throughout their life (12).

A substantial body of evidence from classroom-based interventions shows that sit-stand desk installation is one of the effective interventions for reducing children's prolonged sitting time without affecting their academic achievement (13, 14). Both, a full-desk (a sit-stand desk for every child) and partial desk allocation (limited for children to share and rotate), have provided meaningful contributions to low intensity daily PA (1, 15), yet a full-desk allocation could guarantee optimal health benefits for children as they would have maximum exposure to the desks (16). However, considering financial feasibility, only three studies have adopted the full-desk system (3, 16, 17) and these were usually limited to one school. Regarding the outcomes in the field of children's physical and psychological health, the use of sit-stand desks or standing desks in primary schools has shown mixed effects on energy expenditure, PA, muscular comfort, and concentration, as related to diverse assessments and measurements with low statistical power (18). This systematic review examined the impact of standing desks in 11 studies and showed that such a strategy could be beneficial for some outcomes, including the enhancement of children's reduction in sedentary behavior. However, as a single component intervention design, it has less positive effects when compared with a multicomponent intervention including educational and practical components such as information on health and posture, the creation of a classroom that encourages movement, and a standing workstation area (18). In this case, a multicomponent intervention "package" may be more beneficial for engaging a wider range of needs and interests within classroom settings by integrating PA opportunities and reducing sedentary behavior during school days. Active breaks during recess have been shown to be effective in promoting PA in children and adolescents (19). A recent systematic meta-analysis found a statistically significant trend for PA and step counts, while the outcomes regarding classroom behaviors to those of cognitive functions and academic achievement did not provide conclusive findings in the meta-analysis due to the heterogeneity of the studies (20). McMichan, Gibson (21) also reported that solely PA or sedentary behavior interventions showed a small or even non-significant effect related to limited empirical studies. As such, a blended interventional design that modifies the traditional classroom environment by integrating the implementation of PA and breaking up prolonged sitting seems to be a promising and feasible long-term strategy for enhancing physical and psychological development and fostering physical literacy. Therefore, this study adopts a blended "Stand + Move" design to reduce prolonged sitting and increase school-hour PA engagement through environmental modifications in classroom settings.

Previous research has reported a significant increase in sedentary behavior of children aged 11 years and older, relative to younger age groups (22). Thus, it is necessary to reduce typically observed prolonged sitting among primary school children before transitioning into adolescence. PA recess strategies have also been shown to improve children's motor and cognitive development (23). The physiological and psychological aspects were especially emphasized when evaluating the effectiveness of this blended program while considering targeted outcomes. A previous school-based PA intervention has shown beneficial long-term effects on aerobic fitness performance after a 3 years follow-up (24). An updated review by Kriemler, Meyer (25) found that multicomponent approaches in children during school-based activities have the highest level of evidence for increasing overall PA and fitness, while only 11 of 20 included studies focused on the intervention effects of promoting aerobic fitness. However, motor skills have also been purported as contributing to children's physical, cognitive and social development (26). The study conducted by Ohlinger, Horn (27) investigated the effect of an active workstation on motor skills among university employees while they were in different situations of sitting, standing, or walking. As motor skill development should be a key component in childhood interventions aiming to promote long-term PA (28), it is necessary to include motor skills as one of the outcome variables within the physiological aspect of children's development.

A previous systematic review highlighted the evidence that higher levels of motor skills and cardiorespiratory fitness can contribute to improved cognitive capacity and academic performance in children (29). There were a number of studies evaluating the impact of sit-stand desks on children's executive functions (16, 27, 30), as it contributed to cognitive, academic and overall health-related (physical, metabolic and mental health) outcomes among children and adolescents (31). Additionally, previous studies have also reported that daytime sleepiness is a factor that can impact working productivity of adults (32), while when embedded into real-time settings within school, it would be related to children's effectiveness in learning or even academic performance. All these factors that work together can impact health-related quality of life (33). Having a comprehensive picture guided by the concept of physical literacy, classroom-based interventions to improve health-related outcomes of children and adolescents are required to include various physiological and psychological aspects as outcome variables, including aerobic fitness, motor skills, executive functions, and sleep.

As informed by Sherry, Pearson (18), blended interventional studies targeting sit-stand desks and PA recess not only need to include various health-related outcome variables but also more high-quality study designs. Thus, this study incorporates sit-stand desks and PA recess as novel strategies to benefit the physical and psychological aspects of students in Hong Kong primary schools. It was hypothesized that the blended "Stand + Move" group, compared with the single "Move" and control groups, improved significantly in (1) aerobic fitness, (2) motor skills, (3) inhibitory control, and (4) daytime sleepiness.

Methods

Study design

The "Stand + Move" intervention was designed as a three-arm RCT study, which focused on approximately 9-year-old (4th grade of primary school) students from Hong Kong primary schools. One public school from the New Territories, Hong Kong has been approached and invited to participate. The convenience sampling has been adopted to recruit all the grade 4 students in this school. All the participants were randomly assigned (using Google random number generator) to either control or intervention conditions. Outcome data were collected at baseline, post-intervention and 3-month follow-up for all the variables. Baseline data collection was conducted before the intervention began in January 2019, the post-intervention measure for all the participants was performed successively 13-week after the completion of the intervention during the end of semester in July 2019, and the follow-up measurement was performed 3 months after at the start of the next semester (October 2019). Reporting of the trial follows the CONSORT statement. The study received ethics approval from Survey and Behavioral Research Ethics of the university (Reference No. SBRE 18-108) and all the participants provided written parental consent forms prior to participation.

Participants and intervention

A sample size of 20 in each group [recruiting 24 with an assumed 20% attrition (34)] would have at least power of 80%, an alpha of 0.05, and effect size (r) of 0.3 (35) calculated by G-power software. Children were excluded if they had a disability that prevented standing, or had an injury or illness that limited performing normal daily tasks. All the participants were randomly assigned to either of the three conditions with a 1:1:1 ratio, which included: a blended intervention "Stand + Move" group, a single PA break "Move" intervention group, and a control group (CG). All the participants (i.e., students) were blinded to either the group allocation or the research aims, but the intervention providers (i.e., school teachers, research assistants, etc.) could not be blinded.

The height-adjustable sit-stand desks (Askisi 720, SMART Inc., USA) were placed in the "Stand + Move" students' classroom for two academic semesters. Similar to Hinckson, Salmon (1)'s descriptions, the desk could be moved up and down manually with the use of a lever which would allow the children to work in a seated or standing position. Prior to the intervention phase, a three-hour briefing session regarding the instructions on how to administer the sit-stand desks and PA-based recess was held for all the teachers and parents in order to support them in the development of classroom environment within schools. The research plan of breaking up prolonged sitting every 15 min during two regular classes (each class before the recess) per day could ensure all children in the "Stand + Move" group use the sit-stand desks for at least 1 h per day on average across the week (30). Stools or chairs were retained in the classroom for them to feel free to choose whether they sat or stood when using the sit-stand desks. Teachers encouraged each child to stand at the end of 15-min prolonged sitting. Besides, "Stand + Move" and "Move" children participated in a PA recess during recess time, in which the unstructured outdoor interactive games were introduced to children by PE interns. The PA breaks were up to 15 min in duration and twice a day across the week, which included games such as skipping rope, shuttlecock kicking, hide-and-seek in the specific area, and supplemented with several minutes of cooling down. The students who were assigned to the control condition adhered to their regular class schedules and lesson delivery format. They used their standard classroom desks in the classroom, with no experimental changes made to the environment, and there were no changes or specific activity during their recess. Details of the intervention were described elsewhere in a protocol study (15).

Outcome measures and procedures

Children's height and weight were measured by trained appraisers using standardized procedures, with children in light clothing and shoes removed, using TANITA measuring boards (RD-545-sv) and Seca model 770 scales. Body mass index (BMI, kg/m^2) was then calculated from the measured weight (nearest 0.1 kg) and height (nearest 0.1 cm), with the standard equation (body weight [kg]/height [m^2]).

Aerobic fitness was measured using the FitnessGram 15/20 m Progressive Aerobic Cardiovascular Endurance Run (PACER) (36), which was chosen as the stand-alone measure of aerobic fitness according to its strong correlation with maximum oxygen consumption ($r = 0.83$) (37). The PACER consists of a multistage progressive 15- or 20-m shuttle run requiring students to run laps between two markers in time with prerecorded audible beeps. The time between beeps decreases each minute, requiring a progressive increase in pace, and students run laps until they are unable to finish before the beep on two separate occasions. Due to limited space, all participants in this study ran between two markers set 15 m apart, while keeping pace with a prerecorded Cantonese cadence. The PACER determines aerobic fitness status based on the number of laps completed.

Children's motor skills were measured by the Canadian Agility and Movement Skill Assessment (CAMSA) (38), a sequence test combining fundamental, complex and combined movement skills, such as catching, throwing, skipping, and hopping, for assessing motor competence. Two trained appraisers performed the CAMSA demonstrations twice, with the first progressing slowly through the entire course, along with a detailed verbal description of each skill. For the second demonstration, the appraiser moved at full speed, while maintaining skill accuracy. Each participant performed four trials, two practice, two timed tests, with the best score of the two timed tests as their final grade. All the practices and timed tests have followed the same procedures and have been conducted consecutively. All performances were videotaped for verification of skill accuracy by a third appraiser (39). The score of CAMSA test was composed of time score (14 points) and skill score (14 points), resulting in a total of 28 points (38).

Children's executive inhibitory control was examined using a modified version of the Eriksen flanker task (40) with the Inquisit 5 platform. Participants were required to perform the task in a quiet room under the supervision of an instructor who was trained prior to the testing. This task consisted of five arrows on a screen, and participants were asked to determine the direction of the target arrow in the middle. The two flanker arrows on each side of the target arrow worked as the distractors and would appear as either congruent trial ">>>>>" or congruent trial ">><>>." Each stimulus was shown for 120 milliseconds (ms), and the participants were required to respond within 200 to 1750 ms from the onset of the arrows, for a valid response. This task contained four practice trials and 20 test trials, with an equal number of congruent and incongruent trials occurring in a random order. The main dependent variables were accuracy percentage and mean reaction time (RT).

Daytime sleepiness was assessed using the Pediatric Daytime Sleepiness Scale (PDSS) (41). This was a parent-reported instrument consisting of 8 items, having > 0.40 acceptable factor loadings. Higher scores on PDSS were associated with reduced total sleep time, poorer school achievement, poorer anger control, and frequent illness Internal consistency of the total 8-item scale (factor 1, PDSS) was $\alpha = 0.81/0.80$ for the split-half samples.

Statistical analysis

Descriptive statistics were expressed as means, and standard deviations. All data was imported into SPSS version 23 for analysis. An α level of 0.05 was used for all statistical tests. Shapiro–Wilk and Levene tests were used to check the normality and homogeneity of data. Multivariate analysis of variance (MANOVA) test were used to assess between group comparisons at baseline. A two-factor mixed-design ANOVA was conducted to assess the change in dependent variables over the 3 time points between groups, separately. Adjustments were made for sex, age and BMI category. Effect Sizes (ES) using partial eta squared were calculated and reported, large effect with $\eta^2 \geq 0.14$, medium effect with $0.14 > \eta^2 \geq 0.06$, and $\eta^2 < 0.06$ indicating small effects.

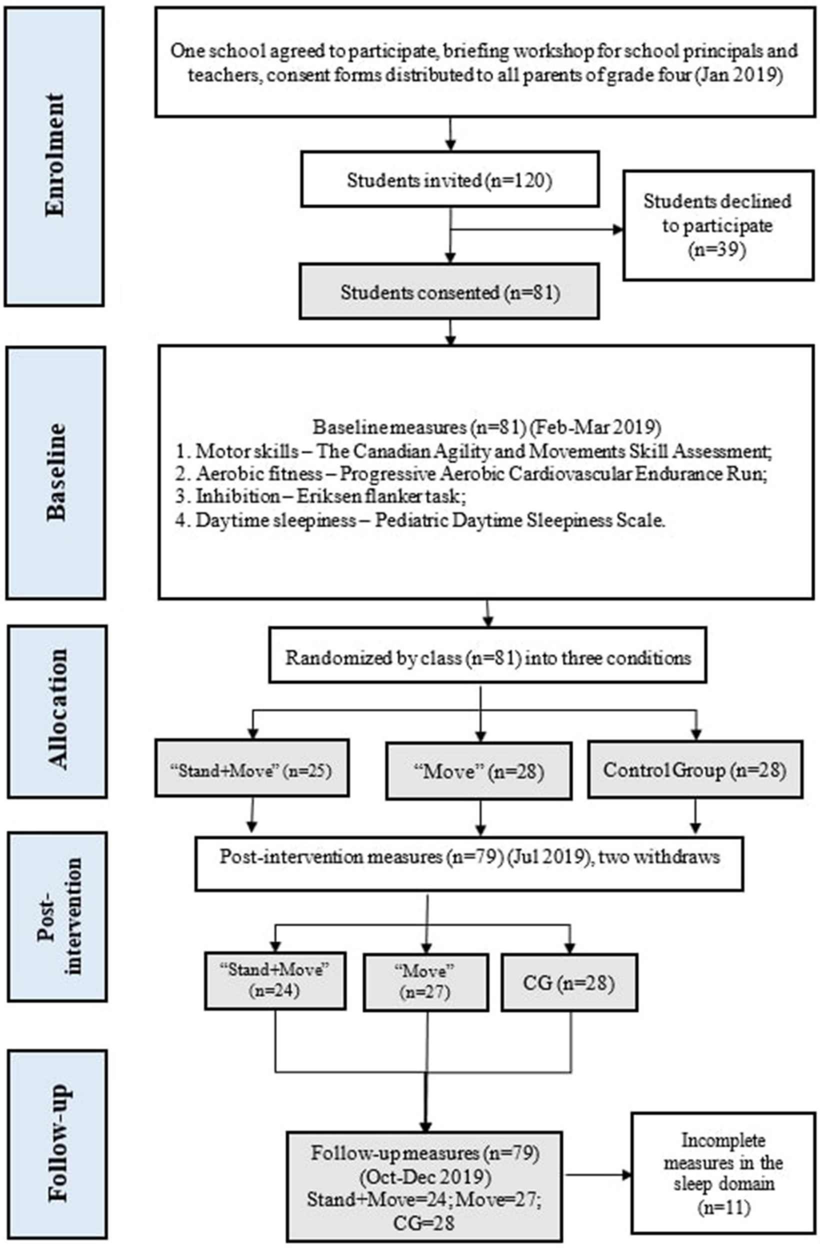

FIGURE 1
Flow diagram for the blended classroom intervention.

Results

All the grade four students (n = 120) were invited and received parent consent forms, and 81 students (response rate = 67.5%) agreed to participate. Of the total sample, 2 dropped out during the intervention, leaving 79 participants (59.5% girls, Mage = 9.6 years [SD = 0.61, range 9.0–12.0]) included for the final analysis. Daytime sleepiness was not available for 11 participants ("Stand + Move" = 3; "Move" = 2; CG = 5) as the questionnaires were not returned from their parents. Figure 1 outlines the flow diagram for the blended intervention. There were no significant differences ($p < 0.05$) between control and intervention groups at baseline for all measured variables. Descriptive statistics of baseline measured variables are presented in Table 1. Intervention effects of the blended "Stand + Move" intervention on all the studied variables over three measurement periods are shown in Table 2. Table 3 displays the mean changes in the measured variables

TABLE 1 Baseline characteristics of study participants.

	Stand + Move ($n = 24$)	Move ($n = 27$)	CG ($n = 28$)	$p =$
Age	9.7 ± 0.7	9.6 ± 0.6	9.6 ± 0.6	0.702
Female	15 (60%)	16 (57.1%)	17 (60.7%)	0.645
BMI (kg/m^2)	16.8 ± 3.0	17.3 ± 3.1	16.9 ± 2.8	0.739
Aerobic fitness (15 m PACER laps)	22.9 ± 12.8	24.0 ± 13.0	23.3 ± 11.0	0.981
Motor skills (CAMSA, 1–24)	19.9 ± 4.1	19.4 ± 3.7	20.5 ± 2.8	0.548
Inhibition Control				
Accuracy – congruent (%)	99.6 ± 2.0	97.8 ± 4.2	98.6 ± 4.5	0.355
Accuracy – incongruent (%)	94.2 ± 18.6	90.0 ± 21.3	95.0 ± 12.0	0.580
RT – congruent (ms)	698.8 ± 203.7	642.2 ± 174.1	626.6 ± 167.4	0.256
RT – incongruent (ms)	795.6 ± 353.2	732.7 ± 239.0	774.7 ± 338.6	0.769
Daytime sleepiness	13.6 ± 5.6	14.6 ± 5.0	13.5 ± 5.8	0.786

BMI, Body mass index; CAMSA, The Canadian Agility and Movements Skill Assessment; Pacer, Progressive Aerobic Cardiovascular Endurance Run; RT, reaction time.

from baseline to immediately post-intervention, while Table 4 displays that from baseline to 3-month follow-up.

There were significant Time x Group interaction effect on aerobic fitness [$F_{(2,76)} = 10.62$, $p < 0.001$, $\eta^2 = 0.22$] from baseline to post-intervention, while no significant interaction effect was found for either motor skill [$F_{(2,76)} = 1.39$, $p = 0.26$, $\eta^2 = 0.04$], inhibition RT [$F_{(1,67)} = 1.41$, $p = 0.25$, $\eta^2 = 0.04$], inhibition accuracy [$F_{(2,67)} = 0.47$, $p = 0.63$, $\eta^2 = 0.01$], or daytime sleepiness [$F_{(1,67)} = 0.07$, $p = 0.79$, $\eta^2 = 0.03$] from baseline to post-intervention. During the period from baseline to follow-up, all variables displayed no significant interaction effect (all $P > 0.05$).

For the main effect from baseline to post-intervention, the blended intervention group and "Move" group significantly increased aerobic fitness (pre – post: −11.75 and −7.22), with blended group showing more improvement. While significant reductions were observed in the intervention groups, with the blended group showing less RT in congruent tests ("Stand + Move": 100.8 ms and "Move": 97.8 ms) and incongruent tests ("Stand + Move": 198.1 ms and "Move": 117.4 ms). At post-intervention, it was interesting to observe that only the blended intervention group showed a significant reduction in daytime sleepiness during this period.

From baseline to follow up, all the groups significantly improved in the measurement of motor skill, with the greatest increase in the blended group (pre-follow up: −2.50). Both reaction time of the congruent and incongruent trials were reduced resulting in better performances in the inhibition tasks performed by two intervention groups and a control group. Participants from "Move" group acquired the largest decrease in the congruent reaction time (192.3 ms [95% CI: 114.9, 269.7]) compared to other two groups, while participants from "Stand + Move" group had the highest mean differences (280.1 ms [95% CI: 788.2, 472.0]) in incongruent responses corresponding to an improved inhibitory control. In addition, there were significant decrease for daytime sleepiness in both "Move" group and CG at follow-up measurements but not for the blended intervention group.

Discussion

This study represents a randomized controlled trial examining the effects of the blended intervention of combining sit-stand desks and PA breaks as a novel strategy for children's health-related outcomes, including aerobic fitness, motor skill, executive control, and daytime sleepiness. Based on the overall findings, this study showed significantly positive interaction effects in aerobic fitness at post-test and main effects for executive control and daytime sleepiness in the intervention groups. The blended classroom-based research design effectively provides more PA opportunities for primary school-aged children for improving their physical and psychological health-related outcomes. As it is the first classroom-based intervention incorporating sit-stand desks and PA recess as the novel strategy to be evaluated in Asia, the compelling evidence benefits children's physical and psychological health in the longer-term (16, 17).

Overall, the intervention had a large positive influence on children's aerobic fitness ($\eta^2 = 0.22$) from baseline to post-intervention, whereas no time-group interactions were observed from baseline to follow-up. This is highlighted by adopting a blended "Stand + Move" program that might provide opportunities to have an acute effect on children's fitness levels. Incorporating sit-stand desks, together with PA breaks, supplemented with teacher training, can be effective in reducing youth sedentary behavior and increasing PA opportunities in classrooms and recess (42). As such, this study supported that

TABLE 2 Characteristics and interventional interaction effects on the studied variables; Mean ± SD.

Outcome	Post-intervention ($n = 79$)			Group*Time P-value	Effect size	Follow-up ($n = 79$)			Group*Time P-value	Effect size
	Stand + Move	Move	CG			Stand + Move	Move	CG		
Aerobic fitness	34.6 ± 17.7	31.2 ± 14.3	24.9 ± 12.3	<0.001*	0.22	24.4 ± 11.1	25.9 ± 12.3	24.1 ± 11.8	0.90	0.003
Motor skills	19.8 ± 4.6	21.4 ± 3.1	21.3 ± 2.6	0.26	0.04	22.4 ± 2.6	21.4 ± 3.2	22.1 ± 2.3	0.58	0.01
Inhibitory Control										
Accuracy-congruent (%)	99.6 ± 2.0	98.2 ± 4.8	97.1 ± 6.0	0.47	0.02	99.6 ± 2.1	96.4 ± 12.2	97.9 ± 5.0	0.82	0.01
Accuracy-incongruent (%)	97.1 ± 4.6	94.4 ± 12.8	95.0 ± 13.2	0.65	0.01	97.4 ± 4.5	92.0 ± 17.1	96.1 ± 5.7	0.88	0.004
RT – congruent (ms)	595.5 ± 154.4	541.4 ± 135.1	583.0 ± 151.3	0.51	0.02	468.8 ± 88.9	472.1 ± 97.3	510.8 ± 112.0	0.85	0.004
RT – incongruent (ms)	599.5 ± 137.0	615.3 ± 163.7	744.5 ± 466.7	0.11	0.06	509.7 ± 94.4	529.4 ± 96.7	518.8 ± 102.1	0.72	0.01
Daytime sleepiness[a]	13.3 ± 5.1	15.6 ± 5.0	13.5 ± 4.7	0.34	0.03	15.1 ± 4.5	16.0 ± 5.4	14.1 ± 4.1	0.28	0.04

[a]n = 68; *p<0.05. SD, standard deviation; CAMSA, The Canadian Agility and Movements Skill Assessment; Pacer, Progressive Aerobic Cardiovascular Endurance Run; RT, reaction time.

more PA opportunities would help enhance the fitness level, which is consistent with an updated systematic review by Neil-Sztramko, Caldwell (43). They found that school-based PA interventions are effective in increasing maximal oxygen uptake or aerobic capacity, reflecting the physical fitness level of an individual (43). There was no significant interaction effect at the 3-month follow-up, which may be related to the cessation of standing desks after the intervention. A previous short-term PA intervention could be compared with the current study, which also focused on the short-term effect leading to positive changes in the aerobic fitness of children (44). However, their study only targeted children with obesity and did not include a control group for comparison. Therefore, this study might provide insightful evidence and could be generalized to a greater population with better design when incorporating sit-stand desks and PA recess as an interventional strategy (18).

In addition, a statistically significant increase in motor skill competence was perceived at follow-up, albeit with no time-group interactions. The results indicated that the blended intervention strategy might have a longer-term effect on motor skill competence than an immediate effect. This interesting finding was in line with Stodden, Goodway (45) developmental mechanisms of PA trajectories in children, in which the reciprocal relationship toward PA was highlighted with motor skill competence development across the lifespan. It indicated that with the maturing of muscles, bones, and engagement in PA, motor skill competence would be improved during the developmental phase (46). More recently, Barnett, Webster (47) systematically compiled mediation, longitudinal, and experimental evidence to support Stodden et al.'s conceptual model. They found strong positive evidence for the fitness-mediated motor competence/PA pathway in both directions, especially in longitudinal studies across childhood and adolescence. As such, PA interventions might be more effective for motor competence/skills in the long term, considering the developmental pathway between motor skills and PA (47). In addition, the outcome variable was measured through a selected group of fundamental, complex, and combined movement skills within one sequence, with the score including both completion time and skill accuracy scores, rather than individual skills scored by the traditional measurements, that is, Test of Gross Motor Development, Second Edition (TGMD-2) (48). Regarding the multifaceted dimensions and components of CAMSA assessment when scoring motor skills, the final score of this outcome variable may be influenced by multiple components, which might be attributed to the lack of significance for motor skill competence in the short-term post intervention.

Another novel finding of this study was the significant impact of the blended "Stand + Move" intervention on children's executive inhibition control (i.e., reduced reaction time for both congruent and incongruent tasks). This was in line with a meta-analysis that investigated the effects of

TABLE 3 Adjusted mean changes (95% CI) from baseline to post-intervention.

	Stand + Move ($n = 24$)	Move ($n = 27$)	CG ($n = 28$)	ES (partial η^2)
Aerobic fitness	**−11.75 (−16.57, −6.93)**	**−7.22 (−10.88, −3.56)**	−1.64 (−5.14, 1.86)	0.185
Motor skills	0.17 (−1.22, 1.55)	−1.89 (−5.59, 1.81)	−0.79 (−1.84, 0.27)	0.107
Inhibitory Control				
Accuracy-congruent (%)	0.00 (−0.01, −0.01)	0.00 (−0.03, 0.03)	0.01 (−0.01, 0.04)	0.013
Accuracy-incongruent (%)	−0.04 (−0.15, 0.08)	−0.04 (−0.16, 0.08)	0.00 (−0.07, 0.07)	0.019
RT – congruent (ms)	**100.8 (14.5, 187.1)**	**97.8 (2.5, 193.1)**	40.3 (−39.2, 119.8)	0.198
RT – incongruent (ms)	**198.1 (37.5, 358.7)**	**117.4 (50.5, 184.4)**	20.4 (−231.0, 271.8)	0.105
Daytime sleepiness	**1.47 (0.06, 2.89)**	0.59 (−0.58, 1.76)	2.08 (−0.04, 4.22)	0.195

Bold values signifies $p < 0.05$. $^*p < 0.05$ for time. CG, control group; ES, effect size; RT, reaction time.

TABLE 4 Adjusted mean changes (95% CI) from baseline to follow-up.

	Stand + Move ($n = 24$)	Move ($n = 27$)	CG ($n = 28$)	ES (partial η^2)
Aerobic fitness	−1.50 (−6.89, 3.89)	−1.89 (−5.59, 1.81)	−0.89 (−3.83, 2.04)	0.010
Motor skill	**−2.50 (−3.81, −1.19)**	**−1.93 (−3.69, −0.23)**	**−1.63 (−2.96, −0.32)**	0.318
Inhibitory control				
Accuracy-congruent (%)	0.00 (−0.01, −0.01)	0.02 (-0.05, 0.08)	0.01 (−0.03, 0.04)	0.013
Accuracy-incongruent (%)	−0.04 (−0.14, 0.08)	−0.02 (−0.14, 0.10)	−0.01 (−0.08, 0.06)	0.019
RT – congruent (ms)*	**170.2 (93.5, 246.8)**	**192.3 (114.9, 269.7)**	**148.8 (67.8, 229.8)**	0.493
RT – incongruent (ms)*	**280.1 (88.2, 472.0)**	**255.7 (86.9, 424.5)**	**214.0 (128.0, 300.0)**	0.434
Daytime sleepiness	1.90 (−1.07, 4.86)	**2.36 (0.05, 4.68)**	**3.39 (1.27, 5.51)**	0.267

Bold values signifies $p < 0.05$. $^*p < 0.05$ for time (whole group). CG, control group; ES, effect size; RT, reaction time.

PA participation on multiple domains of executive functions, which found a positive effect for PA on various subdomains of executive functions (49). Neurocognitive inhibitory control, pertaining to the core executive functions, has been involved in self-controlled behavior, which was under the broader umbrella construct of different disciplines and encompasses cognitive, behavioral, and emotional components, such as inattention, impulsivity, and emotional self-regulation (50). A systematic review showed the overall beneficial effects of PA on executive functions (51), which provided insights into the significance of inhibition in this study. However, heterogeneity of studies and inconsistency of results across studies (52) exists. The inhibitory control can be measured with different tasks. For example, Sjowall, Thorell (53) identified no effects of long-term PA intervention on inhibition control, while their measure used the interference trial from the Color Word Interference Test from D-KEFS (54), which assesses verbal and non-verbal executive functions in children and adults. In this study, the Eriksen flanker task gave the opportunities to disentangle stimulus-level interference from response-level interference (55). The results supported that integrating cognitive and physical demands in a blended PA intervention would be beneficial to enhance motor and cognitive exercise complexity and the affective and motivational factors involved in skill acquisition (56). Such interesting findings and blended research designs have enriched the scope toward the demand for pioneering PA interventions and may provide a theoretical rationale for PA effects on the development of self-control skills (50). It would shed light on applying the theory of ecological dynamics on cognitive performance elicited by PA engagement to inform an individualized enrichment toward the physical literacy journey throughout the lifespan (57).

Regarding the sleep of school-aged children, few studies have examined the effects of a blended "Stand + Move" program that incorporates sit-stand desks and PA recess through a comprehensive physical literacy approach (8), especially considering daytime sleepiness as a result of long-term PA intervention. Previous studies have found that excessive daytime sleepiness affects children's brain functions, including behavioral, cognitive, and health aspects (58), which negatively impacts their school performance and is regarded as a public health concern among children and adolescents (59). A recent systematic review reported that PA programs positively affected various aspects of sleep using both subjective and objective measures, although their population focused on healthy older adults (60). More recently, a cross-sectional study has presented consistent findings that more PA engagement may decrease adolescents' excessive daytime sleepiness, and that daytime sleepiness would increase with a more sedentary lifestyle, especially with prolonged screen time (59). As an emergent field of study, most studies have focused on exploring the associations between PA, sleep, (61–63) and children's sleep behavior to see whether they meet the 24-h Movement Guidelines for Children and Youth (9, 64–66). Few studies have focused on the intervention's effect on daytime sleepiness (67). There is also a need to incorporate specific sleep interventions to enhance the co-development of PA, sedentary behavior, and sleep to enhance children's physical and psychological health with regard to aerobic fitness, motor skills, and cognitive function (68–70). Previous research investigating the relationship between PA and daytime sleepiness may provide evidence that the two domains are significantly associated, suggesting that PA could be one of the factors preventing daytime sleepiness in children aged 9–12 years (67). Considering the harmful effects of excessive daytime sleepiness among children and adolescents (71), the current blended intervention combining PA promotion and strategies to reduce sedentary time may be timely in ameliorating excessive daytime sleepiness in young children.

One of the strengths for this study was the blended design of this study, as it adopted a multicomponent intervention "package" as a novel strategy in school settings (18) and such strategy could provide important evidence to promote children's physical and psychological health to foster a healthy and active lifestyle in children throughout their lifespan (10, 12). As the results shown, a blended research design should be favorably recommended to inform the intervention implementation, combining both quality and quantity of PA included into the "package", especially considering the need to develop physical literacy as a comprehensive construct within the duration of one academic semester and include different intensities of both structured and unstructured activities, which was regarded as the favorable practical recommendations to inform educational activities. In addition, this study supports Cairney, Dudley (72) evidence-informed theoretical model, with current findings supporting the link between physical literacy, PA, and health. The model positioned physical literacy as a determinant of health, and bidirectional associations existed between the constructs of PA, physical literacy, and health outcomes. This study adopted a comprehensive strategy for PA promotion, combining the reduction of sedentary time, which can lead to a variety of positive physiological, psychological, and social adaptations that benefit the development of physical literacy. Meanwhile, the improved health-related outcomes in physical and psychological aspects could make efforts to improve individuals' PA in various settings. Last, this study may also be valuable in contributing to the physical literacy development of the children of Hong Kong children through a comprehensive approach (8).

Nevertheless, the power of this study was limited by its small sample size. Only one school was recruited for this study, as our intervention content was designed to be cognizant of locational factors, such as cultural norms, the education system, and prevailing teaching styles. Therefore, the present intervention should be interpreted with caution regarding the generalizability of the findings.

Conclusion

This is the first classroom-based intervention incorporating sit-stand desks and PA recess as a novel strategy to be evaluated in Asia, and only the third study adopting a full-desk allocation system (16, 17). This blended "Stand + Move" intervention led to short-term improvement in aerobic fitness, executive function, and longer-term improvement in motor skills and executive function in school children. The improvement in daytime sleepiness is encouraging; however, future studies should consider incorporating specific sleep interventions into the co-development with PA intervention and the blended novel intervention strategy could adopted for the scaling up research to benefit more primary school children. Overall, this blended classroom-based intervention provides compelling evidence for a cost-friendly and feasible strategy to enhance children's physical and psychological health.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Survey and Behavioral Research Ethics. Written informed consent to participate in this study was provided by the participants legal guardian/next of kin. Written informed consent was obtained from the individual(s) and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

Author contributions

RS, CS, and ML conceived the study. CS and SW provided guidance and support throughout the study. YW provided professional suggestions in children's sleep measures. CN provide great help for data collection. JR and JC commented the contents, data analysis, and revisions. All authors were involved in the study design, assisted with the drafting, revising of the manuscript, read, and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Associations of emotional/behavioral problems with accelerometer-measured sedentary behavior, physical activity and step counts in children with autism spectrum disorder

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Background: The evidence for associations of emotional/behavioral status with sedentary behavior (SB), physical activity (PA) and step counts is scarce in children with autism spectrum disorder (ASD). Also, ASD-related deficiencies may affect actual levels of PA. We aimed to describe accelerometer-measured SB, PA and step counts in children with ASD, and to examine the associations of emotional/behavioral problems with SB, PA and step counts after assessing associations between accelerometer-measured SB, PA and step counts and ASD-related deficiencies.

Methods: A total of 93 ASD children, aged 6–9 years, were recruited from the Center for Child and Adolescent Psychology and Behavioral Development of Sun Yat-sen University in Guangzhou, China. Participants wore an accelerometer for seven consecutive days. Of the original 93, 78 participants' accelerometer-measured valid PA were obtained, and the data were shown as time spent in SB, light, moderate, moderate-to-vigorous and vigorous PA, and step counts. Participants' emotional/behavioral problems were assessed via the Strengths and Difficulties Questionnaire (SDQ), and anxiety symptoms were evaluated by the Screen for Child Anxiety Related Emotional Disorders (SCARED). ASD-associated deficiencies include restricted repetitive behaviors (Repetitive Behavior Scale-Revised), poor social competence (Social Responsiveness Scale Second Edition) and motor development restrictions (Developmental Coordination Disorder Questionnaire).

Results: Of the 78 participants, daily vigorous PA (VPA) and moderate-to-vigorous PA (MVPA) averaged 15.62 and 51.95 min, respectively. After adjustment for covariates, SDQ emotional symptoms ($\beta = -0.060$, $p = 0.028$) were inversely associated with the average daily minutes in VPA. Meanwhile, SDQ emotional symptoms ($\beta = -0.033$, $p = 0.016$) were inversely associated with the average daily MVPA minutes in the crude model. After adjustment for covariates, SCARED somatic/panic ($\beta = -0.007$, $p = 0.040$)

and generalized anxiety (β = −0.025, $p = 0.014$) were negatively associated with the average daily VPA minutes; SCARED total anxiety (β = −0.006, $p = 0.029$) was conversely associated with daily MVPA duration. After adjustment for covariates, no significant associations between accelerometer-measured SB, PA and step counts and ASD-related deficiencies were found ($p > 0.05$).

Conclusions: Accelerometer-measured SB, PA and step counts showed no associations with ASD-related deficiencies. On this basis, we further found that the emotional symptoms were inversely associated with VPA and MVPA. These results emphasize the importance of VPA and MVPA in children with ASD. The longitudinally investigations on the directionality of these associations between emotional symptoms with VPA and MVPA are needed in the future.

KEYWORDS

emotional/behavioral problems, accelerometer-measured, sedentary behavior, physical activity, step counts, autism spectrum disorder

Highlights

- We described accelerometer-measured SB, PA, and step counts in children with ASD.
- We assessed associations between accelerometer-measured SB, PA and step counts and ASD-associated deficiencies (restrictive repetitive behaviors, poor social competence and motor development restrictions) in children with ASD.
- We examined associations of emotional/behavioral problems with accelerometer-measured SB, PA and step counts in children with ASD.

Introduction

A high rate of children with autism spectrum disorders (ASD), a neuropsychiatric disorder with restricted repetitive behaviors (RRBs) such as repetitive body movements, sensory-stimulant behaviors, object-manipulation behaviors, restrictive interests, insistence on sameness, and repetitive language, as well as with poor social interaction, experience concomitant emotional and behavioral problems (1–3). In fact, the co-existing emotional disturbance and maladaptive behaviors like anxiety, tantrums, sabotage, aggression, hyperactivity and self-injurious are frequent in ASD regardless of age, ability, or schooling (4). The number of problems with emotion regulation and behavior are closely linked to the severity of social deficits as well as to RRBs (5, 6). Additionally, these problems increase the risk of comorbidities for a range of psychiatric disorders including depression, anxiety disorder, behavioral disorder, attention-deficit/hyperactivity disorder, and oppositional defiant disorder (6, 7).

The occurrence of emotional/behavioral problems interferes with rehabilitation training, the quality of life, contributes to substantial impairments in social competence, to academic and occupational underachievement and poor clinical outcomes (8, 9). Clinically, irritability and anxiety are often the reasons families seek unconventional therapies, medical interventions and hospitalization for their ASD children (10). The expenses incurred on the medical treatment and rehabilitation training for ASD will undoubtedly bring heavy economic burden on families and society. This shows that the elimination or attenuation of the concomitant emotional/behavioral problems can be equal or greater concern than control of core features of ASD (11).

Currently, studies have demonstrated the limited improvement of psychotropic medication and behavioral interventions on mental health outcomes in children with ASD (12, 13). Given the benefits of physical activity (PA) among typical children, PA as an appropriate strategy for decreasing ASD outcomes worthy of exploring and studying (14). Previous studies have demonstrated that PA-based interventions can effectively ameliorate autism degree, core symptoms of RRBs and social dysfunction (15–17). Also, ASD children who engage in physical exercise demonstrated substantial improvements in adaptive living skills, communication ability, executive functioning, motor skills, sensory processing skills, and academic engagement (14, 18). In general, PA appears to have benefits for children with ASD, a more rigorous and objective design to determine what intensity and duration of PA can be associated with improved mental health is clearly needed. Furthermore, sedentary behavior (SB) may contribute to adverse health outcomes in children independent of PA (19). To date, there is a relative paucity of studies that have investigated the associations of emotional/behavioral problems with accelerometer-measured SB, PA and step counts in children with ASD. To overcome the challenges of sedentary and inactive lifestyles and an emotional/behavioral problem in ASD children

(2, 3, 20), a first step may be to set up whether cross-sectional relations exist. Most of previous studies collected self- and parent-reported information about SB and PA, which can be subject to report and recall bias (21). Moreover, ASD-related deficiencies including RRBs, poor social competence and motor development restrictions may interfere with PA participation levels (20). It is beneficial to assess the associations between participants' PA engagement and ASD-related deficiencies in order to account for these potential confounding factors on PA levels. Only a handful of studies have considered ASD-related defects that impact levels of SB, PA and step counts, and until now the results were not clear cut (18, 22). Accordingly, the present study had two main aims: (a) describe the accelerometer-measured levels of SB, PA and step counts of children with ASD; (b) examine associations of emotional/behavioral problems with accelerometer-measured SB, PA and step counts on the basis of assessing associations between SB, PA and step counts and ASD-associated deficiencies (RRBs, poor social competence and motor development restrictions) in children with ASD.

Materials and methods

Study design and participants

A cross-sectional study was performed from July 2018 to May 2019. A total of 93 ASD children, aged 6–9 years, were recruited from the Center for Child and Adolescent Psychology and Behavioral Development of Sun Yat-sen University in Guangzhou, China, excluding those who were taking medications for the core symptoms and psychological comorbidities of autism, had diseases affecting motor function, unable to use the accelerometer, and undergoing exercise intervention. Participants who received intervention trainings including the behavioral interventions, educational interventions, social interventions, and the integrated intervention model were not excluded. Of the original 93, 15 were removed due to invalid accelerometer data with a final sample of 78 ASD children, and there was no substantial difference in the distribution of overall demographic information between enrolled and excluded study participants.

The children obtained a diagnosis of autism, and identified as meeting the Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-5) criteria. Childhood Autism Rating Scale (CARS) was conducted to ascertain the diagnosis and to distinguish between mild-to-moderate and severe ASD by two experienced developmental and behavioral pediatricians. According to the manual, the CARS score between 30 and 36.5 is indicative of mild-to-moderate ASD, and the score between 37 and 60 stands for severe ASD (23). We applied the full-scale intelligence quotient (FSIQ) derived from Wechsler Intelligence Scale for Children 4th Edition (WISC-IV) (24) to depict ASD children's general intellectual functioning and then split them into two groups: FSIQ < 70 and FSIQ ≥ 70 (25). This study was conducted in accordance with Good Clinical Practice guidelines, Declaration of Helsinki principles, and the Ethical Committee of the School of Public Health, Sun Yat-Sen University (No. 023 [2018]).

Accelerometer measured SB and PA

The Actigraph GT3X+ accelerometer (Actigraph LLC, Pensacola, FL, USA) was used to measure SB, PA and step counts (26, 27). This is a compact ($3.8 \times 3.7 \times 1.8$ cm), lightweight (27 g) monitor from the new generation of Actigraph devices. Participants and their parents were instructed to wear an accelerometer on the right hip for seven consecutive days (5 working days and 2 weekend days), except while sleeping, bathing and swimming, and parents have been advised to supervise their children's accelerometer use. Accelerometer data were originally collected at 30 Hz and then integrated to 15-second epochs using the normal-frequency filter within ActiLife version 6 software (ActiGraph, Pensacola, FL, USA). Accelerometer files were screened for wear time via Troiano algorithm (28); valid wear was defined as $\geq$4 days (3 work days plus 1 weekend day) with $\geq$10 h per day. Non-wear periods were specified as $\geq$20 consecutive minutes of zero counts per minute (CPM). PA volume were expressed as CPM, and Evenson cutoff points to define PA intensities included: SB = 0–100 CPM; light PA (LPA) = 101–2,295 CPM; moderate PA (MPA) = 2296–4011 CPM; and vigorous PA (VPA) $\geq$4,012 CPM (29). Accelerometer output signals were also recorded as steps per minute and these have been validated (30). The accelerometer data were converted into time (hours/minutes) per valid day in SB, LPA, MPA, VPA and moderate-to-vigorous PA (MVPA), and step counts per valid day and minute. ASD children were categorized as meeting the PA guidelines (PAG) of $\geq$ 60 min/d MVPA according to the World Health Organization 2020 guidelines on PA and SB (31).

Procedures

Following informed consent, parents were invited to fill a basic demographic and assessment questionnaire during their waiting for child to be evaluated. To measure RRBs, social defects and motor development which may affect PA levels, the parent-completed assessment questionnaires included Repetitive Behavior Scale-Revised (32), Social Responsiveness Scale Second Edition (33) and the Developmental Coordination Disorder Questionnaire (34, 35). Enrolled ASD children were scheduled for wearing an accelerometer on the 1st day after assessment. Meanwhile, parents were provided with

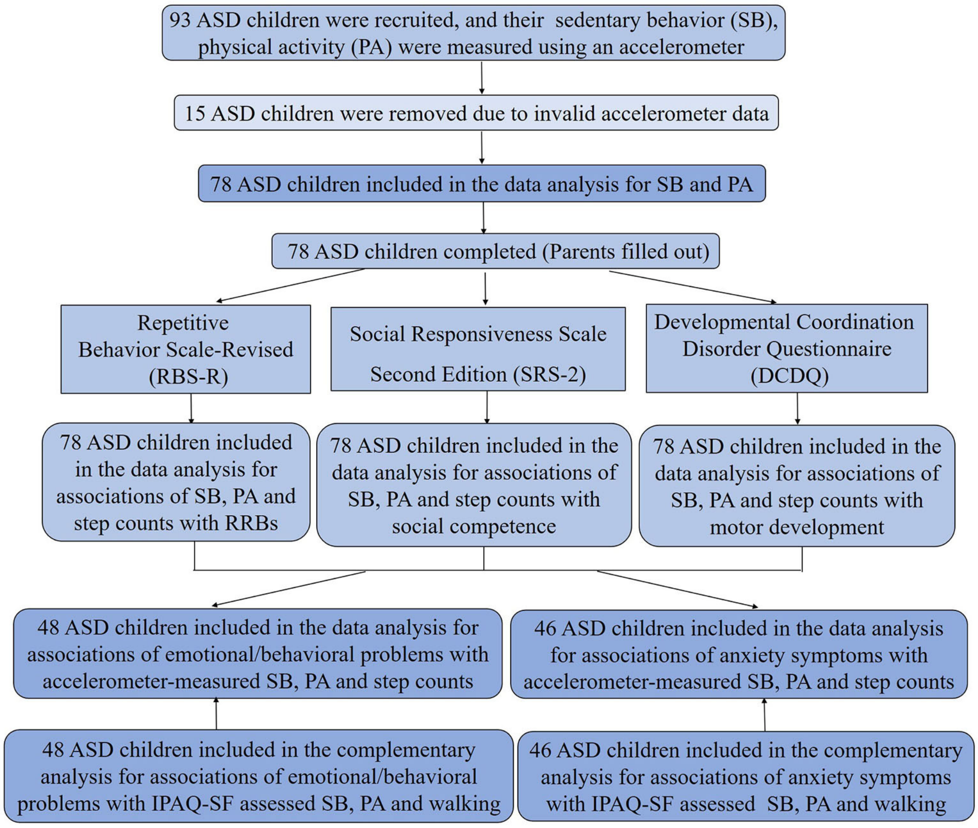

FIGURE 1
Flow diagram of study participant enrollment. IPAQ-SF, International Physical Activity Questionnaire-Short Form.

the Strengths and Difficulties Questionnaire (SDQ) (36, 37) and Screen for Child Anxiety Related Emotional Disorders (SCARED) (38, 39) to record child's emotional/behavioral problems. Also, International Physical Activity Questionnaire-Short Form (IPAQ-SF) (40, 41) was handed out to parents for complementary recording of child's SB and PA. After children were monitored for seven consecutive days, the PA accelerometer devices, SDQ, SCARED and IPAQ-SF scales were returned to the research group by prepaid delivery service. Finally, in 78 valid accelerometer data, 48 effective SDQ and 46 effective SCARED data were obtained (Figure 1).

Restricted repetitive behaviors

Repetitive Behavior Scale-Revised (RBS-R) is a parent or caregiver-report scale for assessing the type and severity of RRBs exhibited by the individuals with ASD. It consisted of 43 items organized into 6 subscales, each corresponding to one of the principal typologies of RRBs: stereotypic behavior, self-injurious behavior (SIB), compulsive behavior, ritualistic behavior, sameness behavior, and restricted interests. Each item is scored on a 0-point (never) to 3-point (always) Likert-type scale; therefore, higher scores indicate more severe RRBs. The RBS-R has been verified to good internal consistency, retest reliability, and discriminant validity (32).

Social competence

Social Responsiveness Scale Second Edition (SRS-2) is a parent-, teacher-, or caregiver-report quantitative measurement of the presence and severity of social deficits (past 6 months) in children aged 4 to 18 years with ASD. The SRS-2 consists of 65-item, and each item is on a 4-point scale from "0" (never) to "3" (always). It generates a total composite score and subscale scores for social awareness, social cognition, social communication, social motivation, and autistic mannerisms. Higher SRS-2 scores indicate more problematic social behaviors. The scale takes a quantitative approach to measuring autistic traits or broader autism symptomology across the entire range of severity that occurs in nature. It showed 0.85 sensitivity and 0.75 specificity for identifying clinically significant autistic traits in validation studies (33).

Motor development

Developmental coordination disorder questionnaire (DCDQ) is a parent-reported questionnaire designed to identify developmental coordination disorder (DCD) in children from 8 years to 14 years 6 months of age. The questionnaire has high internal consistence with a Cronbach's alpha coefficient of 0.88 (34). The validated Chinese version of 17 items of motor development for children aged 6 to 9 years was used in the present study (35). Parents were asked to compare their child's motor performance to that of his/her peers using a 5-point Likert-type scale. The DCDQ provides a total score (17–85 points) as well as splits scores for three results: "an indication of DCD" (≤48 points), "suspect DCD" (49–57 points), and "probably not DCD" (≥58 points) (34).

Emotional and behavioral outcomes

The SDQ is designed to identify and quantify children's emotional/behavioral problems in the past 6 months. The SDQ (age range, 4–16 years) has shown satisfactory psychometric properties confirming it as a valuable tool for detecting psychosocial functioning (36). This questionnaire comprises 25 items, and each item is rated by a 3-point scale (0 = not true, 1 = somewhat true, 2 = certainly true). Every 5 out of the 25 items form a domain, adding up to a total of 5 domains: emotional symptoms, conduct problems, hyperactivity-inattention, peer problems and prosocial behavior scored from 0 to 10 each. A total difficulties score (ranging 0–40) was generated by summing all domains scores except prosocial behavior. High scores signify more unfavorable problems, except for prosocial behavior, for which a higher score indicates a more favorable outcome. The SDQ score can also be used as a categorical variable into three groups of "Normal," "Borderline," and "Abnormal" by standard cutoffs (37).

Anxiety outcomes

Anxiety is a common abnormal emotion state (42), and thus the SCARED as a measure of anxiety symptoms was utilized to assess anxiety levels in youth aged 9–18 years within the past 6 months. The SCARED has demonstrated excellent discriminant validity, concurrent validity, retest reliability and internal consistence (38). We used the Chinese version revised by Chen completed by parents and can be used with children ages 6–12 years (39). The questionnaire contains 26 items assigned to four-dimensional symptoms including social phobia, separation anxiety, panic/somatic, and generalized anxiety. Every item was scored on a four-point Likert-type scale, and the items were summed to produce an overall anxiety score as well as subscale scores with higher scores indicating greater anxiety. Normal range for the norms of subscale and total score of the revised SCARED can be represented as mean ± standard deviation ($\bar{x}$ ± SD), which ≥ $\bar{x}$ + SD manifesting the presence of anxiety symptoms.

IPAQ-SF measured SB and PA

The reliability and validity of IPAQ-SF have been verified across diverse populations (40). The Chinese version of IPAQ-SF used in the present study is originally translated by Macfarlane et al. (41), and was specially used for complementary monitoring of child's SB and PA in our study to further verify the associations of emotional symptoms with SB, PA and walking. Parents were asked to record the number of days children performed each activity (frequency) and the length of time (duration) children were involved in each daily activity for seven consecutive days of accelerometer wear, as well as the average time spent in SB. The results were used to estimate the amount of time spent in PA per day, expressed in Metabolic Equivalent of Task-minutes per day (MET-min/day). According to the official IPAQ-SF scoring protocol, PA was categorized into three different intensity levels: moderate (4 METs), vigorous (8 METs) and walking (3.3 METs) (43, 44).

Statistical analyses

The normal distributions of continuous variables were evaluated by Kolmogorov-Smirnov (K-S) test. The continuous variables were expressed as median ± interquartile range and compared between subgroups applying the Mann-Whitney U test due to a skewed distribution. The categorical variables were expressed as number (percentage) and compared between subgroups by using the chi-square test. Multivariate generalized linear models were performed to determine unstandardized regression coefficient β with 95% confidence interval (CI) for the crude and adjusted associations of SDQ and SCARED continuous outcomes with SB, PA and step counts, and the associations of accelerometer-measured SB, PA and step counts with RRBs, poor social competence and motor development restrictions. The logistic regression models generated odds ratio (OR) with 95% CI were adopted to study the crude and adjusted associations of binary SDQ and SCARED outcomes with SB, PA and step counts, and the associations between PAG of ≥60 min/d in MVPA with RRBs, poor social competence and motor development restrictions. The five SDQ subscales and overall SDQ score were analyzed as a dichotomized variable into two groups: Borderline/Abnormal vs. Normal. The four SCARED subscale scores and the overall anxiety score were divided into asymptomatic and symptomatic groups.

To limit potential bias in the presence of covariates, information about child-, mother-, and family-level covariates was gathered through completing a sociodemographic questionnaire by participant's parents. Child-related covariates included: age (years), gender (girls or boys), severity of ASD symptoms (mild-to-moderate, severe), intellectual functioning (FSIQ < 70, FSIQ ≥ 70), intervention training (yes or no), accelerometer wear season (spring or summer) and daily accelerometer wear time (hours). Mother-level covariates incorporated: maternal age (<35 years, ≥35 years), maternal educational level (junior college or below, university or above). A family-specific covariate was monthly per-capita income (<5,000 Renminbi "RMB," 5,000–7,999 RMB, 8,000–11,999 RMB, or ≥ 12,000 RMB). Of the possible covariates, two covariates (intervention training and accelerometer wear season) were neither associated with dependent variables nor with independent variables (for more details see the related description of the Results section in Table 2 and Supplementary Table 1), and therefore these two variables were excluded from a set of covariates, and the remaining covariates adjusted in all models included children's age, gender, severity of ASD symptoms, intellectual functioning, daily accelerometer wear time, maternal age, maternal educational level and monthly per-capita income. Collinearity diagnosis was performed, and there was no multicollinearity among all the covariates and independent variables included in the models.

In our study, the statistical power (1-β err prob) for multiple linear regression was calculated as 0.84 by using G*Power 3.1 software (45). The significance level for all analyses was set at a two-tailed p-values < 0.05. Data were analyzed using SPSS Statistics 26.0 (IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY, USA: IBM Corp).

Results

Study participants

The descriptive characteristics of 78 participants were presented in Table 1. The median age was 7.0 years, 68 (87.2%) were boys, 54 (69.2%) had mild-to-moderate ASD symptoms, 34 (43.6%) of FSIQ <70, 35 (44.9%) accepted intervention training and 20 (25.6%) wore an accelerometer in spring. Maternal age distribution was < 35 years, $n = 25$ (32.1%). Maternal educational level, junior college or below, $n = 42$ (53.8%). Monthly per-capita income was categorized into <5,000 RMB, $n = 29$ (37.2%); 5,000–7,999 RMB, $n = 23$ (29.5%); 8,000–11,999 RMB, $n = 13$ (16.7%); ≥12,000 RMB, $n = 13$ (16.7%).

SB, PA, and step counts in children with ASD

The median daily duration of SB, PA and step counts were presented in Table 2. Of the 78 participants, daily SB,

TABLE 1 Descriptive characteristics of the participants, their mothers and families.

Characteristics	Overall ($n = 78$)
Child characteristics	
Age, years (median ± IQR)	7.0 ± 2.0
Gender, *n* (%)	
Male	68 (87.2)
Female	10 (12.8)
Severity of ASD symptoms[a], *n* (%)	
Mild-to-moderate	54 (69.2)
Severe	24 (30.8)
Intellectual functioning[b], *n* (%)	
FSIQ <70	34 (43.6)
FSIQ ≥70	44 (56.4)
Intervention training, *n* (%)	
Yes	35 (44.9)
No	43 (55.1)
Accelerometer wear season, *n* (%)	
Spring	20 (25.6)
Summer	58 (74.4)
Daily accelerometer wear time, hours (median ± IQR)	12.7 ± 1.2
Maternal characteristics	
Maternal age, *n* (%)	
<35 years	25 (32.1)
≥35 years	53 (67.9)
Maternal educational level, *n* (%)	
Junior college or below	42 (53.8)
University or above	36 (46.2)
Family characteristics	
Monthly per-capita income, *n* (%)	
<5,000 RMB	29 (37.2)
5,000–7,999 RMB	23 (29.5)
8,000–11,999 RMB	13 (16.7)
≥12,000 RMB	13 (16.7)

ASD, autism spectrum disorder; FSIQ, full-scale intelligence quotient; IQR, interquartile range; RMB, Renminbi.
[a] Assessment by Childhood Autism Rating Scale (CARS).
[b] Assessment by Wechsler Intelligence Scale for Children 4th Edition (WISC-IV).

LPA, MPA, VPA, MVPA, and total PA (LPA, MPA and VPA) averaged 6.99 h, 290.18 min, 36.15, 15.62, 51.95 and 346.71 min, respectively. The percentage of participants meeting the PAG of 60 min of MVPA per day was 37.2%. As for step counts, participants averaged of 9,560 steps per day and 12.00 steps per minute.

Average daily duration of SB, PA variables and step counts across different subgroups were also displayed in Table 2. When analyzed according to the severity symptoms, the subgroup of mild-to-moderate ASD spent less daily VPA time than severe ASD ($p = 0.038$). There were substantial differences in average daily time for SB, VPA, MVPA and step counts between FSIQ

TABLE 2 Sedentary behavior, physical activity, and step counts in children with ASD ($n = 78$).

Variables	Overall ($n = 78$)	Mild-to-moderate ASD ($n = 54$)	Severe ASD ($n = 24$)	FSIQ < 70 ($n = 34$)	FSIQ ≥ 70 ($n = 44$)	Intervention training ($n = 35$)	No intervention training ($n = 43$)	Measuring in spring ($n = 20$)	Measuring in summer ($n = 58$)
SB variables									
SB, hours/d	6.99 ± 1.50	7.16 ± 1.84	6.58 ± 1.41	6.58 ± 1.51	7.21 ± 1.84*	7.16 ± 1.91	6.89 ± 1.47	6.93 ± 2.27	7.04 ± 1.51
PA variables									
LPA, min/d	290.18 ± 64.71	288.84 ± 61.13	293.35 ± 63.56	299.21 ± 68.08	283.36 ± 58.36	284.39 ± 53.86	296.00 ± 80.18	299.41 ± 66.05	288.39 ± 68.57
MPA, min/d	36.15 ± 22.05	35.73 ± 20.17	37.06 ± 21.80	38.93 ± 20.58	34.11 ± 18.42	35.14 ± 19.68	37.20 ± 23.29	33.95 ± 22.56	36.81 ± 20.41
VPA, min/d	15.62 ± 15.56	12.05 ± 16.37	21.26 ± 17.95*	21.18 ± 15.66	11.03 ± 16.27*	11.68 ± 17.03	18.14 ± 15.03	16.13 ± 17.77	15.62 ± 15.37
MVPA, min/d	51.95 ± 37.78	49.11 ± 35.05	60.53 ± 35.86	60.53 ± 32.56	47.21 ± 28.30*	48.46 ± 34.75	54.25 ± 37.06	54.23 ± 43.72	51.54 ± 35.59
MVPA ≥ 60 min/d	29 (37.2)	17 (31.5)	12 (50.0)	17 (50.0)	12 (27.3)*	11 (31.4)	18 (41.9)	7 (35.0)	22 (37.9)
Total PA, min/d	346.71 ± 80.27	336.41 ± 73.24	370.63 ± 81.45	374.30 ± 85.91	330.26 ± 70.63	339.63 ± 76.95	353.79 ± 83.46	350.64 ± 75.90	346.29 ± 82.11
Thousand steps/d	9.56 ± 2.91	9.34 ± 2.97	10.55 ± 4.05	10.22 ± 3.87	9.38 ± 2.63	9.45 ± 4.18	9.61 ± 2.52	9.79 ± 2.90	9.56 ± 3.31
Steps/min	12.20 ± 4.03	12.05 ± 3.95	13.45 ± 5.67	13.15 ± 4.93	11.90 ± 3.82*	13.10 ± 5.20	12.20 ± 3.80	12.25 ± 4.28	12.20 ± 4.03

ASD, autism spectrum disorder; SB, sedentary behavior; PA, physical activity; LPA, low PA; MPA, moderate PA; VPA, vigorous PA; MVPA, moderate-to-vigorous PA; FSIQ, full-scale intelligence quotient; IQR, interquartile range.
Data were reported as median ± IQR or numbers with percentages. Mann-Whitney U and chi-square tests were used to compare variables between subgroups. Total PA included LPA, MPA, and VPA. The intervention trainings included the behavioral interventions, educational interventions, social interventions, and the integrated intervention model.
*Statistically significant differences between subgroups of mild-to-moderate and severe ASD; subgroups of FSIQ <70 and FSIQ ≥70; subgroups of intervention training; subgroups of accelerometer wear season ($p < 0.05$).

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$\geq$ 70 and FSIQ $<$ 70 ($p < 0.05$). Specifically, the SB hours in FSIQ $\geq$ 70 were longer than in FSIQ $<$ 70 ($p = 0.027$). Inversely, the average minutes of VPA and MVPA were shorter, as well as steps per minute were less in FSIQ $\geq$ 70 than FSIQ $<$ 70 ($p = 0.009$; $p = 0.029$; $p = 0.048$). The relatively lower proportion of conforming to the PAG was observed in subgroup of FSIQ $\geq$ 70 ($p = 0.020$). There were no significant differences for SB, PA variables and step counts between the intervention training or not, accelerometer wearing in spring or summer (Table 2). Based on these findings, the SDQ and SCARED scores were compared between the subgroups of intervention training, the subgroups of accelerometer wear season, and no significant differences were observed (see Supplementary Table 1).

Associations between accelerometer-measured SB, PA, and step counts and ASD-related deficiencies in children with ASD

The findings of present study demonstrated that accelerometer-measured SB, PA and step counts had no significant associations with ASD-related deficiencies including RRBs, poor social competence and motor development restrictions ($p > 0.05$) (Supplementary Tables 2–4). With these results, the associations of emotional/behavioral problems with SB, PA and step counts are worthy of being explored.

Associations of emotional/behavioral problems (SDQ) with accelerometer-measured SB, PA, and step counts in children with ASD

The associations between continuous SDQ scores and SB, PA, and step counts were presented in Table 3. Overall, SDQ emotional symptoms were inversely associated with the average daily VPA duration in crude (β = −0.075, p = 0.002, 95% CI [−0.121, −0.028]) and adjusted (β = −0.060, $p = 0.028$, 95% CI [−0.114, −0.006]) models. Additionally, the inverse association between emotional symptoms and daily MVPA duration (β = −0.033, $p = 0.016$, 95% CI [−0.059, −0.006]) was significant for ASD in the crude model.

When the dependent variable SDQ score was modeled as a dichotomous variable (Table 4), the lower odds of emotional symptoms were significantly associated with daily duration of VPA (OR = 0.829, $p = 0.005$, 95% CI [0.727, 0.946]) in crude model. The adjusted logistic regression exhibited the same associations between emotional symptoms and VPA (OR = 0.820, $p = 0.008$, 95% CI [0.708, 0.950]). A significantly lowed odds of emotional symptoms with a duration of MVPA was also observed in both the crude (OR = 0.943, $p = 0.012$, 95% CI [0.901, 0.987]) and adjusted (OR = 0.937, $p = 0.018$, 95% CI [0.888, 0.989]) models. Participants who met PAG showed lower likelihood of emotional symptoms relative to those who did not in both crude (OR = 0.110, $p = 0.044$, 95% CI [0.013, 0.939]) and adjusted (OR = 0.057, $p = 0.034$, 95% CI [0.004, 0.810]) regression models.

Associations of emotional/behavioral problems (SDQ) with IPAQ-SF assessed SB, PA, and walking in children with ASD

When the data were obtained from IPAQ-SF, we identified the consistent inverse associations of emotional symptoms with VPA (β = −0.018, p = 0.010, 95% CI [−0.031, −0.004]) and MVPA (β = −0.009, $p = 0.009$, 95% CI [−0.017, −0.002]), respectively, in crude models. We also discovered the inverse associations of emotional symptoms with VPA (β = −0.020, $p = 0.004$, 95% CI [−0.033, −0.006]) and MVPA (β = −0.011, $p = 0.003$, 95% CI [−0.018, −0.004]), respectively, after covariate-adjustment (Supplementary Table 6).

When the dependent variable was dichotomous, lower odds of emotional symptoms were associated with more VPA (OR = 0.966, $p = 0.039$, 95% CI [0.935, 0.998]) and MVPA (OR = 0.979, $p = 0.041$, 95% CI [0.958, 0.999]), respectively, in adjusted models (Supplementary Table 7).

Associations of anxiety symptoms (SCARED) with accelerometer-measured SB, PA, and step counts in children with ASD

The associations between continuous SCARED scores and SB, PA and step counts were exhibited in Table 5. After adjustment for the covariates, SCARED somatic/panic was inversely associated with the average daily VPA minutes (β = −0.007, $p = 0.040$, 95% CI [−0.013, 0.000]) and generalized anxiety levels were also inversely associated with the average daily VPA minutes (β = −0.025, $p = 0.014$, 95% CI [−0.045, −0.005]). Additionally, SCARED total anxiety levels were conversely associated with the daily MVPA minutes (β = −0.006, $p = 0.029$, 95% CI [−0.011, −0.001]). A lower level of social phobia was associated with ≥60 min/d of MVPA in comparison to <60 min/d (β = −0.391, $p = 0.047$, 95% CI [−0.775, −0.006]).

When SCARED score modeled as a dichotomous variable, decreased odds of generalized anxiety was significantly associated with more accelerometer assessed VPA (OR = 0.928, $p = 0.033$, 95% CI [0.866, 0.994]) in the crude model, see Supplementary Table 5.

TABLE 3 Associations of the levels of emotional/behavioral problems (SDQ) with accelerometer-measured SB, PA and step counts in children with ASD ($n = 48$).

Variables	β coefficient (95% confidence interval)					
	Emotional symptoms	**Conduct problems**	**Hyperactivity-inattention**	**Peer problems**	**Prosocial behavior**	**Total difficulties**
SB (hours/d)						
Crude model	0.461 (−0.038, 0.960)	0.446 (0.104, 0.788)*	−0.227 (−0.855, 0.401)	−0.290 (−0.775, 0.196)	0.186 (−0.412, 0.785)	0.390 (−0.879, 1.660)
Adjusted model	0.538 (−0.138, 1.215)	0.274 (−0.158, 0.706)	−0.502 (−1.331, 0.327)	−0.082 (−0.695, 0.532)	−0.296 (−0.964, 0.373)	0.229 (−1.569, 2.026)
LPA (min/d)						
Crude model	0.000 (−0.013, 0.012)	−0.008 (−0.016, 0.001)	0.012 (−0.003, 0.027)	0.008 (−0.004, 0.019)	0.000 (−0.015, 0.014)	0.011 (−0.019, 0.042)
Adjusted model	−0.006 (−0.019, 0.006)	−0.005 (−0.013, 0.003)	0.007 (−0.008, 0.023)	0.003 (−0.008, 0.014)	0.005 (−0.007, 0.018)	−0.001 (−0.034, 0.033)
MPA (min/d)						
Crude model	−0.030 (−0.078, 0.018)	−0.005 (−0.040, 0.029)	0.029 (−0.030, 0.088)	0.000 (−0.046, 0.047)	−0.011 (−0.067, 0.046)	−0.006 (−0.126, 0.114)
Adjusted model	−0.022 (−0.070, 0.026)	−0.011 (−0.041, 0.020)	0.013 (−0.045, 0.072)	−0.005 (−0.048, 0.037)	0.002 (−0.045, 0.049)	−0.025 (−0.151, 0.100)
VPA (min/d)						
Crude model	−0.075 (−0.121, −0.028)**	−0.016 (−0.052, 0.020)	0.048 (−0.013, 0.109)	0.024 (−0.024, 0.073)	−0.052 (−0.109, 0.006)	−0.018 (−0.145, 0.108)
Adjusted model	−0.060 (−0.114, −0.006)*	−0.006 (−0.041, 0.030)	0.044 (−0.023, 0.111)	−0.019 (−0.068, 0.031)	0.016 (−0.039, 0.070)	−0.041 (−0.186, 0.105)
MVPA (min/d)						
Crude model	−0.033 (−0.059, −0.006)*	−0.007 (−0.026, 0.013)	0.024 (−0.010, 0.058)	0.008 (−0.019, 0.034)	−0.019 (−0.052, 0.013)	−0.008 (−0.077, 0.062)
Adjusted model	−0.024 (−0.053, 0.004)	−0.005 (−0.024, 0.013)	0.017 (−0.018, 0.052)	−0.007 (−0.033, 0.019)	0.005 (−0.024, 0.033)	−0.020 (−0.096, 0.055)
MVPA ≥ 60 min/d[a]						
Crude model	−1.139 (−2.300, 0.023)	−0.408 (−1.252, 0.437)	1.134 (−0.304, 2.573)	0.101 (−1.049, 1.251)	−0.819 (−2.203,0.564)	−0.311 (−3.286, 2.664)
Adjusted model	−0.675 (−1.954, 0.603)	−0.347 (−1.159, 0.465)	0.759 (−0.794, 2.311)	−0.549 (−1.684, 0.585)	0.245 (−1.009, 1.500)	−0.813 (−4.159, 2.532)
Total PA (min/d)						
Crude model	−0.005 (−0.017, 0.006)	−0.459 (−0.920, 0.003)	0.014 (0.001, 0.027)*	0.008 (−0.003, 0.018)	−0.003 (−0.017, 0.010)	0.008 (−0.020, 0.036)
Adjusted model	−0.009 (−0.020, 0.002)	−0.005 (−0.012, 0.003)	0.008 (−0.005, 0.022)	0.001 (−0.009, 0.012)	0.005 (−0.006, 0.016)	−0.004 (−0.034, 0.026)
Thousand steps/d						
Crude model	−0.081 (−0.300, 0.138)	−0.011 (−0.167, 0.144)	0.141 (−0.125, 0.408)	0.100 (−0.108, 0.308)	0.000 (−0.257, 0.256)	0.149 (−0.393, 0.692)
Adjusted model	−0.120 (−0.357, 0.118)	−0.010 (−0.162, 0.141)	0.079 (−0.211, 0.369)	0.012 (−0.201, 0.224)	0.098 (−0.133, 0.330)	−0.040 (−0.662, 0.583)
Steps/min						
Crude model	−0.084 (−0.241, 0.073)	−0.030 (−0.142, 0.082)	0.075 (−0.119, 0.268)	0.071 (−0.080, 0.221)	−0.007 (−0.192, 0.178)	0.031 (−0.361, 0.423)
Adjusted model	−0.096 (−0.275, 0.082)	−0.016 (−0.130, 0.098)	0.059 (−0.159, 0.277)	0.003 (−0.157, 0.163)	0.076 (−0.098, 0.250)	−0.050 (−0.518, 0.418)

SDQ, strengths and difficulties questionnaire; ASD, autism spectrum disorder; SB, sedentary behavior; PA, physical activity; LPA, low PA; MPA, moderate PA; VPA, vigorous PA; MVPA, moderate-to-vigorous PA.
Crude model: no adjust. Adjusted model: adjusted for age, gender, severity of ASD symptoms, intellectual functioning, daily accelerometer wear time, maternal age, maternal educational level and monthly per-capita income.
[a]Compared to MVPA<60 min/d. *Statistically significant associations ($p < 0.05$); **Statistically significant associations ($p < 0.01$).

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TABLE 4 Associations of emotional/behavioral problems (SDQ) with accelerometer-measured SB, PA, and step counts in children with ASD ($n = 48$).

Variables	Odds ratio (95% confidence interval)					
	Emotional symptoms	Conduct problems	Hyperactivity-inattention	Peer problems	Prosocial behavior	Total difficulties
SB (hours/d)						
Crude model	1.470 (0.802, 2.696)	1.735 (0.939, 3.208)	1.005 (0.552, 1.830)	1.191 (0.455, 3.116)	1.043 (0.573, 1.899)	1.187 (0.615, 2.289)
Adjusted model	2.142 (0.809, 5.673)	0.953 (0.259, 3.499)	0.880 (0.302, 2.568)	0.746 (0.064, 8.665)	0.885 (0.288, 2.723)	1.100 (0.385, 3.146)
LPA (min/d)						
Crude model	1.002 (0.988, 1.016)	0.991 (0.977, 1.006)	1.007 (0.992, 1.023)	1.014 (0.986, 1.044)	1.003 (0.988, 1.018)	0.997 (0.982, 1.013)
Adjusted model	0.993 (0.976, 1.011)	1.001 (0.978, 1.024)	0.999 (0.980, 1.019)	1.008 (0.957, 1.062)	1.000 (0.980, 1.021)	0.994 (0.975, 1.014)
MPA (min/d)						
Crude model	0.954 (0.899, 1.013)	1.009 (0.958, 1.063)	1.013 (0.956, 1.073)	1.050 (0.944, 1.167)	0.996 (0.941, 1.053)	1.026 (0.962, 1.096)
Adjusted model	0.944 (0.876, 1.017)	1.008 (0.931, 1.091)	1.017 (0.934, 1.085)	0.975 (0.819, 1.160)	1.016 (0.942, 1.096)	1.021 (0.940, 1.110)
VPA (min/d)						
Crude model	0.829 (0.727, 0.946)**	0.994 (0.940, 1.051)	1.041 (0.971, 1.116)	1.062 (0.930, 1.212)	1.024 (0.960, 1.093)	1.049 (0.968, 1.138)
Adjusted model	0.820 (0.708, 0.950)**	0.995 (0.916, 1.081)	1.076 (0.959, 1.208)	1.089 (0.764, 1.551)	1.020 (0.934, 1.114)	1.083 (0.961, 1.221)
MVPA (min/d)						
Crude model	0.943 (0.901, 0.987)*	1.001 (0.971, 1.032)	1.016 (0.981, 1.052)	1.035 (0.968, 1.108)	1.005 (0.972, 1.039)	1.023 (0.982, 1.066)
Adjusted model	0.937 (0.888, 0.989)*	1.001 (0.957, 1.047)	1.021 (0.969, 1.075)	0.999 (0.886, 1.125)	1.012 (0.966, 1.060)	1.030 (0.973, 1.091)
MVPA ≥ 60 min/d[a]						
Crude model	0.110 (0.013, 0.939)*	1.019 (0.278, 3.737)	1.528 (0.350, 6.674)	1.258 (0.120, 13.245)	1.528 (0.350, 6.674)	4.680 (0.533, 41.069)
Adjusted model	0.057 (0.004, 0.810)*	1.094 (0.139, 8.630)	1.271 (0.184, 8.790)	0.213 (0.003, 14.213)	1.091 (0.143, 8.323)	4.025 (0.317, 51.169)
Total PA (min/d)						
Crude model	0.995 (0.982, 1.008)	0.993 (0.981, 1.006)	1.008 (0.994, 1.023)	1.018 (0.990, 1.047)	1.003 (0.990, 1.017)	1.001 (0.987, 1.015)
Adjusted model	0.987 (0.971, 1.004)	1.001 (0.979, 1.023)	1.002 (0.984, 1.020)	1.005 (0.965, 1.047)	1.002 (0.983, 1.021)	0.998 (0.981, 1.016)
Thousand steps/d						
Crude model	0.875 (0.676, 1.133)	1.067 (0.841, 1.353)	1.054 (0.813, 1.366)	1.112 (0.722, 1.711)	0.840 (0.646, 1.090)	1.015 (0.766, 1.344)
Adjusted model	0.836 (0.594, 1.176)	1.384 (0.831, 2.305)	1.002 (0.685, 1.466)	0.675 (0.195, 2.334)	0.950 (0.651, 1.387)	1.028 (0.685, 1.543)
Steps/min						
Crude model	0.887 (0.730, 1.078)	1.014 (0.854, 1.203)	1.010 (0.839, 1.216)	1.009 (0.748, 1.361)	0.874 (0.727, 1.052)	0.987 (0.808, 1.206)
Adjusted model	0.867 (0.670, 1.123)	1.248 (0.856, 1.819)	1.000 (0.752, 1.331)	0.678 (0.228, 2.019)	0.961 (0.723, 1.277)	1.018 (0.751, 1.379)

SDQ, Strengths and difficulties questionnaire; ASD, autism spectrum disorder; SB, sedentary behavior; PA, physical activity; LPA, low PA; MPA, moderate PA; VPA, vigorous PA; MVPA, moderate-to-vigorous PA.
Crude model: no adjust. Adjusted model: adjusted for age, gender, severity of ASD symptoms, intellectual functioning, daily accelerometer wear time, maternal age, maternal educational level and monthly per-capita income.
[a]Compared to MVPA < 60 min/d. *Statistically significant associations ($p < 0.05$); **Statistically significant associations ($p < 0.01$).

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TABLE 5 Associations of anxiety levels (SCARED) with accelerometer-measured SB, PA, and step counts in children with ASD ($n = 46$).

Variables	β coefficient (95% confidence interval)				
	Social phobia	Separation anxiety	Somatic/panic	Generalized anxiety	Total scores
SB (hours/d)					
Crude model	0.182 (0.043, 0.321)*	0.052 (−0.025, 0.129)	0.054 (0.002, 0.106)*	0.118 (−0.043, 0.278)	0.113 (0.032, 0.194)*
Adjusted model	0.142 (−0.037, 0.322)	0.009 (−0.092, 0.111)	0.004 (−0.061, 0.068)	0.071 (−0.134, 0.275)	0.070 (−0.039, 0.178)
LPA (min/d)					
Crude model	−0.002 (−0.006, 0.002)	−0.001 (−0.003, 0.001)	0.000 (−0.001, 0.001)	−0.001 (−0.005, 0.003)	−0.001 (−0.003, 0.001)
Adjusted model	−0.002 (−0.005, 0.002)	0.000 (−0.002, 0.002)	0.000 (−0.001, 0.001)	0.000 (−0.004, 0.004)	−0.001 (−0.003, 0.001)
MPA (min/d)					
Crude model	−0.012 (−0.026, 0.002)	−0.005 (−0.012, 0.003)	−0.004 (−0.009, 0.001)	−0.006 (−0.022, 0.009)	−0.008 (−0.016, 0.001)
Adjusted model	−0.015 (−0.030, −0.001)*	−0.005 (−0.013, 0.003)	−0.002 (−0.007, 0.004)	−0.010 (−0.027, 0.007)	−0.009 (−0.018, 0.000)*
VPA (min/d)					
Crude model	−0.004 (−0.022, 0.014)	0.001 (−0.009, 0.010)	−0.005 (−0.011, 0.002)	−0.027 (−0.046, −0.008)*	−0.006 (−0.017, 0.004)
Adjusted model	−0.012 (−0.031, 0.007)	−0.004 (−0.015, 0.006)	−0.007 (−0.013, 0.000)*	−0.025 (−0.045, −0.005)*	−0.011 (−0.022, 0.000)
MVPA (min/d)					
Crude model	−0.006 (−0.014, 0.003)	−0.002 (−0.006, 0.003)	−0.003 (−0.006, 0.001)	−0.009 (−0.019, 0.001)	−0.004 (−0.010, 0.001)
Adjusted model	−0.008 (−0.017, 0.000)	−0.003 (−0.008, 0.002)	−0.002 (−0.005, 0.001)	−0.009 (−0.019, 0.001)	−0.006 (−0.011, −0.001)*
MVPA ≥ 60 min/d[a]					
Crude model	−0.239 (−0.641, 0.163)	−0.008 (−0.224, 0.207)	−0.067 (−0.216, 0.081)	−0.329 (−0.769, 0.111)	−0.155 (−0.391, 0.080)
Adjusted model	−0.391 (−0.775, −0.006)*	−0.039 (−0.261, 0.182)	−0.065 (−0.205, 0.075)	−0.337 (−0.775, 0.100)	−0.221 (−0.452, 0.010)
Total PA (min/d)					
Crude model	−0.002 (−0.005, 0.001)	−0.038 (−0.139, 0.063)	0.000 (−0.001, 0.001)	−0.002 (−0.005, 0.002)	−0.001 (−0.003, 0.000)
Adjusted model	−0.002 (−0.005, 0.001)	0.000 (−0.002, 0.002)	0.000 (−0.001, 0.001)	−0.001 (−0.005, 0.002)	−0.001 (−0.003, 0.001)
Thousand steps/d					
Crude model	−0.065 (−0.142, 0.013)	−0.020 (−0.062, 0.022)	−0.015 (−0.044, 0.014)	−0.047 (−0.134, 0.041)	−0.040 (−0.086, 0.006)
Adjusted model	−0.044 (−0.126, 0.039)	−0.012 (−0.058, 0.034)	−0.002 (−0.031, 0.027)	−0.021 (−0.114, 0.072)	−0.024 (−0.074, 0.025)
Steps/min					
Crude model	−0.057 (−0.112, −0.003)*	−0.015 (−0.044, 0.015)	−0.015 (−0.035, 0.006)	−0.036 (−0.097, 0.026)	−0.034 (−0.066, −0.002)*
Adjusted model	−0.035 (−0.096, 0.027)	−0.006 (−0.040, 0.029)	0.000 (−0.022, 0.022)	−0.011 (−0.080, 0.059)	−0.017 (−0.054, 0.020)

SCARED, screen for child anxiety related emotional disorders; ASD, autism spectrum disorder; SB, sedentary behavior; PA, physical activity; LPA, low PA; MPA, moderate PA; VPA, vigorous PA; MVPA, moderate-to-vigorous PA.
Crude model: no adjust. Adjusted model: adjusted for age, gender, severity of ASD symptoms, intellectual functioning, daily accelerometer wear time, maternal age, maternal educational level and monthly per-capita income. [a]Compared to MVPA < 60 min/d. *Statistically significant associations ($p < 0.05$).

Moreover, SCARED social phobia (β = −0.015, p = 0.040, 95% CI [−0.030, −0.001]) and total anxiety levels (β = −0.009, p = 0.043, 95% CI [−0.018, 0.000]) were inversely associated with the average daily MPA minutes as in Table 5.

Associations of anxiety symptoms (SCARED) with IPAQ-SF assessed SB, PA, and walking in children with ASD

When the data were obtained from IPAQ-SF, adjusted negative associations of social phobia (β = −0.006, p = 0.010, 95% CI [−0.011, −0.001]) with VPA, total anxiety levels (β = −0.003, p = 0.014, 95% CI [−0.006, −0.001]) with VPA were identified, respectively, see Supplementary Table 8. When SCARED score modeled as a dichotomous variable, no significant associations of anxiety symptoms with IPAQ-SF assessed SB, PA and walking were found, see Supplementary Table 9.

Associations of emotional symptoms with accelerometer-measured PA in mild-to-moderate and severe ASD children

The associations of emotional symptoms with VPA and MVPA were analyzed in mild-to-moderate and severe ASD children, respectively. After adjusting for covariates, there existed significantly negative associations of emotional symptoms with VPA (β = −0.087, p = 0.029, 95% CI [−0.166, −0.009]) in mild-to-moderate ASD children. Also, there existed significantly negative associations of emotional symptoms with VPA (β = −0.129, $p < 0.001$, 95% CI [−0.165, −0.094]) and MVPA (β = −0.074, $p < 0.001$, 95% CI [−0.084, −0.064]) in severe ASD children, see Supplementary Table 10 for further details.

Discussion

Our findings revealed that no significant associations between accelerometer-measured SB, PA and step counts and ASD-associated deficiencies were identified. Furthermore, the consistent inverse associations of emotional symptoms with VPA and MVPA in crude and adjusted models were discovered, when we combined the accelerometer data with the IPAQ-SF data for verification. Although the subgroup of mild-to-moderate ASD spent less daily VPA time than severe ASD in our study, the adjusted negative associations between emotional symptoms and VPA remained in mild-to-moderate and severe ASD, respectively. This means that the negative association between emotional symptoms and VPA was not altered by the difference in daily VPA time between subgroups of mild-to-moderate and severe ASD. Additionally, after adjusting for covariates, the negative associations between emotional symptoms and MVPA persisted in severe ASD children, but was absent in mild-to-moderate ASD. Future studies with larger sample size are needed to better examine the associations of emotional symptoms with MVPA in mild-to-moderate ASD group. Although statistically significant negative associations with VPA and MVPA were found in one out of the SDQ five domains, the associations of the four remaining domains with VPA or MVPA were not significant: conduct problems, hyperactivity-inattention, peer problems, and prosocial behavior. The accelerometer was worn on the right hip for only 7 days. It is possible that if the accelerometer wear time had lasted for a longer period of time, these domains may show significant associations with VPA and MVPA.

SB, PA, and step counts in children with ASD

A review published in 2020 displayed that a mean MVPA is 56.95 min/weekdays and 55.72 min/weekends in ASD individuals, respectively (46). Another review published in 2017 indicated that estimated MVPA was 34–166 min/day (47). A median daily 51.95 min of MVPA in our study was slight lower than the 56.95 and 55.72 min, but fell within the range of 34–166 min/day aforementioned. Additionally, we found that 37.2% of the participants got 60 min of accelerometer-measured MVPA daily, which was consistent with the conclusion of previous studies that <50% of participants met the PAG of 60-min' daily MVPA (46). In contrast, other studies observed that the majority of elementary school-age children exceed the MVPA guidelines (48). Different proportions of following MVPA guidelines between studies may be attributed to the differences of children's functional ability and their school and/or home environments, leading to different time in MVPA during physical education, at recess or after school (49). For instance, Obrusnikova and Dillon (50) indicated that children with ASD were inactive in physical education (PE), and PE teachers are challenged to engage them in PA during classes. Inversely, Pan reported that ASD children are active and spent more time in MVPA during PE as compared to at recess and after school, which ascribes to the short of verbal or physical prompts from school at recess and the short of positive influence from family after school (51, 52). This suggests that teachers' and parents' involvements were major components of PA participation, and improving their support for ASD children is a viable means of enhancing MVPA.

Our data showed an average of 346.71 min total PA (LPA, MPA and VPA) per day among ASD children. It means that our study participants complied with the recommendation on children's total PA that elementary school-aged children should be physically active of at least 30 min each day to accumulate at least 210 min of overall PA each week raised by Taiwan's Ministry of Education (48). In our study, the average daily number of steps for ASD individuals was 9,560, which was smaller than BMI-referenced recommendations which suggest that 6–12 girls and boys should accumulate 12,000 and 15,000 daily steps, respectively (53). As another study reported, few elementary school-aged children could fulfill the BMI-referenced recommendations of the daily step counts (52), and this phenomenon reminds us that the related recommendation taking into account the type and intensity of PA should be reinstituted. Finally, our 78 participants spent an average of 6.99 h per day with SB. One study has reported that typically developing children (aged 3–11 years, $n = 53$) spent almost 5 h in SB per day of the week (54). This showed that ASD children spent more time in SB than typically developing children, which are supported by other studies conducted in this population (47). As the majority of parents reported that their ASD children went directly home or private nursing/talent class in the community after school and engaged in sedentary and technology-based activities that likely contributed to inactivity. Inactive lifestyles and sedentary habits are linked to high risk for developing cardiovascular diseases, diabetes and obesity (20). We therefore suggest that children with ASD should be provided with PA opportunities from school and families and social support from teachers, peers, and parents to increase PA levels.

Associations of emotional/behavioral problems with SB, PA, and step counts in children with ASD

Given the complexity of ASD, investigating associations of SB, PA and step counts with ASD-related factors would be beneficial for assessing associations of emotional symptoms with SB, PA, and step counts. In our study, accelerometer-measured SB, PA, and step counts were not associated with ASD-related deficiencies (RRBs, poor social competence and motor development restrictions). These results suggest that ASD-related deficiencies might not be the primary effectors of SB, PA, and step counts in children with ASD. Importantly, although the associations of cognitive flexibility, peer problems, and behavioral functioning with VPA and MVPA in ASD have been reported previously (55, 56). To date, however, only few studies have used both standardized objective and subjective tests of SB, PA, and step counts and analyzed the associations of emotional symptoms with SB, PA, and step counts. Taken together, our study found that SDQ emotional symptoms were significantly and negatively associated with the average daily time spent in VPA and MVPA. In addition, we also found that SCARED somatic/panic and generalized anxiety were inversely associated with the average daily VPA minutes. The SCARED total anxiety was inversely associated with the daily MVPA duration in children with ASD. Overall, our findings imply that individuals with ASD need VPA or MVPA to exceed a particular intensity threshold value for the occurrence of positive effects. The possible reason for the threshold effect is that higher-intensity PA is more able to draw the attention away from unpleasant or painful emotional experiences (57). Thus, distraction may account for some of the antidepressant effects of acute exercise (58). Besides, studies have pointed that the presence of an optimal level of arousal modulates stimulation in an organism for maintaining sensory homeostasis, and physical exercise can facilitate arousal and stimulus modulation (59). Accordingly, we postulate that a high-intensity PA like VPA or MVPA, compared to LPA and steps, exceeding a certain stimulation threshold can better play the role of arousal to provide more appropriate sensory feedback. Another fundamental mechanism might be that VPA and MVPA may increase the rate and amount of synthesis and metabolism of neurotrophic factors, endorphins and monoamine neurotransmitters in the brain, thus mimicking the stronger effects of antidepressants and making PA an ideal strategy to manage emotional/behavioral problems with ASD (60, 61). As in one study, conducted with the same exercise frequency and duration and different exercise intensities in two groups of intervention, revealed that higher-intensity exercise group had a larger percentage decrease in serotonin than the control group (59). Decreases in serotonin was found to partially mediate the relationship between exercise and depression (62). Besides, there is the potential explanation for the observed inverse associations of emotional symptoms with VPA and MVPA that high-intensity PA can help to increase self-efficacy or sense of independence, control and success (57). Others have supported these findings, noting that increased self-efficacy was strongly related to adoption of vigorous activity (63). Previous studies suffer from several limitations, such as reliance solely on subjective measures of PA, use only one scale to assess dependent variables and failure to control for covariates in the models (64). Our study mainly used accelerometers, supplemented with IPAQ-SF to measure PA; mainly used the SDQ supplemented with SCARED to assess emotional symptoms; controlled for the covariates, and especially analyzed the associations of PA with ASD-related deficiencies. Our results indicated that emotional symptoms showed negative associations with VPA and MVPA using data from accelerometer and IPAQ-SF. Our findings, although preliminary, are encouraging since the emotional symptoms are common characteristics associated with those who have ASD. Future researches longitudinally investigating on the directionality of these associations are required. Furthermore, our findings make a promising contribution to the literature investigating the impact of different intensities of PA interventions on the emotional symptoms of children with ASD.

After stratified analysis, the negative associations between emotional symptoms and VPA remained in mild-to-moderate and severe ASD, respectively, while the negative associations between emotional symptoms and MVPA only existed in severe ASD children. Although the association of emotional symptoms with MVPA was not significant in mild-to-moderate ASD, there existed a tendency of inverse association between them. This is most likely because better emotion regulation skills possessed by mild-to-moderate ASD children (65), play a more important role than MVPA in regulating emotions. Future work should aim to clarify these complex associations.

Although numerous studies have shown the relationship between more SB and unfavorable mental health outcomes (66, 67). Our findings manifested no associations between emotional symptoms and accelerometer-measured SB. Overall, the associations between mental health outcomes and SB are rather indeterminate (67). For instance, no clear conclusion on SB and depressive symptoms, eating disorder symptoms and anxiety symptom could be drawn from several previous studies (67). The most common reasons for the inconclusive results on associations between mental health issues and SB were the existence and measurement of different types of SB (47). Many studies have used subjectively measured sedentary screen time instead of accelerometer-measured overall SB (54, 68, 69). In fact, sedentary screen time was not a suitable marker for overall SB due to the mechanisms to explain mental health issues include not only sitting time but also the negative media influences brought by screen-based SB. Hence, our results could provide higher reference values for the associations between mental health indicators and accelerometer-assessed total sitting time. Lastly, our findings showed that the SCARED social phobia and total anxiety scores exhibited opposite associations with accelerometer-measured daily MPA. However, SDQ outcome showed no significant associations with MPA. MPA involves complex, dynamic upper body movements (70), and thus future rigorous studies are required to explore an association between emotional/behavioral problems and MPA in children with ASD.

Conclusion

Results of this ASD children-based study found that the emotional symptoms were inversely associated with VPA and MVPA on the basis of our findings that no associations existed between PA and ASD-related deficiencies. Although the subgroup of mild-to-moderate ASD spent less daily VPA time than severe ASD in our study, the negative associations between emotional symptoms and VPA remained in mild-to-moderate and severe ASD, respectively. This means that the negative association between emotional symptoms and VPA was not altered by the difference in daily VPA duration between subgroups of mild-to-moderate and severe ASD. These results emphasize the importance of VPA and MVPA in children with ASD. Our findings justify the need to conduct the longitudinal and interventional research on the directionality of these associations. Also, further research is needed to examine the dose response required to have a benefit for emotional symptoms and to investigate which various emotional symptoms may be differentially affected by PA. Our findings offer potentially fruitful avenue for ASD children and their parents who are interested in improving emotional symptoms. If causal, these associations may also provide positive support to strategies aimed at alleviating emotional symptoms in individuals with ASD and may provide policy makers with an extra motivation to implement PA program with varying intensities.

Limitations

In our study, the cross-sectional design nature and lack of a control group did not permit an investigation on causal association of objectively measured PA with mental, emotional and behavioral health. Future research is encouraged to make a more in-depth exploration of causality and mechanisms between emotional symptoms and SB, PA and step counts among ASD individuals. In addition, unequal gender distributions with smaller sample size of ASD girls were observed in our study due to the higher prevalence of ASD in boys. We will pay more attention to girls with ASD to compensate for unequal gender distributions in the future study.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

Author contributions

JJ conceived the study and responsible for project administration. HL interpreted the data, conducted an in-depth analysis, and wrote the manuscript. YZ, BS, XW, MC, JC, SL, XZ, CJ, and ZG were responsible for data gathering. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.981128/full#supplementary-material

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Association between nutritional status, physical fitness and executive functions in preadolescents: A person-centered approach

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Objective: In the current study, a person-centered approach was adopted to investigate the relationship between nutritional status and physical fitness profiles and executive functions (EF) in preadolescents.
Methods: Participants (M_{age} = 10.8 years; Male = 50.8%) were recruited from two primary schools in Hong Kong. Nutritional status [body mass index (BMI)], physical fitness including cardiorespiratory fitness (CRF, predicted VO_{2max}, multi-stage fitness test) and speed-agility (20-m sprint) were measured on school days. EF performance was measured using the Flanker task (inhibition) and the Sternberg task (working memory).
Results: Data from 120 preadolescents were considered valid. Three distinct profiles were identified by a person-centered approach. Profile 1 was featured by high BMI (21.61 ± 3.38 kg/m^2), poor VO_{2max} (33.29 ± 23.96 ml/kg/min), and slow 20-m sprint (4.51 ± 0.13 s). Profile 2 was featured by low BMI (15.99 ± 3.38), fair VO_{2max} (44.98 ± 23.96) and fast 20-m sprint (3.97 ± 0.13). Profile 3 was featured by low BMI (15.63 ± 3.38), poor VO_{2max} (32.37 ± 23.96), and slow 20-m sprint (4.48 ± 0.13). Wald chi-square test revealed preadolescents in profile 1 and profile 2 performed better than profile 3 in accuracy of Flanker task (1 vs. 3: χ^2 = 12.23, P < 0.001; 2 vs. 3: χ^2 = 10.86, P = 0.001). That is, for normal weight preadolescents with poor CRF and speed-agility, those with superior nutritional status performed better in inhibition. For normal weight preadolescents with poor nutritional status, those with superior CRF and speed-agility had better inhibitory capacity.
Conclusion: Compared to the commonly used variable-centered approach, this person-centered approach is a valuable addition that expands the understanding of the association between nutritional status, physical fitness and EF in preadolescents. Results are discussed with regards to maximizing health behaviors and implications for educational policy.

KEYWORDS
body mass index, exericse, latent profile analysis, inhibition, working memory, attention, cognition

Introduction

Executive function (EF) refers to high-level, self-regulatory neurocognitive processes that help monitor and control thoughts and goal-directed behavior (1). Components of EF include inhibitory control, interference control, working memory, and cognitive flexibility (1). EF is critical for children and adolescents' academic performance and serves as a cornerstone for social behaviors that are exhibited across the lifespan (1). For children and adolescents, nutritional status and physical fitness have been proposed to be closely related to EF performance (2, 3). Understanding the correlation between the integration of nutrition status and physical fitness on domain-specific EF performance may provide insights into the potential of dietary behaviors and physical activity-based interventions to improve EF performance in children and adolescents.

To date, most studies examining the relationship between nutritional status and physical fitness on EF performance in children and adolescents have used a variable-centered approach (i.e., describing and providing information on the strength of the associations between variables, such as regression) and yielded inconsistent findings. Body mass index (BMI), the most commonly used and simplest indicator of nutritional status, was generally reported to be reversely associated with EF performance (i.e., higher BMI is associated with poorer EF performance, especially for obese children) (4, 5). However, cross-sectional studies found that in school-aged children, there was no significant association between BMI and attention (6, 7), working memory (6), and cognitive processing (8). The components of cardiorespiratory fitness (CRF), muscle strength, and motor capacity are key indices of physical fitness that are reported to be associated with EF performance in children and adolescents (3, 9). Esteban-Cornejo et al. (2017) observed that CRF and motor capacity but not muscular strength was associated with greater gray matter volume in different cortical regions (i.e., frontal, temporal and calcarine cortices) of the brain (10), which in turn, affect the children' EF (11). Controversially, one experimental study adopting advanced functional magnetic resonance imaging (fMRI) found that cardiorespiratory fitness (CRF) was not predicting inhibition control (measured by Flanker task) in preadolescents (12). Ruiz et al. (2010) reported that physical activity during leisure time positively influenced EF performance, but the beneficial effect was independent of CRF and BMI (13). The discrepancies suggest that the variable-centered approach may not be able to reveal the complex association between nutritional status and physical fitness on EF performance, as this approach only considers associations that are identified across a sample to summarize the population with a single set of parameters (14).

Notably, the correlation between nutritional status and physical fitness underscores the need to view them as a holistic concept that influences EF in children and adolescents (15, 16). In recent years, a person-centered approach—latent profile analysis—has been developed and is attracting growing interest in the sports field. Latent profile analysis is a categorical latent variable modeling approach that focuses on identifying latent subpopulations within a population based on a certain set of variables (17). Compared to the traditional variable-centered approach, this person-centered approach identifies individuals who share similar patterns of variables in the same profile and compares them to other profiles, both in terms of how the variables are combined to form the profiles and how these combinations relate to other variables (e.g., demographic characteristics) (17). The profiles may provide additional insight into preadolescents' alignments of their nutritional status and physical fitness, as well as their collective association with EF. Specifically, this approach allows investigation of whether nutritional status and physical fitness are aligned in most children (e.g., good nutritional status, CRF, and speed-agility) or if some children have divergent levels of these indices (e.g., good nutritional status, poor CRF and speed-agility). It may also contribute to a better understanding of EF in preadolescents by examining the combined importance of nutritional status and physical fitness in relation to EF performance and determining whether children with different profiles of nutritional status and physical fitness differ in their EF performance. Studies using both a variable-centered and a person-centered approach have yielded the consistent (18) or conflicting (19) results on the relationships between a particular set of key variables, suggesting that the use of latent profile analysis may provide additional information on relationships from a more nuanced person-centered perspective.

Previous empirical studies have adopted latent profile analysis in the sports field. For example, Berlin et al. (2017) found that students' physical activity, sedentary behavior and nutritional choices profiles predicted BMI and psychosocial functioning (20). Cheung and Li (2019) identified three academic burnout profiles and reported that the "well-functioning group" reported significantly higher levels of physical activity and mental toughness than the other two groups (21). To date, however, no study has used latent profile analysis to investigate the relations between nutritional status and physical fitness profiles on EF performance. Understanding the profiles of preadolescents' nutritional status and physical fitness could help identify preadolescents with similar patterns of these indices and examine the relationships between the profiles and EF performance from an individual perspective. The research questions of this study were: (1) what are the latent profiles of nutritional status and physical fitness of preadolescents? (2) what are the relations between the latent profiles of nutritional status and physical fitness and EF performance of preadolescents?

Materials and method

Participants

A total of 184 right-handed children from two elementary schools in Hong Kong were recruited by convenience sampling. Of them, 120 children (male = 50.8%) who completed anthropometric measures, physical fitness and EF tests are considered valid data. The remaining 64 participants were excluded from the analysis because they were absent from one or more assessments. The mean age was 10.8 (±0.5) years with a chronological range of 10–12 years (see **Table 1**, Participants' characteristics). Children with color blindness, sensory deficits, special needs, or a condition in which movement is contraindicated and could interfere with testing were excluded. Informed consent was obtained from the children's parents/guardians before the study. The University Ethics Committee approved the protocol in accordance with the Declaration of Helsinki (No. 2017-2018-0404).

Procedure

The study was a cross-sectional study. Prior to the tests, a screening survey was conducted to exclude ineligible individuals. Data were collected in each school for two consecutive weeks within one semester. Participants' weight and height were collected barefoot and lightly clothed in the school. The EF tests were conducted using a laptop in a quiet classroom at the school at a constant temperature of 22 °C. Participants were instructed to practice the test battery twice before the formal test to familiarize themselves with the tasks and avoid the learning effect. The order of the tasks was consistent during the assessment, i.e., the Flanker task (FT) was completed first, followed by the Sternberg task (SBT), and there was a 1-minute break between the two tests. The CRF and 20-m sprint were assessed in PE class by a trained research assistant with the assistance of the school PE teacher. After a 10-min warm-up (400-m jog and stretch), the 20-m sprint was assessed first. After a break of several minutes, participants were instructed to complete the 15-m version of the multi-stage fitness test on an outdoor playground to determine maximal oxygen consumption (VO_{2max}) for CRF. Anthropometric measurement (weight and height) and EF tests were measured in the first phase, followed by the second phase of the CRF test and 20-m sprint. The specific time for conducting the measurements depends on the availability of the children and teachers in the school.

TABLE 1 Participants' characteristics (*N* = 120).

Preadolescents	Mean	SD
Age (years)	10.8	0.5
Height (cm)	144	8
Weight (kg)	36.6	9.1
BMI (kg/m^2)	17.25	3.13
VO_{2max} (ml/kg/min)	37.22	7.71
20-m sprint (sec)	4.3	0.44

BMI, Body mass index.

Measurements

Nutritional status was assessed using anthropometric measurements, expressed as BMI in kg/m^2 (22, 23). The categories of nutritional status referred to the World Health Organization (WHO) recommendation for children aged 5–19 years, with overweight is defined as a BMI-for-age value greater than 1 SD, obesity as a BMI-for-age value greater than 2 SD and underweight as BMI-for-age less than 2 SD of the mean (23, 24). The BMI value of our sample was compared to a large sample study of Chinese urban primary children expressed in the form of a percentile grid (Cut-off value for overweight >21.61, obesity >24.87 and underweight <11.83 kg/m^2) (25).

Cardiorespiratory fitness was measured using a 15-m version of the multi-stage fitness test (i.e., VO_{2max}) (26). The test required participants to run between two labeled lines 15-m apart. The running speed started at 8.0 km/h, then increased to 9.0 km/h, and increased 0.5 km/h for every minute. Participants were required to shuttle run following the audio instruction to the point of volitional exhaustion or until they could no longer keep pace with the audio signal. The Ramsbottom equation was used to predict the VO_{2max} from the performance of the multi-stage fitness test (26).

Speed-agility was measured by 20-m sprint. The sprint began after a signal was issued by PE teacher with an upright posture at the start line and recorded the performance at the stop line by a research assistant *via* a stopwatch. Participants were instructed to sprint twice (sprint and walk back for a second sprint). The best performance was recorded for further analysis.

Two widely used tasks in a computerized battery were adopted to assess EF performance, which have been described and successfully applied in several studies (27–32). Each test was preceded by six practice stimuli to re-familiarize the participant with the task and negate any potential learning effects. The Flanker Task assesses selective attention and the inhibitory control domain of EF (33). In this task, the target is located in the center and flanked by non-target stimuli. Participants were requested to press the left or right arrow key corresponding to the direction of the target. There are two types of non-target stimuli in the FT, congruent and incongruent. In the congruent condition, the direction of the non-target stimuli is the same as that of the target, while in the incongruent condition, the direction of the non-target stimuli is the opposite direction of the target. Each target and its corresponding non-target stimuli appear for 3 s, and there is a one-second pause between each target. The task takes an average of 3 min to complete. The task has a total of 60 trials. The response time of correct responses and the proportion of correct responses made were recorded for analysis.

The Sternberg task assesses how individuals store and retrieve random information from short-term memory, and measures the working memory domain of EF (34). The task consists of three ascending levels with a total of 80 trials. Participants were instructed to remember a random number or a series of letters with a random sequence, starting with the one-item level (easy mode, to remember one single number) and followed by the three- and five-item levels (hard mode, to remember five random letters). Once the letter disappeared from the screen, a single number/letter was presented in the center of the screen, and participants were required to recall if this number/letter was present in the previous letter set or not as quickly as possible. If the number/letter had previously been presented, participants should press the right arrow. If the number/letter had not previously been presented, the left arrow key should be pressed. The task takes approximately 5 min to complete. The response time of correct responses and the proportion of correct responses made were recorded for analysis.

Statistical analysis

Statistical analyses were conducted in Mplus Version 8.1. BMI, VO_{2max}, and 20-m sprint were subjected to a robust maximum likelihood estimation of latent profile analysis. In the analysis, 1,000 random starting values were used to ensure the validity of each class solution. The number of latent classes (groups) was determined as follows. Starting with a single latent class, additional classes were added in sequence, until a model was found that met optimal selection criteria. In the present study, the optimal statistical number of classes was determined using the Bayesian Information Criterion (BIC), the sample-size Adjusted BIC (ABIC), the Lo-Mendell-Rubin likelihood ratio test (LRT), and the Adjusted LRT (ALRT). Lower BIC and ABIC values indicate a better model. The LRT and the ALRT test a model with K classes vs. a model with K-1 classes. A significant *P*-value indicates that the model with K classes is better than the model with K-1 classes. A non-significant *P*-value indicates that the model with K classes does not improve the model with K-1 classes. Although entropy is generally not used to determine the model with the optimal number of classes, it is useful as it summarizes classification accuracy (whether individuals are classified neatly into one and only one category). Entropy varies from 0 to 1, with values closer to 1 indicating fewer classification errors. The Entropy above 0.76 is associated with at least 90% correct assignment for 3 latent classes, and above 0.84 for 5 latent classes, respectively (35). The final model was chosen based on both statistical results and theoretical implications.

The relations between profiles and constructs related to EF (i.e., response times and accuracy on the FT and SBT) were examined by Wald chi-square tests [i.e., Bolck, Croon, and Hagenaars (BCH) method]. The BCH procedure is the robust and recommended method for examining relationships between classes and continuous variables (36).

Results

Latent profiles

To identify the optimum number of BMI, VO_{2max}, and 20-m sprint profiles, we computed models with 2–5 profiles. **Table 2** provides BIC, ABIC, LRT, ALRT and entropy models. Both the BIC and ABIC decreased sequentially from the 2- to 3- to 4-profiles. The BIC value for the 4-profiles model was slightly lower than that of the 3-profiles model ($\Delta BIC = -6.2$), and the ABIC value for the 4-profiles was lower than the 3-profiles model ($\Delta ABIC = -18.85$). The BIC was higher in the 5-profiles model than the 4-profiles model ($\Delta BIC = 7.85$), and the ABIC was lower in the 5-class model than the 4-class model ($\Delta ABIC = -4.79$). The LRT and ALRT values for the 2-profiles LPA solution were significant at $P < 0.001$, and for the 3-, 4- and 5-profiles LPA solutions were not significant. Collectively, these findings do not support the 5-profiles model, and it is not necessary to test models with more profiles. The overall classification accuracy (Entropy) was 0.73 for the 2-profile model, 0.78 for the 3-profiles model, 0.82 for the 4-profile model and 0.8 for the 5-profile model.

Although the LRT and ALRT results support the 2-profiles model, the improvement of the 3-profiles model over the 2-profiles model was observed in BIC, ABIC and Entropy. The 4-profiles model also increased in BIC, ABIC and Entropy compared to the 3-profiles model. For the 3-profiles model, the percentage of individuals correctly classified were 94% for profile 1, 91% for profile 2, and 87% for profile 3. For the 4-class model, the percentage of individuals correctly classified were 88.7% for profile 1, 85.6% for profile 2, 95% for profile 3, and 87.9% for profile 4. These findings indicate greater parsimony for the 3-profiles model than the 4-profiles model. Thus, the 3-profiles model was applied in the current study. Profile 1, 2, and 3 consisted of 23.33% ($N = 28$), 35.83% ($N = 43$), and 40.83% ($N = 49$) of the sample, respectively. The gender composition was balanced among three classified profiles ($\chi^2 = 0.06$). Profile 1 was featured by high BMI (21.61 ± 3.38 kg/m^2), poor VO_{2max} (33.29 ± 23.96 ml/kg/min),

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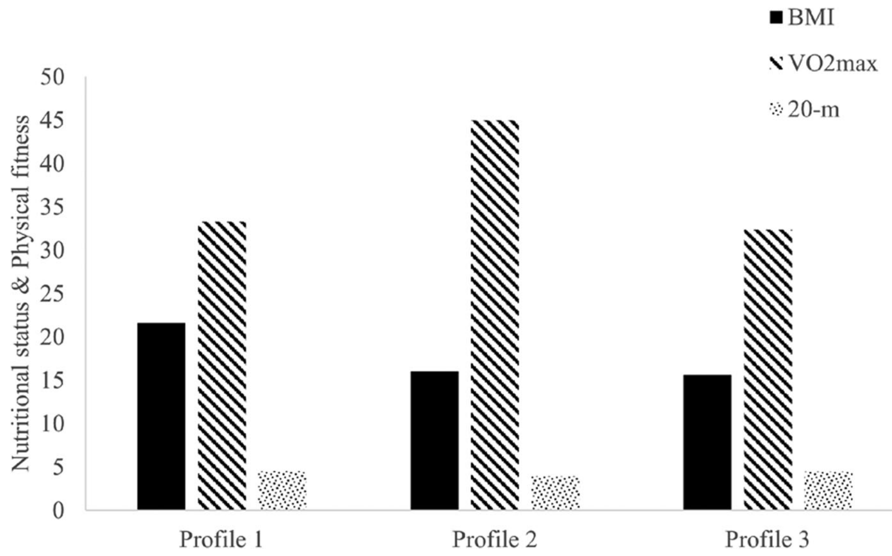

FIGURE 1
Characteristic of classified three profiles. Note: BMI, Body mass index, values are within the Normal weight range for three profiles. Profile 1—high BMI, poor VO_{2max}, and slow 20-m sprint; Profile 2—low BMI, fair VO_{2max}, and fast 20-m sprint; Profile 3—low BMI, poor VO_{2max}, and slow 20-m sprint.

TABLE 2 Fit statistics of the latent profile analysis models.

Model	BIC	Adjusted BIC	LRT P-value	Adjusted LRT P-value	Entropy
2-class	1578.54	1546.92	0.00	0.00	0.73
3-class	1570.99	1526.73	0.19	0.20	0.78
4-class	1564.79	1507.88	0.14	0.15	0.82
5-class	1572.64	1503.09	0.67	0.68	0.80

BIC, Bayesian information criterion; LRT, Lo-Mendel Rubin likelihood ratio test.

TABLE 3 Characteristic of classified three profiles.

	BMI (kg/m^2)	VO_{2max} (ml/kg/min)	20-m sprint (sec)
Profile 1	21.61 (0.52)	33.29 (1.4)	4.51 (0.12)
Profile 2	15.99 (0.45)	44.98 (1.26)	3.97 (0.05)
Profile 3	15.63 (0.35)	32.37 (1.02)	4.48 (0.06)

Data presented as mean (SE). BMI, Body mass index, values are within the normal weight range for three profiles.

and slow 20-m sprint (4.51 ± 0.13 s). Profile 2 was characterized by low BMI (15.99 ± 3.38 kg/m^2), good VO_{2max} (44.98 ± 23.96 ml/kg/min) and fast 20-m sprint (3.97 ± 0.13 s). Profile 3 was featured by low BMI (15.63 ± 3.38 kg/m^2), poor VO_{2max} (32.37 ± 23.96 ml/kg/min), and slow 20-m sprint (4.48 ± 0.13 s) (See **Figure 1** and **Table 3**).

Executive functions

For FT accuracy, preadolescents in Profile 1 and Profile 2 performed better than those in Profile 3 (1 vs. 3: $\chi^2 = 12.23$, $P < 0.001$; 2 vs. 3: $\chi^2 = 10.86$, $P = 0.001$). No group difference was observed between Profile 1 and Profile 2 ($\chi^2 = 0.12$, $P = 0.73$). No group difference was observed in FT reaction time (all $P > 0.05$) for the three profiles. No group difference was

TABLE 4 Mean of physical fitness across test sample ($N = 120$): executive function.

	Profile 1 $N = 28$	Profile 2 $N = 43$	Profile 3 $N = 49$	Overall Wald χ^2
Flanker task				
Reaction time (ms)	691.17 (26.99)	668.24 (20.92)	707.64 (28.67)	$\chi^2 = 1.16$, $P = 0.56$
Accuracy (%)	98.33 (0.94) ***	97.89 (0.81) **	89.33 (2.31)	$\chi^2 = 12.44$, $P = 0.002$
Sternberg task				
Reaction time (ms)	926.49 (39.14)	893.46 (37.38)	923.06 (42.96)	$\chi^2 = 0.41$, $P = 0.81$
Accuracy (%)	94.72 (1.06)	94.58 (1.69)	92.45 (1.52)	$\chi^2 = 1.46$, $P = 0.48$

Data are presented as mean (SE). Profile 1 = high BMI—poor VO_{2max}—slow 20-m sprint; Profile 2 = low BMI-fair VO_{2max}—fast 20-m sprint; Profile 3 = low BMI—poor VO_{2max}—slow 20-m sprint **$P < 0.01$, ***$P < 0.001$ compared with Profile 3.

observed in SBT accuracy and reaction time for the three profiles (all $P > 0.05$) (see **Table 4**).

Discussion

Compared with the widely used variable-centered approach, the current study is the first to adopt a person-centered approach to explore the relationship between nutritional status (BMI) and physical fitness (CRF [predicted VO_{2max}] and speed-agility [20-m sprint]) profiles and EF in preadolescents. Three distant profiles were identified: Profile 1 (high BMI, poor VO_{2max}, and slow 20-m sprint). Profile 2 (low BMI, fair VO_{2max}, and fast 20-m sprint) and Profile 3 (low BMI, poor VO_{2max}, and slow 20-m sprint). Referring to the WHO guidelines, the nutritional status among the three profiles belongs to normal weight. Preadolescents in profiles 1 and 2 performed better on FT accuracy than those in profile 3. Results suggest that (1) among preadolescents with poor CRF and low speed-agility ability, those with superior nutritional status showed better inhibitory control performance than their peers with poor nutritional status; (2) among preadolescents with poor nutritional status, those with higher CRF and speed-agility showed better inhibitory control performance compared to preadolescents with worse physical fitness; (3) no association between profiles and working memory was observed.

The findings that preadolescents with poor CRF and low speed-agility showed better EF performance when they had higher BMI (superior nutritional status) appear to be at odds with the mainstream of the literature using the variable-centered approach. For example, a review study that pooled nine cross-sectional studies of the relationship between obesity and cognition in children and adolescents found that eight of the nine studies showed significantly worse EF indices in obese individuals than normal-weight individuals (37). Using a linear regression model, increasing BMI was associated with lower EF (5), and overweight or obese adolescents showed poorer inhibitory control than their normal-weight peers (4). From a neurophysiological perspective, high BMI is significantly related to the low cortical thickness of eighteen cortical regions, particularly the prefrontal cortex in preadolescents (38). In addition, BMI in obesity was found to be associated with decreased frontal and limbic gray matter volume (39). Both the reduced cortical thickness and volume of brain regions suggest the possibility of poorer EF performance.

However, this linear relationship does not always exist. According to Raine et al. (2018), visceral adipose tissue (VAT) was positively associated with EF in normal weight children (aged 8–10 years), but high VAT was associated with poor EF performance in children with obesity (40). The results suggest that VAT is selectively and negatively related to cognition in children with obesity, and thus the relationship between BMI and EF should be reconsidered based on children's BMI levels (i.e., obesity or not). In our study, preadolescents in profile 1 had, on average, a BMI in the upper range of normal urban Chinese weight but did not reach overweight (Cut-off, BMI = 21.61 kg/m^2) (23, 25), indicating a superior nutritional status in normal weight. For this range, better nutritional status was found to have a positive effect on EF (40), which may explain the finding that profile 1 performed better than profiles 2 and 3. However, this finding is preliminary, and it is recommended that further RCT studies be designed to validate this finding.

Another plausible explanation is that BMI not only represents nutritional status but also predicts the developmental trajectories of children and adolescents (24). The better performance in profile 1 could be due to the fact that preadolescents developed earlier in this profile than in the other profiles, as there is a shift in the relationship between developmental domains as a function of age. Specifically, among Chinese children and adolescents, especially those in Hong Kong, BMI for girls increased from aged 9 to 13 and became stable at age 14 and 15; whereas BMI for boys increased from aged 9 to 11, became stable between aged 11 and 14 (from 17.4 to 20.0 kg/m^2) (41). Participants in our sample were in a fast-developing phase, and the average BMI in profile 1 was slightly higher than the stable phase value mentioned above (i.e., >20.0 kg/m^2), which may indicate that preadolescents in profile 1 were faster developed than preadolescents in the other profiles (e.g., 15.99 kg/m^2 in profile 2 and 15.63 kg/m^2 in profile 3). According to a previous study, preadolescents in older group (11–12 yrs) performed better in inhibition control (Flanker task) and working memory (2-back task) than younger group (9–10 yrs), and regression analysis showed that age was generally associated with better performances of executive function (42). Therefore, it is plausible that preadolescents in profile 1 developed faster than those in other profiles, leading to better cognition performance.

Consistent with previous variable-centered studies that physical fitness benefits EF in preadolescents, our second finding indicated that among preadolescents with poor nutritional status, those with higher CRF and speed-agility showed better inhibitory performance compared to preadolescents with worse physical fitness (43). The combination of CRF and speed-agility appears to promote EF together. According to a review, CRF was not associated with EF when speed-agility was controlled (44). An empirical study found that children with better results in CRF (predicted VO_{2max}) and speed-agility (4×10 m shuttle run test) scored better in all cognitive dimensions, even after controlling for BMI (15). Nevertheless, CRF and speed-agility were also reported to be individually associated with EF. For example, after correcting for age, gender and BMI, Ludyga et al. (2019)

observed that motor ability was associated with conflict score on the Flanker task in preadolescents (45). Drozdowska et al. (2021) observed a weak but significant positive correlation between speed (20-m sprint) and FT reaction time performance in a German study of 211 preadolescents (46). CRF (predicted VO_{2max}) is generally reported to be associated with EF performance in Chinese preadolescents (42, 47). The possible mechanism is that participants who exhibited better physical fitness had better cerebral oxygenation (48, 49), and cognitive processing critically depends on adequate blood flow to meet the energy and oxygen demands of the brain's cortical tissue (50). According to the standard provided by a large Chinese sample study (51), preadolescents in profile 2 have a fair CRF with good speed-agility, and those in profile 3 have a poor CRF with worse speed-agility. Therefore, with poor nutritional status preadolescents, improving EF by promoting physical fitness (i.e., CRF and speed-agility) seems feasible. Preadolescents should engage in moderate to vigorous physical activity, which correlates positively with CRF and speed-agility and is recommended by the World Health Organization (52, 53).

No association was found between nutritional status, physical fitness profiles and working memory. This is consistent with a review study of differences in cognition between overweight and normal weight children, which found that only one of four individual studies reported the correlation between BMI and working memory (4). However, the correlation between the 20-m sprint and working memory is controversial. In a study using two tasks to measure working memory, the speed of the 20-m sprint was weakly but significantly related to the score of the Corsi-block tapping task, but not to the 2-back task (46). This discrepancy may be explained by a measurement bias in working memory that is common in neurobehavioral experiments. Regarding CRF, consistent with a UK study using the same cognitive battery with the same task as the current study (i.e., SBT, working memory), CRF (predicted VO_{2max}) is not associated with the "three- and five- items" for both reaction time and accuracy (54). However, most recent studies assume that a higher CRF is correlated with better working memory. For example, Zhan et al. (2020) found that CRF level (predicted VO_{2max}) was positively associated with response accuracy in the 2-backward task (42). A similar result was also observed after controlling for demographic characteristics (e.g., age, gender, grade) in preadolescents (55, 56). An intervention study found that increased CRF was associated with improved performance on the SBT in preadolescents (57). The mixed results indicate the need for further investigation, with the present study adding to the literature by using a person-centered (latent profile analysis) approach for the first time, compared to the more commonly used variable-centered approach.

There are a few limitations of our study. First, this study is cross-sectional and causality of the observed associations cannot be determined. Future studies should consider a rigorous study design such as RCT to better understand the associations and validate the results of our study. Second, we used single measurements for all variables. Future studies might consider using multiple measurements for the key variables, such as adding the Stroop task to measure inhibition, the Corsi-block tapping task and the 2-back task to measure working memory, and adding visceral adipose tissue as an indicator of the nutritional status.

Conclusion

Compared with the commonly used variable-centered approach, this study, which took a person-centered approach, provided addictive information on the association between nutritional status, physical fitness profiles and EF in preadolescents. Findings suggest that for normal weight preadolescents, promoting EF by improving nutritional status may be effective for those with poor physical fitness. For preadolescents with poor nutritional status, improving CRF and speed-agility may be beneficial for EF.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by The Education University of Hong Kong (No. 2017-2018-0404). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

Conceptualization, YZ, FS and TYG; methodology, YZ and ST; software, FS and SBC; validation, YZ, FS and TYG; formal analysis, YZ and ST; resources, FS and TYG.; data curation, YZ; writing—original draft preparation, YZ, TYG and ST; writing—review and editing, SBC, FS and TYG; supervision, FS and TYG. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Establishing childhood disability clinics may help reduce the prevalence of disability among children in Africa: A viewpoint

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Globally, there are about a billion people comprising of about 95 million children who experience disability. The number of people in Africa living with disability is about 80 million people; out of which 10%–15% are children of school age. The causes of disability among these children include epilepsy, vision loss, or hearing loss, cerebral palsy, poliomyelitis, tetanus, cerebrospinal meningitis and malaria. However, these causes of disability are preventable and can be managed with proper care. The aim of this article is to propose the establishment of childhood disability clinics in Africa in order to help prevent or reduce the incidence/ prevalence of disability among children. Some of the mandates of the clinics will be to carry out routine assessment of children for disability, to provide education on disability and strategies for disability prevention to parents and caregivers, to promptly prevent and manage disability or its causes. However, establishing these clinics requires shared commitment of all the stakeholders.

KEYWORDS

children, disability, Africa, quality of life, sustainable development goal

Introduction

According to the UN Convention on the Rights of Persons with Disabilities (UNCRPD), disability refers to having impairments in physical, mental, intellectual or sensory functions that can hinder one's full and effective participation in the society on equal basis with others (1). Statistics indicates that, about 14%–15%, which equals to about a billion people of the world's population, experience one form of disability or the other (2, 3). This statistics could be much higher when the families of those living with disabilities are considered since they also bear the burden of their loved ones with disabilities (4).

The prevalence is however higher in the developing countries (3). This is attributed to the increased prevalence of chronic health conditions, violence and conflict, and delay in accessing health services (5, 6). Among children, prevalence of disability ranges between 0.4% and 3%, and is higher in boys (7). Specifically, the Global Burden of Disease estimates childhood disability prevalence to be 95 million (5.1%) children, of whom 13 million (0.7%) has severe disability (3). However, the higher prevalence in boys compared

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to girls, has been argued to be due to lack of universal criteria for defining disability types such as learning disability, and genetic factors such as in the case of autism spectrum disorder (8, 9).

Although, estimating the extent of disability among communities is a herculean task (10); it is estimated that there are about 80 million people living with disability in Africa (11, 12). Out of this number, 10%−15% are children of school age (11, 12). Causes of disability among children and adolescents include epilepsy, cerebral palsy, poliomyelitis, tetanus, cerebrospinal meningitis, malaria and limb amputation (3, 6, 13).

The viewpoint

The problem in focus

Childhood is supposed to be a sweet experience. This sweet experience may be shattered by having a disability (14). This is because people living with disabilities have a higher incidence of chronic conditions and health-related disparities (15, 16). Chronic conditions in turn can also cause disability, which can also increase the risk for other conditions (5).

In Africa, the commonest cause of disability is infection, followed by trauma due to accidents or war, congenital and non-infectious diseases such as epilepsy, poor quality of perinatal care, malnutrition, and chronic medical conditions such as diabetes and HIV/AIDS (17–20). Infants who are HIV-positive have increased prevalence of developing neurological problems such as movement and cognitive impairment that can result in disability (17).

When a person has disability, they may experience physical challenges, cognitive problems, stigmatization, loss of employment opportunity, poor productivity and economic loss, and impose caregiver burden and economic burden to families and government (3, 7, 12, 21). For instance, a child with lower limb amputation may find it difficult to walk and carry out his activities of daily living (ADL). Similarly, a child with cognitive problem may find it difficult to pay attention in class to learn; or learn social skills that can help them relate with peers and other people. Thus, it is imperative that causes of disability and disability during childhood are recognized and dealt with promptly.

Unfortunately, often times due to the nature of the health systems in Africa, healthcare professionals see children in the clinics only when they present with serious health problems. However, most health problems in children such as impairment in movement, cognitive ability and social skills development become obvious only when the children are growing up (22, 23). As a result of this, only very skilled healthcare professionals or special educationists may be able to observe that something is wrong with the child. Therefore, even though, there are postnatal and children clinics in Africa, these clinics do not specifically focus on disability assessment and prevention. As such, there is a need for clinics that will specifically focus on routine assessment of children for impairment and/ or disability even if they are apparently healthy at least once every month. The aim of this paper is to provide an argument for establishing childhood disability clinics in Africa.

The mandates of the clinics

The mandates of the clinics will be to provide many services related to disability prevention and treatment such as the following:

Routine assessment of children for disability

Assessments for physical and cognitive health, and social skills development should be carried out. Through these assessments, existing and potential problems can be recognized or predicted. Consequently, training and advice can be offered to the parents/caregivers. In addition, services such as surgical or medical treatments, rehabilitation, special education and nursing can be provided. Assessment for disability can help improve outcome in people living with disabilities (24). This is because knowing a problem is half way to solving it. For instance, if it is realized that a child has weakness of the lower limb, the muscles can be strengthened or they will be provided with an orthotic device such as the calipers. Similarly, if a child has hearing problem, hearing aids or appropriate services can be provided promptly.

However, for assessment of disability among children to be effective, it needs to be comprehensive and carried out at many different intervals, not once (25). That is to say, the assessment should be carried out routinely. Some of the factors that will ensure effective and comprehensive routine assessment of children with disabilities include the organizational structures, resources, therapists within the organizations, assessment tools, and families of members of the children (26). Therefore, utilizing these factors appropriately can help in supporting effective assessment of children with disabilities. Consequently, the WHO International Classification of Functioning, Disability and Health Child and Youth Version Activities and Participation D Codes can be used for the assessment (25). If after the assessment, a child is discovered to have a certain disability, prompt intervention should be given in order to ensure the child enjoy a full and decent life, in conditions which ensure dignity, promote self-reliance and facilitate the child's active participation in the community, according the UN Convention on the Rights of the Child (27).

Disability education for parents and/or caregivers

This should involve education on the misconception of causes of disability. In many parts of the world, many people still believe that disability is caused by spiritual attack or the fault of the parents (28). This can affect readiness of families to seek for right help for their children. In addition, provision of training and offering advice to parents and caregivers on how to prevent and/ or manage conditions or symptoms such as fever, recognize adverse events such as fever, swelling and pain following immunization, and prevent falls and its consequential injuries should also be given priority. For this, a manual can be provided after the training to help easily guide the parents/ the caregivers. An example of this is the training manual for caregivers of children living with disabilities developed by the UNICEF (29).

Furthermore, the education and training should include adequate information on disabilities of their children, the help the caregivers can offer on their own and the support they need and where they can get it (21). This can serve as a form of empowerment to their caregivers to become advocates, and can help them get the courage to assist the child with disability to be as independent as they can in carrying out their ADL (21). This is because active engagement of caregivers in the care of their children with disabilities may help improve outcomes (30).

Provision of prompt prevention and intervention strategies for childhood disability

This should include treatment and rehabilitation, nursing services, dietary advice, special education and counseling. In addition, play therapy should also be used. Accordingly, there have been calls for action for early intervention services and early childhood development for children living with disabilities (31, 32). These interventions should help minimize the disabling effects of impairments (31). Examples of these can include provision of orthotic devices for children such as those with polio to start using them in order to prevent contracture and further disability. In addition, a child with tetanus infection can be managed using therapeutic positioning to prevent development of joint stiffness and contractures. Similarly, maternal care can be enhanced to help prevent perinatal conditions that can result in disabilities (31). For instance, use of mosquito nets can be encouraged to prevent pregnant women from malarial infection. Malarial infection can affect the developing feotus and cause stillbirth and low birth weight (33, 34). Low birth weight is a predisposing factor for conditions such as cerebral palsy (CP) which can cause disabilities in children (35).

Provision of training to those who are providing the services

The African Child Policy Forum (ACPF) recommends capacity building in terms of technical skills and know-how for the stakeholders involved in the care of children with disabilities (31). According to the forum, regular training and support through regular site visits, call centers, resources centers and online support using online materials and phone calls should be provided. This will help to enhance the capacity of the care providers and the clinics as well. In particular, capacity building for healthcare providers who are involved in the caring of people with disability in the low and middle income countries has been emphasized (36). This capacity building should also include training on assessment of disability (37). Building capacity can help improve outcomes in healthcare practice (38).

Research and development

Research is the backbone of knowledge. It gives insights about phenomenon or happenings in the world. Thus, through research, the stakeholders will further understand and come up with innovative ways to help prevent or manage disability in children including the needs of the children and their families. However, for any research on children with disabilities, the research should include people living with disabilities in the research team, as it will enhance understanding of the relevance of the findings to all the stakeholders (39).

Possible composition of the team to manage the clinics

The team shall comprise of the caregivers/parents, clinical psychologists/psychiatrists, dietitians, nurses, pediatricians/surgeons, and rehabilitation professionals such as the physiotherapists, occupational therapists, speech therapists, audiologists and special educationists. Where possible the tasks of routine assessment of the children for disability can be shifted to trained Community Health Officers or Extension Workers or the caregivers. However, to ensure effective task shifting, adequate training needs to be given. When adequate training is given, task shifting is feasible and can result in the success of the task (40).

Methods of service delivery

The service can be provided in the clinic, the community and through telecare. The advantage of providing the service in the clinic is that, the service can be integrated into the already existing postnatal or pediatric clinic to help conserve resources. Providing the service in the community on the other hand may also have its own advantage since sometimes patients prefer to be treated at home (14, 31). Similarly, telecare can also be used to reach people living with disabilities especially those who are in remote areas. This can help facilitate self-management (41).

Stakeholders for establishing the clinics

The stakeholders for establishing the clinics should include healthcare professionals, people living with disabilities, parents/caregivers, pressure groups such as the non-governmental organizations, the community and the government. The health professionals should educate the general public including the government on the need to establish such clinics. People living with disabilities, parents/caregivers, non-governmental organizations, and the community can serve as pressure groups that will persuade governments to establish the clinics. In addition, if possible, public/private sector partnership can be used in establishing such clinics when the stakeholders deem that this can give the clinics better prospects. According to Cameroun et al., healthcare professionals who are involved in the care of children with disabilities in low middle income countries (LICs) can get help in many ways (42). For instance, they can receive training and grant supports from many non-governmental organizations such as Médecins Sans Frontières (Doctors without Borders) and the United Nations Children's Fund support programs for children (42).

Conclusion

Establishing childhood disability clinics in Africa may help prevent or reduce the incidence or prevalence of disability among children. Interestingly, establishing the clinics could be possible since there are already existing postnatal and children clinics in most health facilities. However, this requires shared commitment of all the stakeholders. In addition capacity building of all the stakeholders involved with the clinics is very important. Furthermore, tasks shifting whereby staffs such as the Community Health Officers are trained to carry out some of the mandates of the clinics may help make the service delivery easier.

Author contributions

All authors contributed to the writing and approved the manuscript for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Clustering patterns of metabolic syndrome: A cross-sectional study in children and adolescents in Kyiv

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Aliusef MH, Gnyloskurenko GV, Churylina AV and Mityuryayeva IO (2022) Clustering patterns of metabolic syndrome: A cross-sectional study in children and adolescents in Kyiv.
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Objective: The aim: to identify subgroups by cluster analysis according parameters: original homeostatic model of insulin resistance (HOMA-1 IR), updated computer model of insulin resistance (HOMA-2 IR), β-cell function (%B) and insulin sensitivity (%S) for the prognosis of different variants of metabolic syndrome in children for more individualized treatment selection.
Patients and methods: The observational cross-sectional study on 75 children aged from 10 to 17 with metabolic syndrome according to the International Diabetes Federation criteria was conducted at the Cardiology Department of Children's Clinical Hospital No.6 in Kyiv. HOMA-1 IR was calculated as follows: fasting insulin (μIU/ml) × fasting glucose (mmol/L)/22.5. HOMA-2 IR with %B and %S were calculated according to the computer model in [http://www.dtu.ox.ac.uk]. All biochemical analysis were carried out using Cobas 6000 analyzer and Roche Diagnostics (Switzerland). The statistical analysis was performed using STATISTICA 7.0 and Easy R. The hierarchical method Ward was used for cluster analysis according the parameters: HOMA-1 IR, HOMA-2 IR, %B and %S.
Results: Four clusters were identified from the dendrogram, which could predict four variants in the course of metabolic syndrome such that children in cluster 1 would have the worst values of the studied parameters and those in cluster 4 – the best. It was found that HOMA-1 IR was much higher in cluster 1 (6.32 ± 0.66) than in cluster 4 (2.19 ± 0.13). HOMA-2 IR was also much higher in cluster 1 (3.80 ± 0.34) than in cluster 4 (1.31 ± 0.06). By the analysis of variance using Scheffe's multiple comparison method, a statistically significant difference was obtained between the laboratory parameters among the subgroups: HOMA-1 IR ($p < 0{,}001$), glucose ($p < 0.001$), insulin ($p < 0{,}001$), HOMA-2 IR ($p < 0.001$), %B ($p < 0.001$), %S ($p < 0.001$), TG ($p = 0.005$) and VLDL-C ($p = 0.002$).
Conclusions: A cluster analysis revealed that the first two subgroups of children had the worst insulin resistance and lipid profile parameters. It was found positive correlation between HOMA-1 IR, HOMA-2 IR, %B and %S with lipid metabolism parameters TG and VLDL-C and negative correlation between %B and HDL-C in children with metabolic syndrome (MetS).The risk of getting a high TG result in the blood analysis in children with MetS was significantly dependent with the HOMA-2 IR >2.26.

KEYWORDS
cluster analysis, insulin resisitance, insulin-secreting cells, metabolic syndrome, waist circumference

Introduction

The prevalence of metabolic syndrome in children varies widely according to different sources (1) and various diagnostic methods (2) This is due to not only the differences between nations and races, but also to lack of a unified diagnostic consensus in the pediatric population. Metabolic syndrome (MetS) represents a combination of multiple disorders including central or abdominal obesity, elevated blood pressure, dislipidemia, type 2 diabetes mellitus or impaired glucose tolerance. According to the guidelines established by the International Diabetes Federation (IDF), MetS is diagnosed in children from the age of 10 years with the following criteria: abdominal obesity plus any two of four factors including high blood pressure, high triglyceride, low high-density lipoprotein cholesterol, high fasting plasma glucose (3).

The definition assumes that MetS is heterogeneous disease and one individual may have abdominal obesity, low HDL-C and high fasting plasma glucose, while another one has abdominal obesity, high blood pressure and high TG. Therefore, it is important to cluster patients based on one of the etiological mechanisms of the disease. One of the main long-established pathogenetic underpinnings for the development of the MetS is insulin resistance (IR) (4, 5). Many methods to measure IR have been published in the past. The most commonly used is the homeostatic model of insulin resistance (HOMA-IR), which is based on fasting insulin and glucose values. The original HOMA-1 IR model was described in 1985. Reduced β-cell function was modeled by changing the β-cell response concentration of plasma glucose. An updated HOMA (HOMA-2 IR) is the computer model in 1996 was calibrated to obtain β-cell function (%B) and insulin sensitivity (%S), given that a level of 100% is normal and IR of 1 (6). HOMA2-IR model has nonlinear solutions and these should be used compared with the HOMA1-IR minimal model. Also, HOMA-2 IR model accounts for variations in hepatic and peripheral glucose tolerance and reduced peripheral glucose uptake stimulated by glucose. Previously, it was thought that insulin resistance causes an increase in plasma glucose levels, which contribute to the need for pancreatic insulin-secreting cells (β-cells) to produce and secrete more insulin. Chronic exposure to elevated glucose leads to β-cell dysfunction and cell deathcausing diabetes (7).

However, recently the theory that insulin resistance precedes beta cell dysfunction has been challenged and it is believed that beta cell hyperfunction leads subsequently to IR (8).

Therefore, appreciable destruction of β-cell, may occur often before the impaired glucose tolerance or persistent elevation of fasting glucose. It is also known that excessive cholesterol accumulation in β-cells can cause lipotoxicity and reduce insulin secretion, causing a reduction in the number of β-cells (9). Early studies have shown that people with hyperglycaemia have a more severely impaired lipid profile. Studies demonstrate that LDL-C inhibits glucose-stimulated insulin secretion and β-cell proliferation *via* LDL receptor mechanisms. Also, high levels of LDL-C (>6 mmol/L) cause β-cell apoptosis (10). Given the pathogenetic links between the processes outlined above, we suggested that beta cell activity and insulin sensitivity may be prognostic criteria for severity of the MetS. Therefore, the aim of our study was to identify subgroups of children with metabolic syndrome based on these indicators.

Materials and methods

The observational cross-sectional study on 75 children aged 10–17 with metabolic syndrome (MetS) was conducted at the Cardiology Department of Children's Clinical Hospital No.6 in Kyiv. The sample size was calculated using the the package G*Power 3.1.9.7 (11). under the assumption of odds ratio =5 with frequency of qualitative characteristics −0.5 (50%) and a critical significance level of 0.05 and power −0.8. Calculation for quantitative characteristics was done assuming odds ratio =5 with a change of 0.5σ with a critical significance level of 0.05, power −0.8. Inclusion criteria: all children who came to the clinic with the complaint of being overweight and who were diagnosed with MetS based on the IDF criteria: which include abdominal obesity plus two or more factors including blood pressure ≥130/85 mmHg, triglyceride level ≥1.7 mmol/L, high-density lipoprotein cholesterol <1.03 mmol/L, fasting plasma glucose ≥5.6 mmol/L. Exclusion criteria: patients with metabolic syndrome, associated with genetic syndromes. All anthropometric measurements were performed immediately upon the patient's admission to the department. Body mass index and waist circumference according to growth charts were determined at all children (WC). BMI was assessed according to WHO growth charts. Abdominal obesity was established by measuring the WC ≥90 percentile for age and sex-specific. As there are no national WC charts, it was used the British references in adolescents as they reflect the patterns of WC in Caucasian children (12). 24-h ambulatory blood pressure monitoring was performed using ABM-04 («Meditech», Hungary) (13, 14). There were determined the parameters of the lipid profile which include total cholesterol (TC), triglycerides (TG), high-density lipoproteins (HDL-C), low-density lipoproteins (LDL-C), very low density lipoproteins (VLDL-C), atherogenic coefficient (AC). HOMA-1 IR was calculated using the formula: fasting insulin (μIU/ml) × fasting glucose (mmol/L)/22.5. HOMA-2 IR with beta-cell function (%B) and insulin sensitivity (%S) were calculated according to the computer model in [http://www.dtu.ox.ac.uk]. All biochemical analysis were carried out by enzymatic colorimetric method of Cobas 6000, Roche Diagnostics (Switzerland) analyzer and test system. No patient was excluded at the end of the study. The hierarchical method Ward was performed for cluster analysis using the statistical package STATISTICA 7.0, which aim to minimize the main

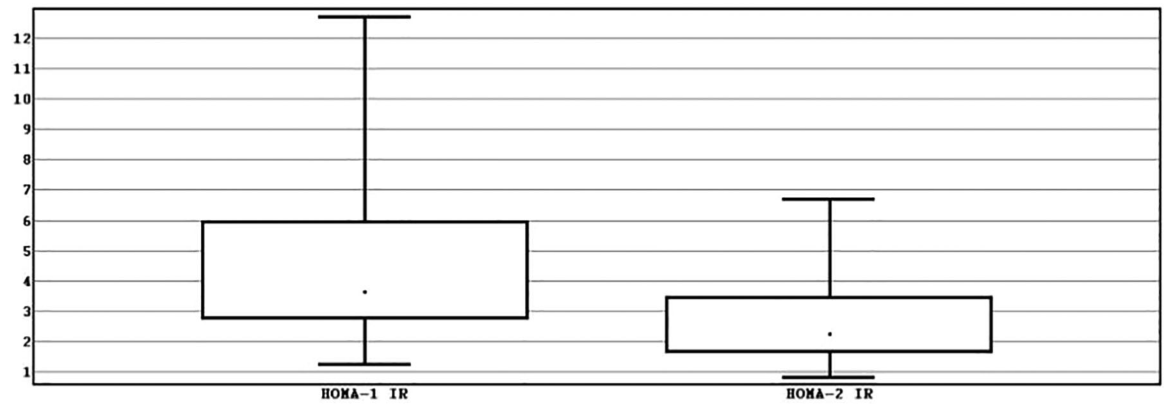

FIGURE 1
Interval evaluation of HOMA-1 IR and HOMA-2 IR.

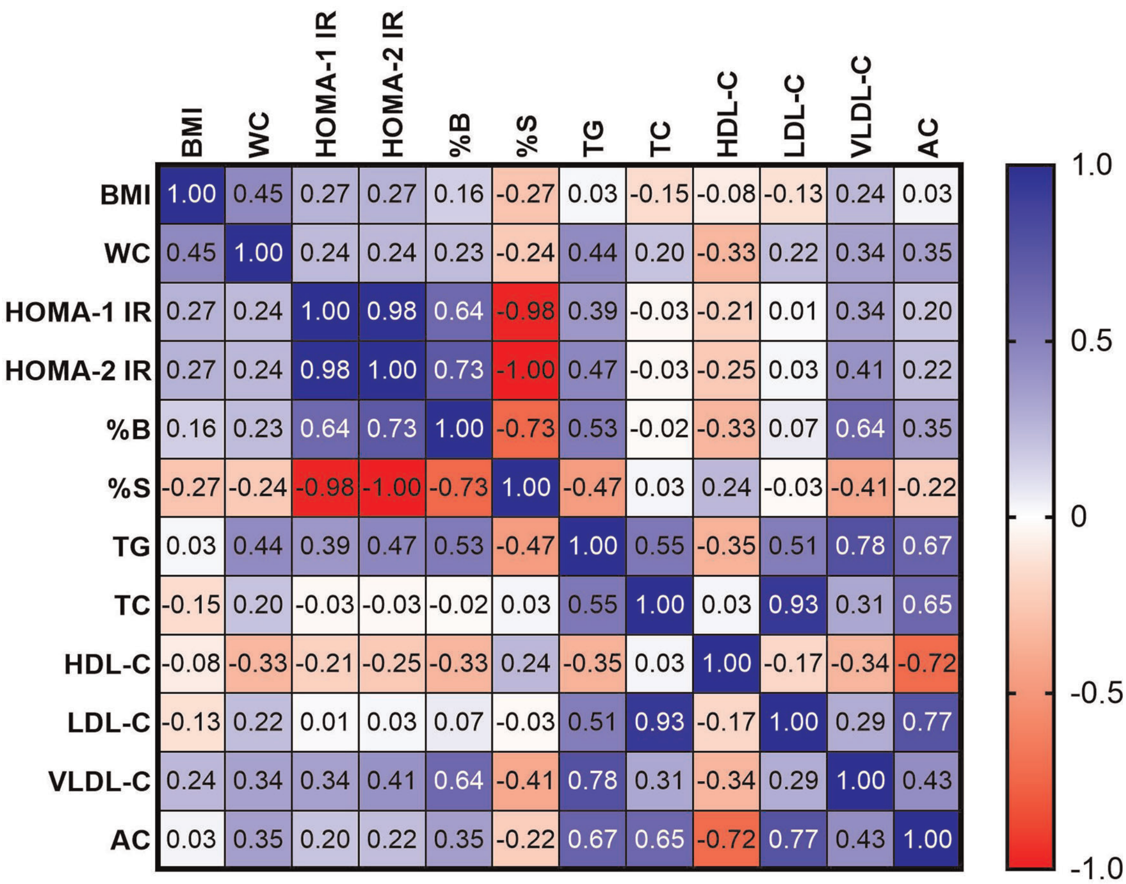

FIGURE 2
Heat map correlation between parameters of insulin resistance and parameters of lipid profile.

variation within groups based on Euclidean distances. A non-parametric Spearman rank correlation test was used for the correlation analysis. The critical level of significance was estimated to be equal to or less than 0.05. In order to predict the binary initial variable under the influence of the factor variables, a logistic regression model was used. ROC-curve analysis was used to assess the quality of the logistic regression model. The statistical analysis was performed using EZR (Easy R) version 1.54 (December 24, 2020).

There may be some possible limitations in this study. This research is a pilot study and it is limited to the city of Kyiv. Also, the IDF classification limits the diagnosis of MetS to children from the age of 10 years, so the results of this article cannot be extrapolated to younger children. For children from 2 to 11 years, the IDEFICS classification should be used to diagnose MetS (15).

Results

The sample consisted of more males −60% ($n = 60$) than females −20% ($n = 15$) with a median of age of 15 years [interquartile range (IQR) 14–16]. Median BMI was of 28.73 kg/m^2 (IQR 26.85–31.74). Median WC – 91.5 cm (IQR 87.00–96.00). Median HOMA-1 IR was significantly higher −3.65 (IQR 2.75–5.96) than median HOMA-2 IR – 2.26 (IQR 1.64–3.46), $p < 0.001$ (**Figure 1**).

Median %B – 198.95 (IQR 142.35–253.65), median %S – 44.7 (IQR 29.05–61.4).

There was no significant difference between the median BMI of boys (28.71 ± 0.59), and girls (30.43 ± 1,47), $p = 0.344$. The WC was significantly higher in boys (92 ± 1.79) compared to girls (86 ± 1.52). HOMA-1 IR did not differ

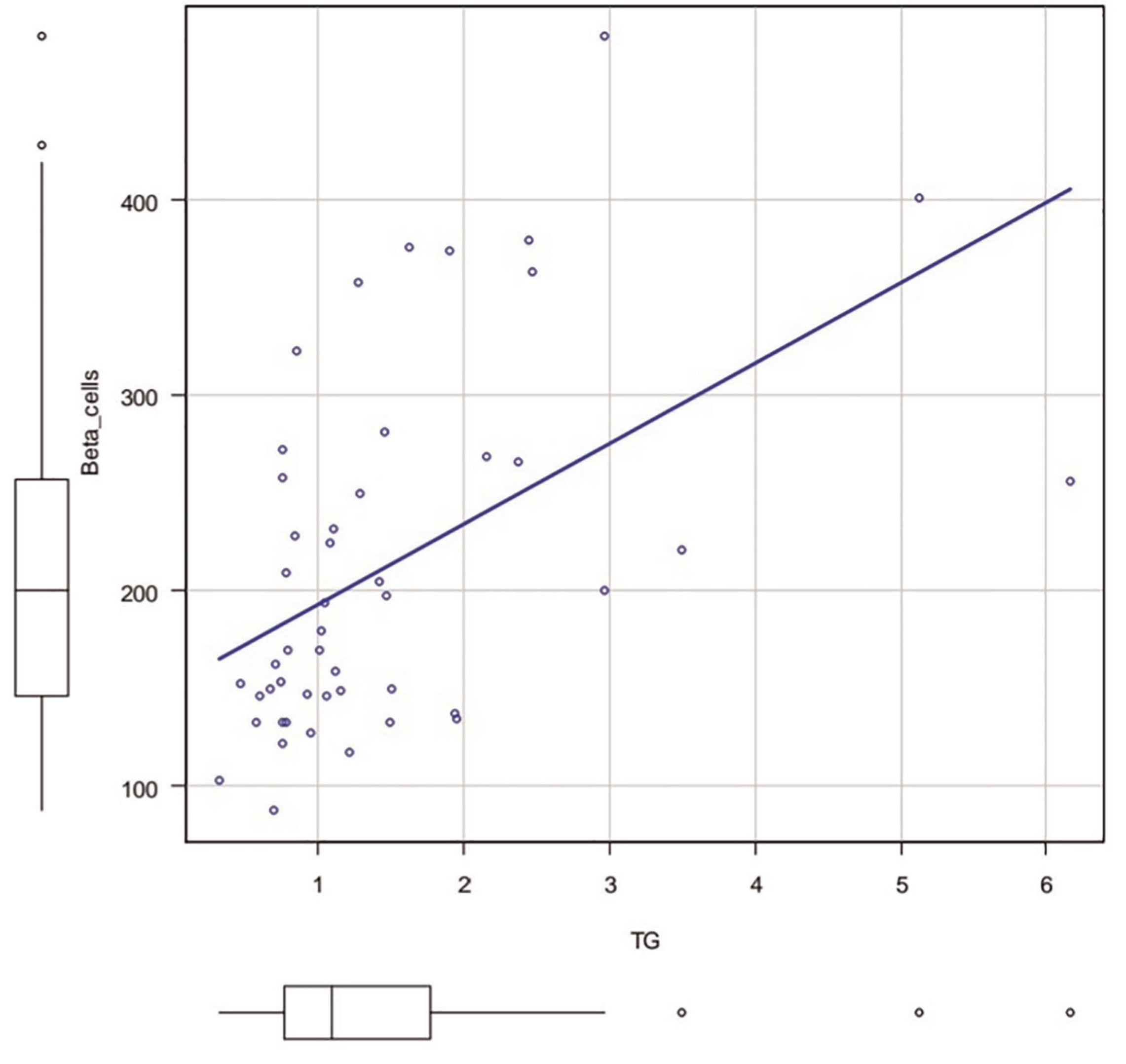

FIGURE 3
Correlation field in coordinates: TG (X axis) and %B (Y axis). Spearman's rank correlation coefficient 0.53 *p*.value = 0.000105.

between the groups: 3.54 ± 0.37 and 5.99 ± 0.96 respectively, p = 0.085. HOMA-2 IR had a gender difference with score for males −2.17 ± 0.19 and females −3.38 ± 0.502, p = 0.049. Glucose levels did not differ between genders −4.76 ± 0.09 and 4.99 ± 0.18, p = 0.269. The median insulin in boys (17.5 ± 1.702) was significantly lower than girls (27 ± 4.56), p = 0.045. Accordingly, %S showed higher values in boys (46.05 ± 3.53) than girls (29.6 ± 6.87) with p = 0.049. The median %B did not differ significantly between the males – 186.3 ± 13.22 and females – 224.1 ± 36.51 with p = 0.206.

In order to assess the relationship between the parameters of insulin resistance and lipid metabolism, a correlation analysis was performed. The results of the study are summarized in the heat map (**Figure 2**). The positive correlations were found between TG and HOMA-1 IR (r = 0.39), HOMA-2 IR (r = 0.47) and %B (r = 0.53) and negative correlation between TG and %S (r = −0.47), p < 0.05. VLDL-C was positively correlated with HOMA-1 IR (r = 0.34), HOMA-2 IR (r = 0.41) and %B (r = 0.64) and negatively with %S (r = −0.41). The negative correlation was observed between HDL-C and %B with r = 0.33 (p < 0.05). The positive correlation was found between AC and %B (r = 0.35), p < 0.05.

The **Figures 3**, **4** show the correlation field of a pair of indices, where a correlation of medium strength was detected (**Figures 3**, **4**).

Since the correlation analysis only answers the question of the presence of the relationship between the parameters, but not the cause-and-effect relationship, It was conducted a logistic regression model, where Y is a binary initial sign of the influence of factor variables: X_1, X_2,…X_m. Hence, for

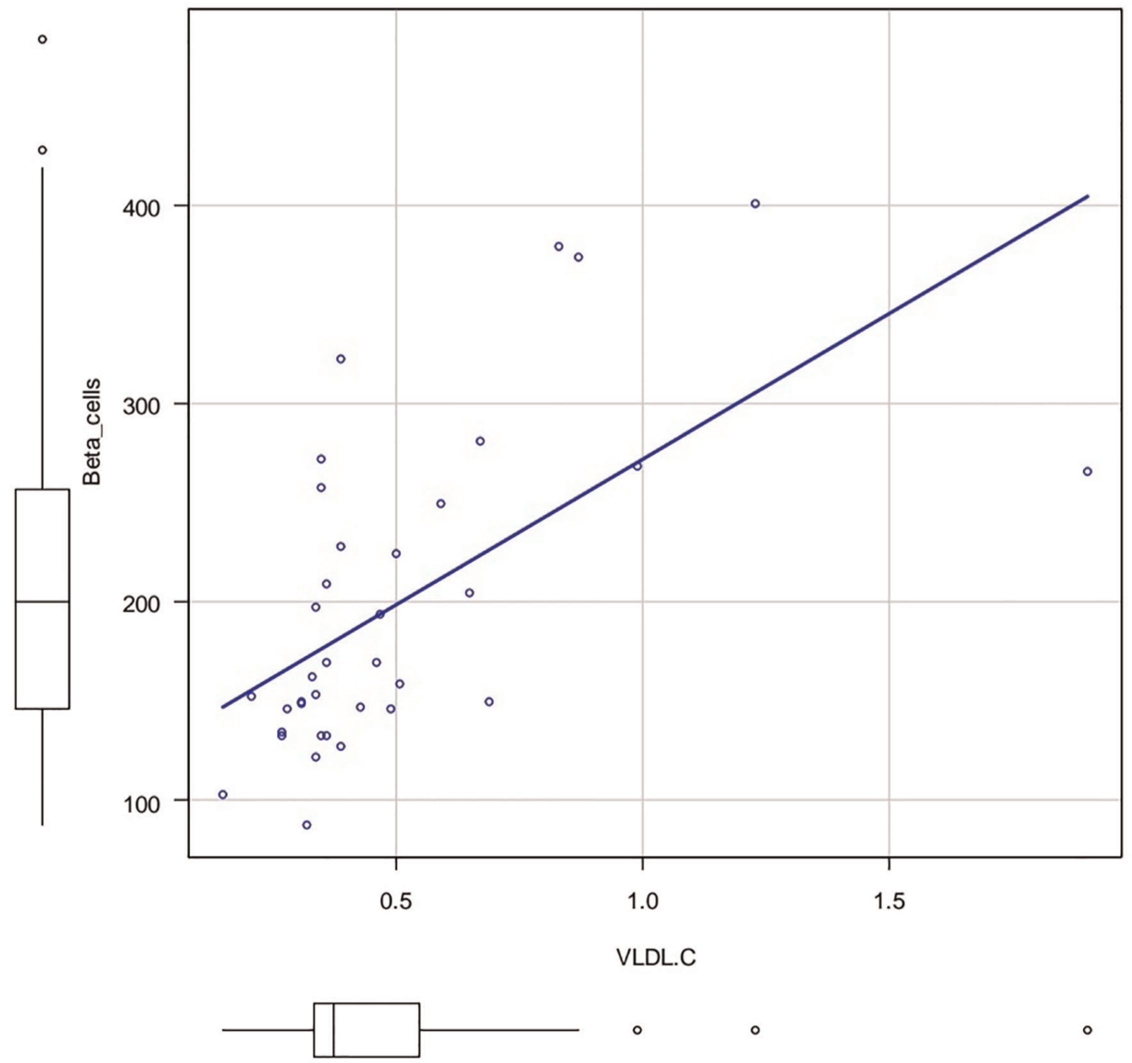

FIGURE 4
Correlation field in coordinates: VLDL-C (X axis) and %B (Y axis). Spearman's rank correlation coefficient 0.641 p.value = 0.0000257.

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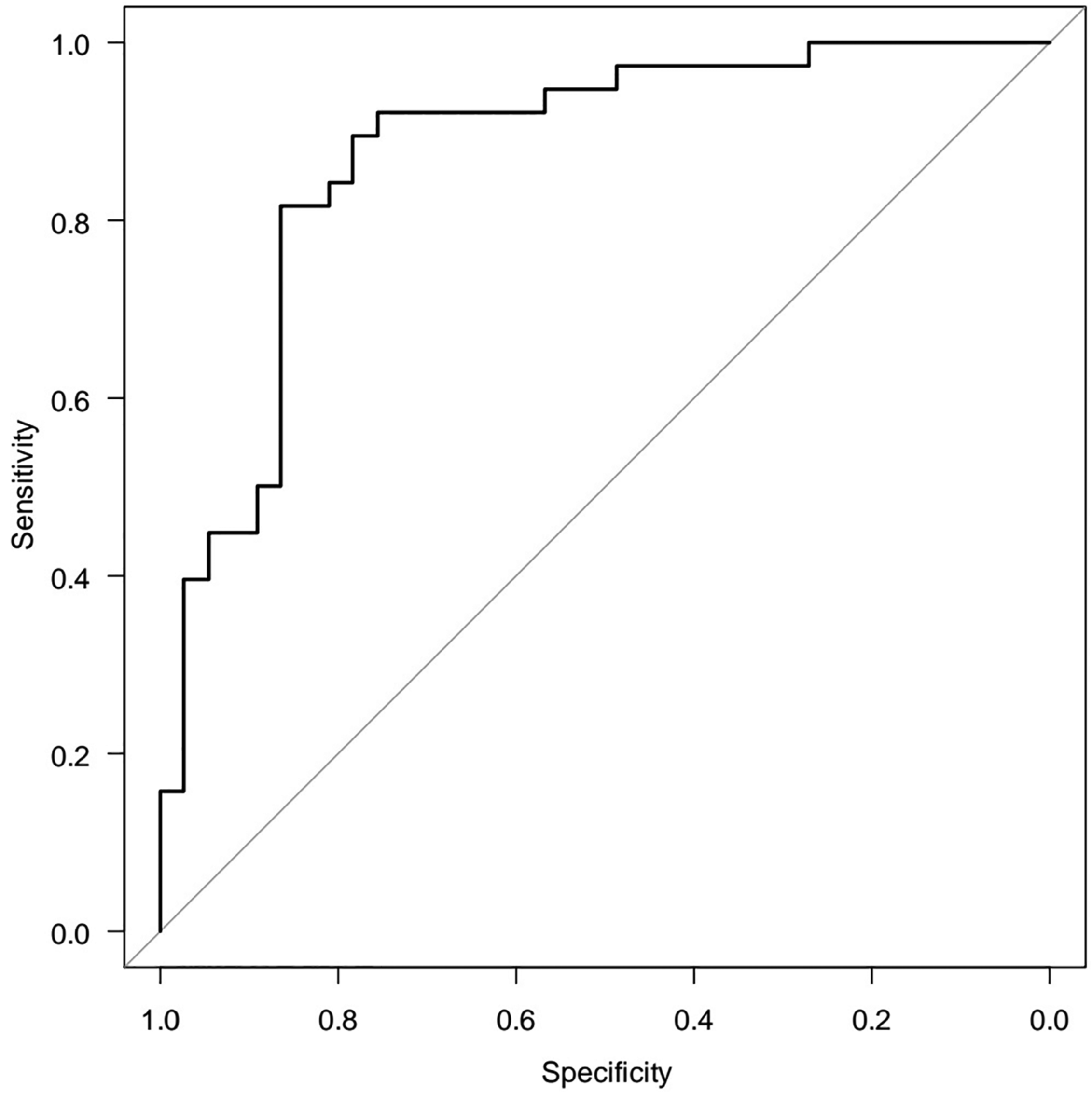

FIGURE 5
ROC-curve two-factor logistic regression model (AUC = 0.876 95% CI 0.794–0.957).

HOMA-2 IR there are no stabilized reference values, we suggested HOMA-2 IR ≤2.26 as the normal range and >2.26 as high. The relationship between normal and high ranges HOMA-2 IR (Y) with age (X_1) and beta cell function (X_2) was analysed. A two-factor model revealed a relationship between HOMA-2 IR and beta cell function [OR = 1.020 (95% CI 1.010–1.040) $p = 0.0000588$] and age [OR = 0.663 (95%CI 0.463–0.951) $p = 0.256$]. The area under the ROC (receiver operating characteristics) curve, AUC = 0.876 (95%CI 0.794–0.957), is significantly ($p < 0.05$) greater than 0.5, indicating the adequacy of the constructed model. The quality of the model was assessed as "very good" (**Figure 5**).

A five-factor model reveals the dependence of HOMA-2 IR (Y) on age (X_1) and metabolic syndrome criteria (X_2, X_3, X_4) the area under the ROC curve AUC = 0.836 (95% CI 0.717–0.956) is significantly ($p < 0.05$) greater than 0.5. To select a minimum set of factor features associated with objective variable, the method of step-by-step rejection/inclusion of explanatory variables (stepwise) was certified. Triglyceride level ≥1.7 mmol/L was statistically associated with the risk of high HOMA-2 IR [OR = 5.730 (95%CI 1.280–25.60) $p = 0.0223$] (**Figure 6**).

According parameters: HOMA-1 IR, HOMA-2 IR, %B and %S a dendrogram was constructed using Ward's hierarchical method, which clearly showed four clusters (**Figure 7**). We

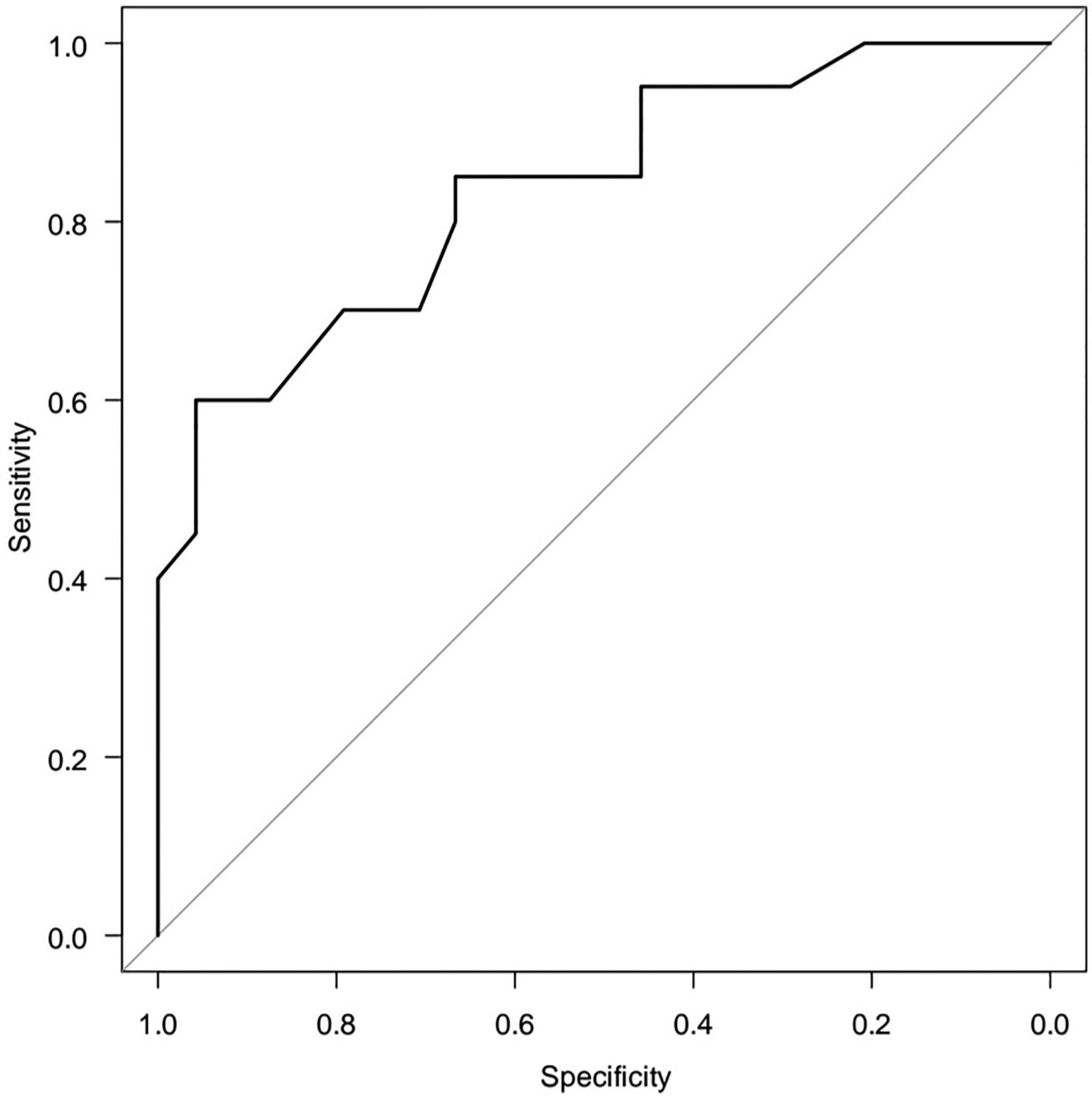

FIGURE 6
ROC-curve five-factor logistic regression model (AUC = 0.836 95% CI 0.717–0.956).

classified the resulting subgroups so that cluster 1 had the worst values of the studied parameters and cluster 4 had the best values (**Table 1**). By substituting anthropometric and lipid metabolic values into subgroups, a multiple comparison was made between the 4 samples. The *Kruskal-Wallis* one-way *analysis-of-variance-by-ranks* H-test of BMI ($H = 4.1$, $p = 0.248$) and WC ($H = 3.9$, $p = 0.272$) non-significant difference were obtained. It was found, that HOMA-1 IR was much higher in cluster 1 (6.32 ± 0.66) than in cluster 4 (2.19 ± 0.13). HOMA-2 IR was also much higher in cluster 1 (3.80 ± 0.34) than in cluster 4 (1.31 ± 0.06). By analysis of variance using Scheffe's multiple comparison method, a statistically significant difference was obtained between the laboratory parameters among the subgroups: HOMA-1 IR ($p < 0.001$), glucose ($p < 0.001$), insulin ($p < 0.001$), HOMA-2 IR ($p < 0.001$), %B ($p < 0.001$), %S ($p < 0.001$), TG ($p = 0.005$) and VLDL-C ($p = 0.002$). No statistically significant difference was found between other parameters of lipid metabolism: TC ($p = 0.292$), HDL-C ($p = 0.213$), LDL-C ($p = 0.441$), AC ($p = 0.187$) (**Table 1**).

Discussion

In our study, there was a predominance of boys over girls, which confirms the results of a meta-analysis, where according to the IDF criteria MetS was more prevalent in males (3.46%; 95% CI 2.69, 4.23, I2 = 97.6%) than females (2.99%; 95% CI 2.34, 3.65, I2 = 95.6%) (2). The median of HOMA-1 IR was

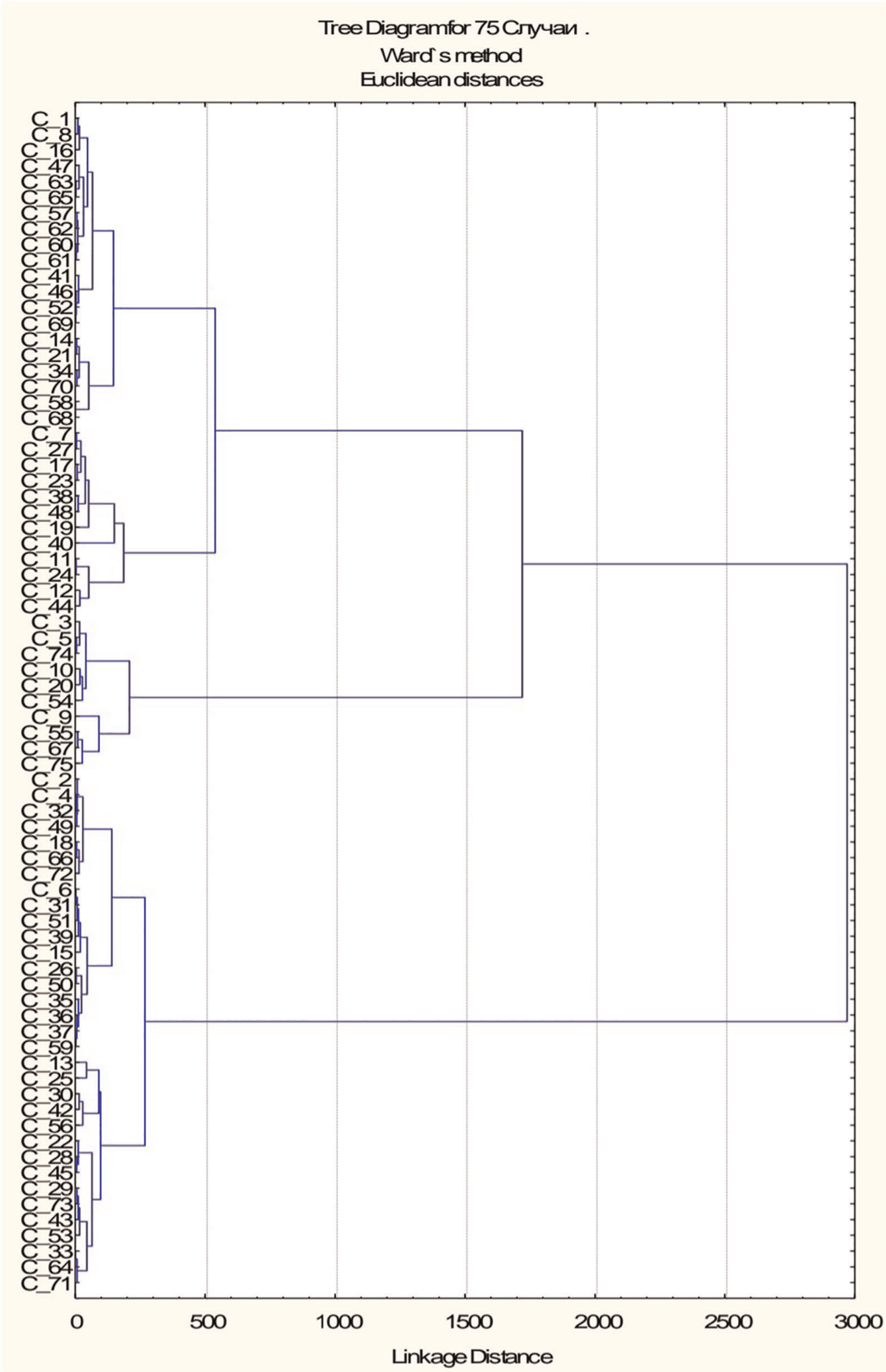

FIGURE 7
Ward's hierarchical dendrogram.

TABLE 1 Characteristics of the studied patients by subgroups (clusters).

	Cluster 1 $n = 20$	Cluster 2 $n = 22$	Cluster 3 $n = 18$	Cluster 4 $n = 15$	[a]p
Variables	Me ± m (Q1;Q3)	Me ± m (Q1;Q3)	Me ± m (Q1;Q3)	Me ± m (Q1;Q3)	
Age (y)	14 ± 0.36 (13;15)	15 ± 0.49 (14;16)	15 ± 0.52 (14;16)	15 ± 0.70 (11;15)	$p = 0.086$
BMI (kg/m²)	30.01 ± 1.25 (27.73;33.96)	27.89 ± 0.83 (26.56;30.82)	29.07 ± 1.07 (27.38;32.61)	27.45 ± 1.18 (24.68;30.56)	$p = 0.248$
WC (cm)	94 ± 2.36 (86;100)	90 ± 1.78 (88;92)	93.5 ± 2.03 (89;96)	90 ± 2.03 (86;92)	$p = 0.272$
	Mean ± SD (Min ÷ Max)	**Mean ± SD (Min ÷ Max)**	**Mean ± SD (Min ÷ Max)**	**Mean ± SD (Min ÷ Max)**	[b]p
HOMA-1 IR	6.32 ± 0.66 (2.98 ÷ 9.06)	5.23 ± 0.38 (1.55 ÷ 12.7)	3.57 ± 0.22 (2.28 ÷ 5.67)	2.19 ± 0.13 (1.26 ÷ 3.15)	$p < 0.001$
Glucose (mmol/L)	4.28 ± 0.11 (4.19 ÷ 5.75)	4.89 ± 0.09 (3.28 ÷ 5.25)	5.15 ± 0.11 (4.4 ÷ 6.09)	4.78 ± 0.11 (3.88 ÷ 5.48)	$p < 0.001$
Insulin (mIU/mL)	32.24 ± 2.97 (15.6 ÷ 36.8)	23.75 ± 1.30 (10.62 ÷ 60.8)	15.76 ± 0.56 (12.4 ÷ 21.3)	10.27 ± 0.46 (6.62 ÷ 13.3)	$p < 0.001$
HOMA-2 IR	3.80 ± 0.34 (1.92 ± 4.65)	2.98 ± 0.17 (1.21 ± 6.71)	2.03 ± 0.08 (1.54 ± 2.82)	1.31 ± 0.06 (0.83 ± 1.74)	$p < 0.001$
%B	329 ± 14.38 (178.9 ± 235.6)	212.1 ± 3.77 (249.6 ± 483.1)	146.6 ± 3.38 (121.3 ± 169.7)	127.6 ± 4.99 (87.5 ± 159)	$p < 0.001$
%S	32.49 ± 3.76 (21.5 ± 52)	35.64 ± 1.99 (14.9 ± 82.5)	50.39 ± 1.87 (35.5 ± 64.8)	78.99 ± 4.32 (57.5 ± 121.1)	$p < 0.001$
TC (mmol/L)	3.97 ± 0.18 (2.83 ± 5.36)	3.73 ± 0.28 (3.06 ± 4.91)	3.62 ± 0.23 (2.42 ± 4.9)	4.29 ± 0.37 (2.1 ± 5.93)	$p = 0.292$
TG (mmol/L)	2.24 ± 0.39 (0.78 ± 3.5)	1.52 ± 0.29 (0.76 ± 6.16)	1.05 ± 0.14 (0.58 ± 1.95)	0.85 ± 0.09 (0.32 ± 1.21)	$p = 0.005$
HDL-C (mmol/L)	1.03 ± 0.04 (0.7 ± 1.66)	1.16 ± 0.09 (0.77 ± 1.33)	1.18 ± 0.08 (0.8 ± 1.9)	1.26 ± 0.09 (0.77 ± 1.77)	$p = 0.213$
LDL-C (mmol/L)	2.67 ± 0.16 (1.7 ± 3.96)	2.29 ± 0.26 (2.02 ± 3.71)	2.42 ± 0.21 (1.42 ± 3.72)	2.66 ± 0.32 (0.58 ± 4.1)	$p = 0.441$
VLDL-C (mmol/L)	0.82 ± 0.15 (0.34 ± 0.65)	0.45 ± 0.05 (0.35 ± 1.9)	0.37 ± 0.04 (0.27 ± 0.69)	0.34 ± 0.04 (0.15 ± 0.51)	$p = 0.002$
AC (IU)	3.09 ± 0.31 (1.45 ± 3.6)	2.26 ± 0.32 (1.62 ± 5.1)	2.31 ± 0.35 (1.24 ± 4.99)	2.15 ± 0.37 (0.35 ± 3.71)	$p = 0.187$

[a]Kruskal-Wallis rank one-way analysis on ranks with multiple comparisons for 4 samples (clusters)
[b]Analysis of variance. Scheffe's method of multiple comparisons for 4 samples (clusters)

significantly higher than HOMA-2 IR, so by determining only the HOMA-1 IR we may lose some patients, on the other hand determining insulin resistance with HOMA-2 IR may be a more sensitive method and represent data from the current population. However, further studies of the MetS with a control group of healthy children are necessary. In a recent study, it was shown that HOMA-2 IR is more predictive than HOMA-1 IR for the progression to diabetes in pre-diabetes group, but there was no statistically significant difference in the non-diabetic group (16). An interesting phenomenon was that although males are more likely to suffer from MetS than females, they were found to have a higher insulin sensitivity. Further research is needed on gender differences in beta cell activity and insulin sensitivity in a larger sample of patients. Since there are no national reference values for HOMA-2 IR, we proposed level >2.26 to be the cut-off value for children and adolescents with MetS. However, the creation of national HOMA-2 IR percentile tables based on the age of child is important. It maybe emphasize that HOMA-2 IR was find to be even more sensitive for gender diferences than HOMA-1 IR. It was also also showen that TG level ≥1.7 mmol/L as one of the criteria of MetS was statistically associated with the risk of HOMA-2 IR >2.26. We found the correlations between HOMA-1 IR, HOMA-2 IR, %B and %S with TG and VLDL-C and a significant negative correlation between %B and HDL-C in childrens and adolescents with MetS. Similar results have been shown previously demonstrated by Shuang Zheng et al., in adults without diabetes (17). Surprisingly, by constructing a logistic model of regression, we found that the risk of high HOMA-2 IR decreases with age. This phenomenon requires further research.

Clustering of MetS in children and adults based on HOMA-1 IR, HOMA-2 IR, %B and %S on the basis of one pathological mechanism – insulin resistance, we conducted for the first time. Thus, we identified four subgroups at risk for the development of Mets complications. We recommend paying special attention to the first two subgroups, because they have poorer values not only of key indicators, but also to lipid metabolism. The first and the second clusters have the highest level of %B and the lowest level of %S. An abnormality in beta cell activity and loss of tissue sensitivity to insulin with decreased activity in peripheral tissues (mainly such as muscle, adipose and liver tissue) caused a number of metabolic and related diseases (18). A number of studies have shown that insulin resistance has been associated with a risk of developing asthma due to decrease glucose utilization and induction of abnormal fat metabolism in the skeletal muscles of respiratory system (19). A high prevalence of asthma was also found in children with high serum TG level (20). The elevated insulin can lead to increased androgen production, which can impair insulin sensitivity and lead to the metabolic imbalance that characterizes polycystic ovarian syndrome (PCOS) (21). Also, insulin resistance was associated with severity of obstructive sleep apnea (22). Based on data from earlier studies, it may be assumed that children in first two subgroups are more likely to have a high risk of developing comorbidities related to metabolic syndrome such as bronchial asthma, polycystic ovarian syndrome, behavioral disorders, obstructive sleep apnea and non-alcoholic fatty liver disease (23). So, the screening for these conditions should be recommended. All children of all subgroups we recommend to do HOMA-1 IR and HOMA-2 IR test with assessing β-cell function every 6 months.

Conclusion

1. Median HOMA-1 IR was significantly higher than median HOMA-2 IR and that's why determinations insulin resistance only by HOMA-1 IR can ignore most patients.
2. We proposed HOMA-2 IR level >2.26 to be the cut-off value for children and adolescents with MetS.
3. Males had lower HOMA-2 IR and higher insulin sensitivity compared with females. No gender differences were found when comparing the HOMA-1 IR.
4. HOMA-1 IR, HOMA-2 IR, %B and %S were correlated with lipid metabolism parameters: TG and VLDL-C and negative correlated between %B and HDL-C in children and adolescents with MetS. The risk of getting a high TG result in the blood analysis in children with MetS was significantly associated with the HOMA-2 IR >2.26
5. Identification of four subgroups at risk of MetS complications in children and adolescentsis an effective tool in predicting the development of MetS in children and adolescents from mild to more severe and will help pediatricians to individualize their approach to the treatment of MetS.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author/s.

Ethics statement

The studies involving human participants were reviewed and approved by Commission on Bioethical Expertise and Research Ethics at the Bogomolets National Medical University. Written informed consent to participate in this study was provided by the participant's legal guardian/next of kin.

Author contributions

MHA: collected and analyzed the data, wrote the article; GVG: analyzed the data; AVC: helped design the study and revise article; IOM: conducted a critical revision of the manuscript. All authors have read and approved the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Optimal BMI cutoff points in obesity screening for Chinese college students

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Objective: An accurate BMI classification system specific to the population is of great value in health promotion. Existing studies have shown that the BMI recommended cut-off value for adults is not suitable for college students. Thus, the current study aims to identify optimal BMI cutoff points in obesity screening for Chinese college students.

Methods: Anthropometric assessments were performed on 6,798 college students (Male=3,408, Female=3,390) from three universities in Jiangsu, China. Exploratory factor analysis (EFA) was conducted to establish the standardized models to estimate anthropometry for male and female students. Further indices were derived from the assessments, including body mass index (BMI), relative fat mass (RFM), obesity degree percentage (OBD%), waist-to-hip ratio (WHR), waist circumference (WC), and body fat percentage (BF%). The anthropometric index with the highest correlation to the models for male and female students were selected as the gold standard for obesity screening. Receiver operating characteristic (ROC) curve was applied to evaluate diagnostic value of each anthropometric index according to the area under curve (AUC). Youden index maximum points determined the optimal cutoff points with the highest accuracy in obesity screening.

Results: The anthropometric models for both male and female students consisted of three factors. Vervaeck index was selected as the gold standard for obesity screening. By comparing AUC of the anthropometric indices, we found BMI provided the highest value in obesity screening. Further analysis based on Youden index identified the optimal BMI of 23.53kg/m^2 for male and 23.41kg/m^2 for female. Compared with the universal standard recommended by World Health Organization (WHO), the adjusted BMI criteria were characterized by high sensitivity as well as specificity.

Conclusion: BMI is the most appropriate anthropometric index of obesity screening for Chinese college students. The optimal cutoff points were lower than the WHO reference. Evidence substantiated the adjusted BMI criteria as an effective approach to improve accuracy of obesity screening for this population.

KEYWORDS

college students, BMI cutoff points, ROC curve, obesity, China

Introduction

Obesity is ranked as the fifth leading cause of death globally, which has raised serious public health concerns (Safaei et al., 2021). Researchers estimated that, by 2025, global obesity prevalence would exceed 18% in men and 21% in women, of which 6% in men and 9% in women would be categorized as severe obesity (Collaboration, 2016). Obesity significantly increases risks of morbidity and mortality associated with cardiovascular disease (Khan et al., 2018), sleep disorder breathing (Peppard et al., 2000), diabetes, cancers (Bhaskaran et al., 2014; Hu et al., 2020), and musculoskeletal disorder (Jiang et al., 2011). Evidence has shown the close connection between quality of life and body weight management. Improved quality of life is evident after weight loss interventions in different age groups (Payne et al., 2018; Diao et al., 2020). Body mass index (BMI) is the most widely used measure to diagnose obesity and provide guidelines for weight loss and control in clinical practice (Seidell et al., 2001; Romero-Corral et al., 2008). World Health Organization (WHO) has defined the cutoff points of overweight and obesity for Asian populations as 23 and 25 kg/m^2, respectively (Barba et al., 2004). To increase accuracy and generalizability of BMI classifications, an increasing number of research has examined obesity cutoff points for different populations (Rahman and Berenson, 2010; Hunma et al., 2016; Chen et al., 2018).

The collegiate period has been considered a critical time to develop lifelong healthy behaviors such as physically active lifestyle and healthy dietary patterns (Karabulut et al., 2018; Niedermeier et al., 2018; Saghafi-Asl et al., 2020). Accurate BMI classifications for college students are of great value in not only anthropometric assessment but also influence on the young generation's behaviors in future. A recent study in Chinese college students reported that 23.5% in male and 11.9% in female were classified as either overweight or obese (Chen et al., 2020), indicating immediate attention to address the prevalent issue. The number of college students in China has been growing in the past decades and reached 44.3 million in 2022 (Ministry of Education of the People's Republic of China, 2021). An accurate BMI standard which is specific to college students in China can make significant contributions to public health in consideration of the large population size. BMI is characterized by a number of practical advantages such as simplicity, low cost, and noninvasive measure, which make BMI an efficient screening tool for such a population size in China. However, a major concern has been noticed with respect to the precision of applying the current WHO standard to specific populations (Romero-Corral et al., 2008). Considering potential limitations of a universal BMI standard, researchers have been investigating population and ethnicity specific BMI criteria over the past decade (Hunma et al., 2016; Karabulut et al., 2018; Itani et al., 2020). The research that improves accuracy of BMI based obesity screening for Chinese college students is warranted.

The current study aims to develop an evidence-based obesity screening tool for Chinese college students. Stringent procedures were conducted to ensure robustness of the research findings. Based on a set of anthropometric measures, exploratory factor analysis (EFA) was used to establish a standardized model (z-score model) for the college students' physique. Further analysis identified the gold standard in terms of the standardized model. The anthropometric index with the highest correlation to the z-score model was the gold standard. It is worth pointing out that the current study does not assume BMI the most appropriate measure in obesity screening. In fact, the area under the receiver operating characteristic (ROC) curve was used to identify the screening tool from available anthropometric measures. The anthropometric index with the largest area under curve (AUC) would be selected for obesity screening. Optimal cutoff points of the selected anthropometric index were calculated by the Youden index. Additionally, agreement measures of the cutoff points were assessed by Kappa index. By following the aforementioned procedures, the current study identifies the anthropometric index for obesity screening, and then determines the cutoff points of obesity.

Materials and methods

Participants

The current study was approved and supported by Jiangsu Physical Fitness and Health Promotion Center. The center is an official institution which administers annual fitness examination and evaluation for students in Jiangsu, China. Participants were recruited from three randomly selected universities in the province. Eligible participants must meet the following criteria: (i) undergraduate students aged between 18 and 22 years old, (ii) no chronic disease or functional impairment, and (iii) no mental health issues. Information on research purpose and procedures was acknowledged prior to the study. All participants provided written informed consent and voluntarily completed all the required tests. A total of 6,798 college students (Male = 3,408; Female = 3,390) agreed to participate in the study.

Anthropometric measures

Height and weight were measured by a calibrated electronic scale with the precision of 0.1 cm and 0.1 kg (HM1000-SZ, HeMei Tech Corp., China). Participants were light clothing with shoes off. Participants stood in an anatomical position in the measure of standing height. Sitting height was measured as the height from the seat of the chair in which a participant was sitting to the top of the head. Participants were asked to keep the back of the head, shoulder blades and buttocks in touch with the vertical board. The thighs of the participants were touching closely together on the sitting board, forming a right angle with the trunk (Zhang and Li, 2015).

Chest, waist, and hip circumferences were measured by a nonelastic tape with a precision of 0.1 cm. For chest

TABLE 1 Anthropometric measures of participants.

Measures	Male (N = 3,408)	Female (N = 3,390)
	$x \pm s$	$x \pm s$
Height (cm)	173.28 ± 5.51	160.99 ± 5.05
Weight (kg)	65.20 ± 9.90	52.74 ± 6.69
Sitting height (cm)	92.14 ± 3.46	86.42 ± 3.18
Chest circumference (cm)	86.61 ± 6.83	81.40 ± 5.73
Waist circumference (cm)	76.15 ± 8.54	69.29 ± 6.46
Hip circumference (cm)	92.68 ± 6.57	89.813 ± 5.12
Triceps skinfold (mm)	13.04 ± 6.38	17.07 ± 4.40
Subscapular skinfold (mm)	15.05 ± 6.74	16.13 ± 4.65
Abdominal skinfold (mm)	17.90 ± 9.19	19.80 ± 5.84

circumference (CC), the tape was placed at the level of the fourth rib and set snug around the body (Trüb et al., 2020). Waist circumference (WC) was measured at the midpoint between the lower edge of the rib cage and the iliac crest after a full expiration (Shrestha et al., 2021). Hip circumference (HC) was measured at the maximum protuberance of the buttocks (Skrypnik et al., 2015). Skinfold thickness was measured by a caliper in 0.1 cm. Triceps, subscapular, and abdominal site were selected for skinfold measurement. Trained research assistants measured circumferences and skinfold thickness twice for each site, with the average used for data analysis. Anthropometric measures of the participants were summarized in Table 1.

Anthropometric indices

Six indices were derived from the anthropometric measures to provide further insights into the physique of college students. BMI was calculated based on body weight (BW) in kilograms (kg) and height in meters (m). The WHO recommended cutoff point for obesity is above 28 kg/m^2 (Barba et al., 2004). BMI calculation was presented as Equation 1.

$$\text{BMI} = \text{BW} / \text{Height}^2 \tag{1}$$

Relative fat mass (RFM) has been proved a valid estimator of whole-body fat percentage. Based on the measurements of height and WC in meters, the cutoff points of obesity for male and female are 22.8 and 33.9, respectively (Woolcott and Bergman, 2018). RFM for male and female was calculated as follows (Equations 2-1, 2-2):

$$\text{RFM for male} = 64 - 20 \times \text{Height} / \text{WC} \tag{2-1}$$

$$\text{RFM for female} = 76 - 20 \times \text{Height} / \text{WC} \tag{2-2}$$

Obesity degree (OBD) was a commonly used method for obesity screening among Chinese adults. This index is a percentage based on the calculation of BW in kg and height in cm. Individuals with OBD% above 20% are classified as obesity (Zhang et al., 2017). Calculation of OBD% was presented as Equations 3-1, 3-2.

$$\text{Standardized BW} = (\text{Height} - 100) \times 0.9 \tag{3-1}$$

$$\text{OBD\%} = (\text{BW} - \text{Standardized BW}) / \text{Standardized BW} \times 100\% \tag{3-2}$$

Waist to hip ratio (WHR) was calculated by WC and HC in cm (Equation 4). Males with the WHR above 0.90 and females with the ratio above 0.85 were considered obese (Liu et al., 2018).

$$\text{WHR} = \text{WC} / \text{HC} \tag{4}$$

Calculations of body fat percentage (BF%) consisted of a series of steps involving body density (BD) and skinfold (SF). SF was the sum of triceps and subscapular thickness in millimeters (Equation 5-1), which led to BD for male (Equation 5-2) and female (Equation 5-3). Based on BD for individuals, BF% was calculated by Equation 5-4. The cutoff points of obesity for both male and female were set at 25 and 30%, respectively (Barba et al., 2004).

$$\text{SF} = \text{Triceps thickness} + \text{Subscalpular thickness} \tag{5-1}$$

$$\text{BD male} = 1.0913 - 0.00116\text{SF} \tag{5-2}$$

$$\text{BD female} = 1.0897 - 0.00133\text{SF} \tag{5-3}$$

$$\text{BF\%} = (4.570 / \text{BD} - 4.142) \times 100 \tag{5-4}$$

Vervaeck index was calculated based on BW in kg, CC in cm, and height in cm (Equation 6). The index remains stable in adulthood, which makes it suitable for obesity screening among college students. The value above 94.3 was defined as obesity for Chinese (Shang et al., 2007).

$$\text{Vervaeck index} = (\text{BW} + \text{CC}) / \text{Height} \times 100 \tag{6}$$

Statistical analysis

EFA was used to extract key factors of the standardized anthropometric model (z-score model) for college students. Varimax orthogonal rotation was conducted to examine model fit

TABLE 2 Rotated factor loading of the anthropometric measures.

Measures	Male			Female		
	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
Height (cm)	0.202	−0.050	**0.866**	0.223	−0.121	**0.867**
Weight (kg)	**0.830**	0.301	0.299	**0.786**	0.272	0.347
Sitting height (cm)	0.056	0.018	**0.905**	0.049	0.102	**0.903**
Chest circumference (cm)	**0.865**	0.292	0.085	**0.864**	0.237	0.073
Waist circumference (cm)	**0.823**	0.449	0.014	**0.869**	0.192	−0.034
Hip circumference (cm)	**0.805**	0.328	0.151	**0.816**	0.213	0.234
Triceps skinfold (mm)	0.315	**0.854**	−0.025	0.193	**0.817**	0.013
Subscapular skinfold (mm)	0.345	**0.860**	−0.006	0.435	**0.733**	−0.051
Abdominal skinfold (mm)	0.354	**0.854**	0.001	0.159	**0.863**	0.035

The bold numbers highlight the anthropometric measures in accordance with one of the factors of the standardized model for male and female students.

TABLE 3 Correlation coefficients of anthropometric indices to the *z*-score model.

Indices	Correlation to *z*-score model	
	Male	Female
Vervaeck index	0.847**	0.817**
OBD%	0.761**	0.643**
RFM	0.771**	0.602**
WHR	0.544**	0.333**
WC	0.887**	0.767**
BMI	0.798**	0.740**
BF%	0.815**	0.713**

**$p < 0.001$; OBD%, obesity degree percentage; RFM, relative fat mass; WHR, waist-to-hip ratio; WC, waist circumference; BMI, body mass index; BF%, body fat percentage.

and calculate factor loadings. The factors were identified based on eigenvalues, factor loadings, and the interpretability of the extracted factors. The gold standard for obesity screening was selected from the anthropometric indices with the highest correlation to the standardized model. The ROC curve was drawn by MedCalc 18.2. Area under curve (AUC) reflects the diagnostic value, with 0.5<AUC ≤ 0.7 for low diagnostic value, 0.7<AUC ≤ 0.9 for medium diagnostic value, and AUC>0.9 for high diagnostic value (Dou et al., 2016). The anthropometric index with the highest diagnostic value would be chosen as the tool for obesity screening. Youden index maximum points helped to identify the optimal cutoff points for obesity screening. Kappa index was used as agreement measures to testify and improve accuracy of the cutoff points in screening obesity. The significance level was set at the value of p of 0.05. All statistical analyses were conducted by SPSS 25.

Results

EFA identified three primary factors of the anthropometric model for both male and female college students. The three factors accounted for 83.61 and 78.09% of the variance in the anthropometric data for male and female, respectively. Factor 1 (z_1) consisted of BW, CC, WC, and HC. Factor 2 (z_2) identified three skinfold measures of triceps, subscapular, and abdominal thickness. Factor 3 (z_3) included two measures of height which were standing height and sitting height. Factor loadings of the extracted anthropometric measures were above 0.7. The standardized (z-score) models for male and female students were presented as Equations 7-1, 7-2, respectively. Table 2 indicated factor loadings of the anthropometric measures for male and female students.

$$Z_{male} = 41.857\% z_1 + 35.682\% z_2 + 22.461\% z_3 \quad (7\text{-}1)$$

$$Z_{female} = 43.958\% z_1 + 31.096\% z_2 + 24.947\% z_3 \quad (7\text{-}2)$$

Vervaeck index was chosen as the gold standard because of the highest correlation to the z-score model. The coefficients for male and female were $r = 0.847$ and $r = 0.817$, respectively. Table 3 summarized the correlation coefficients of anthropometric indices to the z-score models.

ROC curves display the accuracy of BMI, OBD%, RFM, WC, BF%, and WHR in obesity screening for male and female students (Figure 1). With Vervaeck index as the gold standard, the mean AUC of BMI was greater than that of other factors for both male (AUC = 0.986, 95% CI: 0.981–0.990) and female students (AUC = 0.983, 95% CI: 0.979–0.988), suggesting the best accuracy of using BMI to diagnose obesity for the college students. The mean AUC of each anthropometric index was listed in Table 4.

The optimal cutoff points of BMI for obesity screening were determined by the maximum point of Youden index. The BMI cutoff point for male students is 23.53 kg/m^2 in corresponding to the Youden index of 0.877. Compared with the WHO reference of 28 kg/m^2, the optimal cutoff point shows prominent improvement in sensitivity from 19.91 to 93.77% and decline in specificity from 99.96 to 93.93% (Table 5). The Youden index for female students is 0.8726 in corresponding to the optimal BMI cutoff point of

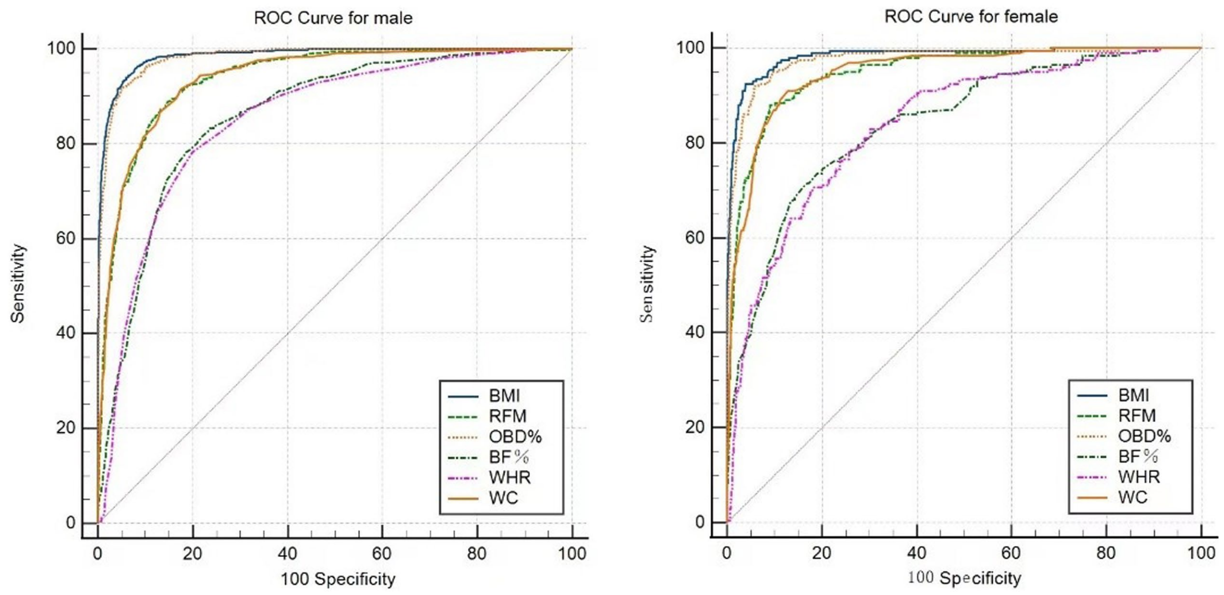

FIGURE 1
ROC curves for male (left) and female (right).

TABLE 4 AUC by the anthropometric indices.

Indices	Male	Female
BMI	0.986 (0.981–0.990)	0.983 (0.979–0.988)
RFM	0.939 (0.931–0.947)	0.949 (0.941–0.956)
OBD%	0.983 (0.978–0.987)	0.977 (0.971–0.981)
WHR	0.853 (0.840–0.864)	0.838 (0.825–0.850)
WC	0.939 (0.931–0.947)	0.949 (0.941–0.956)
BF%	0.859 (0.847–0.871)	0.844 (0.832–0.856)

OBD%, obesity degree percentage; RFM, relative fat mass; WHR, waist-to-hip ratio; WC, waist circumference; BMI, body mass index; BF%, body fat percentage.

23.41 kg/m^2. Compared with the WHO reference, the adjusted value shows an increased sensitivity from 14.63 to 91.22% and a drop in specificity from 100 to 96.04%. The optimal BMI cutoff points indicate a remarkable improvement in the sensitivity associated with a high level of specificity for both male and female college students (Table 5).

Adjusted BMI cutoff points largely increased agreement to the gold standard (Vervaeck index) for obesity screening, which was evident by significant improvement in Kappa index for male (Original cutoff point = 0.289, adjusted cutoff point = 0.817) and female students (Original cutoff point = 0.251, adjusted cutoff point = 0.697). Statistics of Kappa index associated with the adjusted BMI cutoff points were listed in Table 6.

The adjusted BMI cutoff points classified higher proportion of college students into obesity than the WHO reference. According to the new BMI cutoff points, 23.00% of male and 9.29% of female students were identified as obesity, while the original criteria (BMI ≥ 28 kg/m^2) only accounted for 3.93 and 0.91% of male and female students, respectively (Table 7). The results suggest that the adjusted BMI be more powerful in obesity screening and effectively lower the risk of false classifications.

Discussion

The current study explored the optimal BMI cutoff points for obesity screening among Chinese college students. Compared with the WHO standard for general population (BMI ≥ 28 kg/m^2), the cutoff points for Chinese male (BMI ≥ 23.53 kg/m^2) and female college students (BMI ≥ 23.41 kg/m^2) were lower. The reduced BMI cutoff points were characterized by high sensitivity and specificity as well as good consistency with the gold standard based on Vervaeck index, which substantiated the new criteria in obesity screening. According to the adjusted BMI standard, an increased number of students were classified as obesity.

The evidence indicated that the original cutoff point may be too high to accurately reflect obesity prevalence among college students in China. Indeed, prominent differences across populations implied the necessity of developing population-specific criteria for obesity screening (Deurenberg, 2001). The use of BMI cutoff points for classifying obesity should account for ethnicity given that a universal BMI standard may be not appropriate in clinical practice (Norgan, 1994). Cumulative evidence suggests that, compared with the WHO reference, lower BMI values should be applied particularly in Asians (Mascie-Taylor and Goto, 2007). Nguyen and colleagues provided evidence for lower BMI cutoff point in Chinese adults than that in Western populations (Nguyen et al., 2008). Such a conclusion was substantiated by the research in which Taiwan Chinese were characterized by lower BMI associated with higher BF% than

TABLE 5 Sensitivity and specificity of original and adjusted BMI cutoff points.

Sex	Original cutoff points (kg/m²)			Adjusted cutoff points (kg/m²)			
	Reference	Sensitivity (%)	Specificity (%)	Youden index	Adjustment	Sensitivity (%)	Specificity (%)
Male	≥28	19.91	99.96	0.877	≥23.53	93.77	93.93
Female	≥28	14.63	100.00	0.873	≥23.41	91.22	96.04

TABLE 6 Kappa statistics of original and adjusted BMI cutoff points.

		Kappa	SD	*t*	Value of *p*
Original BMI	Male	0.289	0.020	23.921	<0.001
	Female	0.251	0.037	22.047	<0.001
Adjusted BMI	Male	0.817	0.012	48.014	<0.001
	Female	0.697	0.024	41.684	<0.001

TABLE 7 Comparisons between original and adjusted BMI cutoffs in obesity screening.

		Obesity	Non-obesity	Obesity %
Original BMI	Male	134	3,274	3.93
	Female	31	3,359	0.91
Adjusted BMI	Male	784	2,624	23.00
	Female	315	3,075	9.29

Caucasians (Chang et al., 2003). Further analysis indicated that the BMI obesity cutoff point of 30 kg/m² for Caucasians was comparable to 25 kg/m² for Taiwan Chinese. Consistent evidence can be found in a study involving Hong Kong Chinese (Ko et al., 2001). Researchers identified a BMI of 26 kg/m² in corresponding to obesity defined by BF%.

Education is another important consideration in obesity classification. Research has shown that obesity is more prevalent among the low educated individuals compared with college graduates (Cohen et al., 2013). The lower BMI cutoff points identified in the current study can be justified by the inverse relationship between education level and obesity (Hermann et al., 2011; Boing and Subramanian, 2015). People with higher educational attainment may be better aware of the consequences of obesity and approaches to a healthy lifestyle through restricted diet and regular exercise (Eide and Showalter, 2011). In addition, social network also has substantial impact on health-related behaviors (Kim, 2016). The networks formed by individuals with higher educational attainment may provide financial, physical, and emotional support for health promotion (Berkman, 1995). It is reasonable to apply lower BMI classifications to obesity screening among college students compared with general populations.

In developed countries the rate of obesity in females is 1.5 to 2 times as many as that in males (Seidell, 2005). The current study also identified difference between male and female students, but the rate of obesity in male students (23.00%) is over twice as many as that in females students (9.29%). It is worth noting that preferences for physical appearance impose particular influences on females in Asian countries (Jackson et al., 2016). In China, more female college students are categorized as normal weight and underweight than male counterparts (Chen et al., 2020). An epidemic study in obesity prevalence in urban adults of Northeast China also identified higher obesity rate in males than that in females (Wang et al., 2012). It is worth pointing out potential sociocultural influence on body image among Chinese, as females reported greater body dissatisfaction than males. While males consider increasing muscle mass and weight essential to enhance body image, females show particular interests in body weight management (Xu et al., 2010). A recent study identified a quadratic relationship between female BMI and attractiveness ratings. Young females perceived a BMI of 22.00 ideal for body attractiveness, which was lower than the BMI preference (BMI = 25.75) in males (Han et al., 2021). The distinct perceptions on body image led to different body change behaviors between males and females in China, which could interpret the lower BMI and obesity prevalence among females.

The current study identified high sensitivity (93.77% for male and 91.22% for female) as well as specificity (93.93% for male and 96.04% for female) of the optimal BMI cutoff points in obesity screening for college students. However, the poor sensitivity has been considered a limitation of the BMI classifications in previous research. Sensitivity of the WHO reference (BMI ≥ 30 kg/m²) for older adults was only 14.5% for male and 23.4% for female, indicating poor efficacy of identifying obesity in this population (Batsis et al., 2016). In another research on Chinese children and adolescents, the sensitivity of BMI references for obesity varied between 12.8 and 47.3%, indicating limited accuracy of diagnosis (Chen et al., 2018). A meta-analysis provided robust evidence for accuracy of commonly used BMI values for obesity screening. The results reported a sensitivity of 50%, indicating that half of individuals with excess BF% failed to be identified based on the BMI classifications (Okorodudu et al., 2010). Therefore, increasing the sensitivity of BMI is needed to reduce the false negative rate in obesity screening (Fu et al., 2003).

The lower BMI cutoff points of the current study resulted in a higher sensitivity, which was substantiated by the previous research involving Saudi adult population. Compared with the BF%-defined obesity (83.9% in men and 97.3% in women), the BMI cutoff point of 30 kg/m^2 classified only 29% of men and 53% of women as obesity. The BMI sensitivity reached a comparable level to the BF% classification as the BMI cutoff points were reduced to 24 kg/m^2 (Alammar et al., 2020). It is reasonable to adopt a more stringent standard with lower BMI cutoff points for the concerns with the low BMI sensitivity in obesity screening (Javed et al., 2015). The current study proposed the BMI references with high sensitivity as well as specificity which may be attributed to age of the participants due to the strong correlation between age and body fatness (Gallagher et al., 1996). Other factors such as the gold standard for reference, prevalence of obesity, and populations can also impact specificity and sensitivity of BMI (Leeflang et al., 2013; Gába and Přidalová, 2016).

The current study has some specific contributions to the field of public health. Existing research on Chinese college students is limited, which demands practical and reliable approach to identify obesity prevalence for this population. Exercise intervention during an individual's college period is particularly important for obesity prevention in lifetime. The lower BMI cutoff points with high sensitivity for obesity screening would facilitate obesity prevention for college students in China. The new BMI cutoff points increased the number of college students who were not considered obese by the commonly used BMI reference. It is possible that a few students may be falsely categorized as obesity, but the benefits associated with the higher sensitivity would exceed potential costs in corresponding to the increased obesity prevalence. Compared with previous research which selected bioelectrical impedance analysis of body composition and dual-energy x-ray absorptiometry as the gold standard (Anderson et al., 2012), the current study chose Vervaeck index which was convenient to use in clinical practice. BMI-based assessment allows quick and non-invasive applications to a large population. Precise cutoff points specific to Chinese college students are crucial for obesity screening and prevention.

Conclusion

Compared with other anthropometric measures, BMI is the best approach of obesity screening for Chinese college students. The optimal cutoff points for both male and female students are lower than the WHO reference, leading to a higher proportion of obesity. Prominent increase in sensitivity was identified along with high level of specificity in the adjusted BMI, which substantiated applications of the new cutoff points to obesity screening. The current study provides health policy implications. On the one hand, the population-based cutoffs improve screening accuracy in clinical practice. In addition, the findings highlight the feasibility of implementing a stricter BMI standard for college students in China.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study involving human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was obtained from the participants.

Author contributions

ZW and QF: Conceptualization, methodology, and writing - original draft preparation. ZW and JL: Validation. JL, QT, and JW: Investigation. ZW, YS, JL, and JW: Resources. ZW and MW: Data curation. QF: Writing - review and editing. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The effects of football practice on children's fundamental movement skills: A systematic review and meta-analysis

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The purpose of this systematic review and meta-analysis was to explore the effects of different soccer practices on fundamental movement skills (FMS) of children of different ages and genders, in order to help children to improve their fundamental movement skills through soccer practice more effectively. The databases of CNKI, Wanfang database, Pubmed, Web of science and Cochrane library were searched to collect relevant studies on the effects of soccer practices on FMS, and the quality of the included studies was evaluated by using the Cochrane Risk of Bias Tool, and Meta-analysis was conducted by Review Manager 5.4 software. 16 studies were finally included, with a total of 3,121 subjects were included. The results showed that soccer had a positive effect on linear sprint ability [SMD 95% CI = −0.37 (−0.61, −0.14), $P = 0.002$], horizontal jump [SMD 95% CI = 0.22 (−0.34, 0.77), $P = 0.003$], object control [SMD 95% CI = 1.32 (0.8, 1.85), $P = 0.0003$], Closed-eye single-leg test [SMD 95% CI = 0.87(0.48,1.25), $P < 0.0001$],while countermovement jump [SMD 95% CI = 0.50(−0.35,1.35), $P = 0.25$] and flamingo balance [SMD 95% CI = −0.16(−0.31,−0.02), $P = 0.03$] had a less significant effect. Meanwhile, the effect of the practice was mainly influenced by the total duration of the intervention, age and gender of the intervention subjects, in which the total intervention time longer than 1,800 min promoted linear sprint ability, horizontal jump and flamingo balance test better than those below 1,800 min; the promotion effect of linear sprint ability and horizontal jump was better in children aged 7–9 years than 10–13 years, while Children aged 10–13 years showed better improvement in Closed-eye single-leg test after the intervention than 7–9 years; Girls were better promoted in linear sprint ability and Closed-eye single-leg test, but the horizontal jump is better for boys to improve the effect. It is recommended that the effects of different soccer practice contents on fundamental movement skills can be further explored in the future to improve the relevance and efficiency of fundamental movement skill development for children.

KEYWORDS
children, soccer, physical practice, fundamental movement skills, meta-analysis

Introduction

Fundamental movement skills (FMS) refers to the ability to coordinate the use of human basic movements (1), and is an important part of motor skills, consisting of locomotion, such as walking, running, jumping, sliding, etc.; object control, such as grasping, throwing, kicking, catching, etc; stability, such as rotation, turning, bending, etc (2), are considered to be the basic "building blocks" of advanced and complex motor sequences required for various sports, games, or physical activities (3). Childhood is an important stage of motor development, and the level of gross and fine motor movements at this stage has a significant impact on future motor development (4, 5), and failure to acquire FMS at the appropriate age may increase the risk of children experiencing long-term physical and mental health problems (6) However, at a time when physical inactivity and sedentariness in young children are global problems (7), increasing numbers of children have severely limited development of fundamental movement skills (8). The implementation of effective exercise interventions to improve children's FMS is necessary in this current situation, but current studies have focused on the effects of exercise interventions on children's physical fitness. Studies have shown that regular participation in physical activity is beneficial in improving physical fitness (9), and considering that FMS can indicate levels of physical fitness, therefore, there may be a correlation between FMS and physical activities (10, 11), so that soccer practice may be a viable way to develop FMS in children. Some studies have confirmed that soccer practices promote overall FMS in children, such as P. F. Nazario (12) in 2013, who confirmed the effect of soccer on children's locomotion such as linear sprint ability, sliding, horizontal jump, and object control such as catching, throwing, and kicking through a 25-week soccer practices, and Yangyang Guo (13) in 2020, who came to a similar conclusion through an 8-week soccer intervention. But there were some differences between the two studies in the effects of other parts of object control and locomotion. In addition, there are differences in the effects of soccer on children's balance (14–20), And the content of the practice and the characteristics of the subjects may be the reasons for the different results.

Previously, some reviews have been conducted for the relationship between physical activity and FMS (21–24), but the experimental subjects were mostly young children (21, 22) or young children and children and adolescents as a whole (23, 24), and fewer review have been conducted for children. It has been demonstrated that physical activity has a facilitative effect on FMS in young children aged 2–6 years (21, 22) and that moderate and high motor intensity physical exercises have a low and moderate relationship with some FMS subordinate skills (22). And another review (23) conducted a study on resistance exercise and FMS in children and adolescents aged 5–18 years and found that resistance training had a facilitative effect on FMS such as running, jumping and throwing. Specifically for soccer, some researchers (25) have conducted review for the effects of different training methods on the physical fitness of athletes, but no studies have been conducted for different soccer practices on different groups of children with FMS.

Therefore, this study considers the following deficiencies in the current domestic and international studies of soccer practices for FMS: (1) The effects of different soccer practice times and methods on children's FMS are unclear. (2) The effects of soccer practices on FMS subordinate skills are controversial. (3) The effects of interventions for different age and gender groups of children are unclear.

Materials and methods

Experimental approach to the problem

This study was guided by the Preferred Reporting Items for Systematic Evaluation and Meta-Analysis (PRISMA) (26) and registered in the PROSPERO database under number CRD42022340727. By searching databases such as CNKI, Wanfang database, Pubmed, Web of science, and Cochrane library, the search time period is from the creation of the database to April 2022, with the last search date being April 27, 2022. The search formula in Chinese and English was (FMS OR fundamental movement skill OR basic motor skill OR gross motor skill OR physical fitness OR gross motor skill OR speed OR run OR jump OR object control OR stability OR balance) AND (children OR kid OR student) AND (football OR soccer).

Eligibility criteria

Inclusion criteria

(1) Randomized controlled trials about soccer practices for children with FMS or subordinate skills of FMS, with language limited to Chinese and English. (2) Normally physically developed children aged 7–13 years, regardless of gender. (3) The total length of soccer practice is over 8 weeks.

Exclusion criteria

(1) Study that did not satisfy the inclusion criteria. (2) Children with behavioral disorders. (3) Unreasonable interventions in the experimental and control groups, such as additional psychological interventions. (4) Lack of basic information about the experimental subjects. (5) Duplicate detections of the study. (6) Systematic analysis of the study. (7) Study lacking full text.

Interventions

The experimental group used soccer practices (The total length of soccer practice >8 weeks, intensity, frequency, and form of practice were not limited); the control group did not have additional intervention or participated in the physical education course normally.

Outcome indicators

(1) linear sprint ability, linear sprint ability is one of the locomotion, this study used 15 m–50 m fast running as the test method in s; (2) jumping ability, jumping ability is also one of the locomotion, this study used horizontal jump and countermovement jump as the test method; (3) object control, through TGMD-2 as the test method, mainly including two-hand striking a stationary ball, stationary dribbling, catching, kicking, overhand throwing and underhand rolling (27); (4) balance, which was analyzed by two test methods, closed-eye single-leg test and flamingo balance (28).

Data synthesis and analysis

In this study, two researchers conducted the quality evaluation and data extraction, a third researcher was involved in the joint work for the areas of disagreement. After extraction, the difference between the pre- and post-intervention means and the standard deviation was calculated by subtracting the base-measure value from the post-measure value, and the standard deviation was calculated by "$SD_{difference}^2 = SD_{base\ value}^2 + SD_{post\ value}^2 - 2{*}R{*}SD_{base\ value} * SD_{post\ value}$, $R = 0.5$" (29). According to the Cochrane Handbook of Systematic Evaluation (30), the baseline is balanced and comparable between groups in randomized controlled trials, and theoretically there is no difference between the comparison of post-intervention measurements and the comparison of pre- and post-intervention differences. In this study, post-measure values of object control indicators were analyzed for comparison because of the relatively small number of study and missing baseline for some indicators.

Quality evaluation and statistical analyses

Cochrane Handbook for Systematic Reviews of Interventions (30) were used to score the included studies for (1) random sequence generation; (2) allocation concealment; (3) blinding of participants and personnel; (4) blinding of outcome assessment; (5) incompleteness of outcome data; (6) selective reporting; (7) other bias. Each criterion has three options of low risk, high risk, and unclear risk, and can be classified in category A when the number of low risks in the study is ≥4, in category B when the number of low risks in the study is ≥2 and <4, and in category C when the number of low risks in the study is <2. As shown in **Figures 1**, **2**, only 4 studies were standardized in the generation of random sequences generation (14–16, 31), and most of the studies were not assigned to concealment, because the sports interventions could not be set up double-blind, most of the experiments were mainly instrumental measurements, and the subjective influence of the evaluator on the experimental results was small, Therefore, "blinding of outcome assessment" scores are usually high. A total of 14 included studies met the criteria of category A (13–18, 20, 31–37) and 2 met the criteria of category B (12, 19), and the overall quality of the study was high.

Meta-analysis was performed using Review Manager 5.4 software (38). Heterogeneity was tested using I^2, and heterogeneity was considered to exist when $I^2 > 50\%$ (39), and a random-effects model was selected; while $I^2 < 50\%$ was used to study homogeneous effects and a fixed-effects model was selected. Standardized mean difference (SMD) and 95% confidence interval (95% CI) were chosen as the effect scale to combine effect sizes, and small effects were considered when the absolute value of SMD was 0–0.4, moderate effects were considered when 0.4–0.8, and high effects were considered when greater than 0.8, and differences were considered significant when $P < 0.05$, and subgroup analysis was performed for highly heterogeneous study results (39).

Results

Study search results

Through the search of Chinese and English study, a total of 2,036 studies were retrieved, 595 duplicate studies were excluded, 1,391 studies were excluded after reading the titles and abstracts, 37 studies were excluded by reading the full text, and 16 studies were finally screened (12–20, 31–37), including a total of 7 studies in English (12, 14–16, 31–33) and 9 studies in Chinese (13, 17–20, 34–37) (**Figure 3**).

Study characteristics

In all included studies(**Tables 1**, **2**), there were 3,121 children aged 7–13 years, including 1,958 in the experimental group and 1,163 in the control group; there were 7 studies with more than 100 participants (14–16, 20, 31, 34, 35), 8 studies with 20–100 participants (12, 13, 17–19, 33, 36, 37), and 1 study with less than 20 participants (32); 5 studies interventions were only for boys (13, 15, 17, 32, 33), 7 studies were co-educational interventions (14, 19, 20, 31, 34–36), and 4 did not specify the proportion of interventions (12, 16, 18, 37). The interventions were all based on soccer practice and 4 studies stated the intensity of the intervention (15, 19, 36, 37);

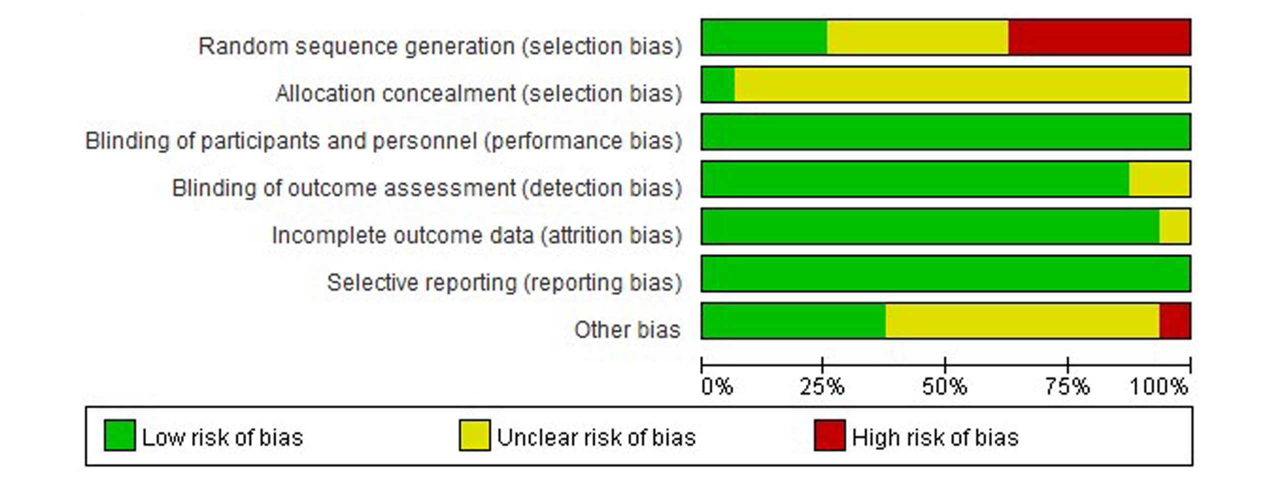

FIGURE 1
Risk of bias summary for all included study.

a total of 10 studies (13, 14, 17, 18, 20, 31, 33–36) for less than 20 weeks and 6 studies (12, 15, 16, 19, 32, 37) for more than 20 weeks; a total of 11 studies practiced at least 3 times per week (13, 15–19, 32–36) and 5 less than 3 times (12, 14, 20, 31, 37); 6 studies with weekly intervention time less than 120 min (13–15, 18, 20, 31) and 10 with intervention time more than 120 min (12, 16, 17, 19, 32–37); a total of 15 studies with baseline testing and comparison before the experiment (13–20, 31–37); for test results, a total of 13 studies with less association with rater subjectivity, such as horizontal jump, linear sprint, and Closed-eye single-leg test (14–20, 31–37), and a total of 2 studies with rater subjectivity scoring (12, 13); all included studies were published after 2013.

Results of meta-analysis

Meta-analysis of the effect of soccer on locomotion

Linear sprint ability

Linear sprint ability is measured in seconds, and a decrease in value represents an increase in ability. A total of 9 papers containing studies on linear sprint ability in soccer. As shown in **Figure 4**, $\chi^2 = 30.91$, df = 11 ($P = 0.001$), $I^2 = 67\%$ between the experimental and control groups, which can be considered as heterogeneity between the two groups, using a random effects model. The results showed that the combined sample size was 1,205 cases, SMD = −0.37, 95% CI: [−0.61, −0.14], Z = 3.11, $P = 0.002$, the combined effect was statistically significant, the small diamond-shaped squares fell to the left of the null line and did not intersect, indicating that there was a moderate effect and the soccer practices had a facilitative effect on children's linear sprint ability. The pre and post intervention in the experimental group $\chi^2 = 22.36$, df = 11 ($P = 0.02$), $I^2 = 51\%$, SMD = 0.41, 95% CI: [0.21, 0.61], $P <$ 0.0001, indicating the existence of a medium effect size and an increase in linear sprint ability in the experimental group after the intervention.

Jumping ability

A total of 9 studies were included in jumping ability, mainly using horizontal jump and countermovement jump to measure children's jumping ability. In **Figure 5**, there was a high heterogeneity between the experimental group of horizontal jump and the control group with $\chi^2 = 37.75$, df = 6 ($P <$ 0.00001), $I^2 = 84\%$, and a random effects model was used. The results showed that the sample size was 983 cases, the combined effect was statistically significant, SMD = 0.62, 95% CI: [0.21, 1.04], $P = 0.003$, the small diamond-shaped squares were located to the right of the null line and did not intersect, indicating the presence of a moderate effect and a better promotion of the soccer practices on the horizontal jump. Pre and post intervention in the experimental group $\chi^2 = 78.19$, df = 6 ($P < 0.00001$), $I^2 = 92\%$, SMD = −0.78, 95% CI: [−1.27, −0.28], $P = 0.002$, |SMD| > 0.4, indicating the presence of a moderate effect size and a significant increase in the level of horizontal jump after the intervention in the experimental group.

From **Figure 6**, it can be obtained that the countermovement jump $\chi^2 = 7.08$, df = 2 ($P = 0.03$), and $I^2 =$ 72% between the experimental and control groups, which can be considered as heterogeneity between the two groups, and Meta-analysis was performed with a random effects model. The results showed that the sample size was 102 cases, SMD = 0.50, 95% CI: [−0.35, 1.35], $P = 0.25$, and the small diamond-shaped square intersected with the null line,

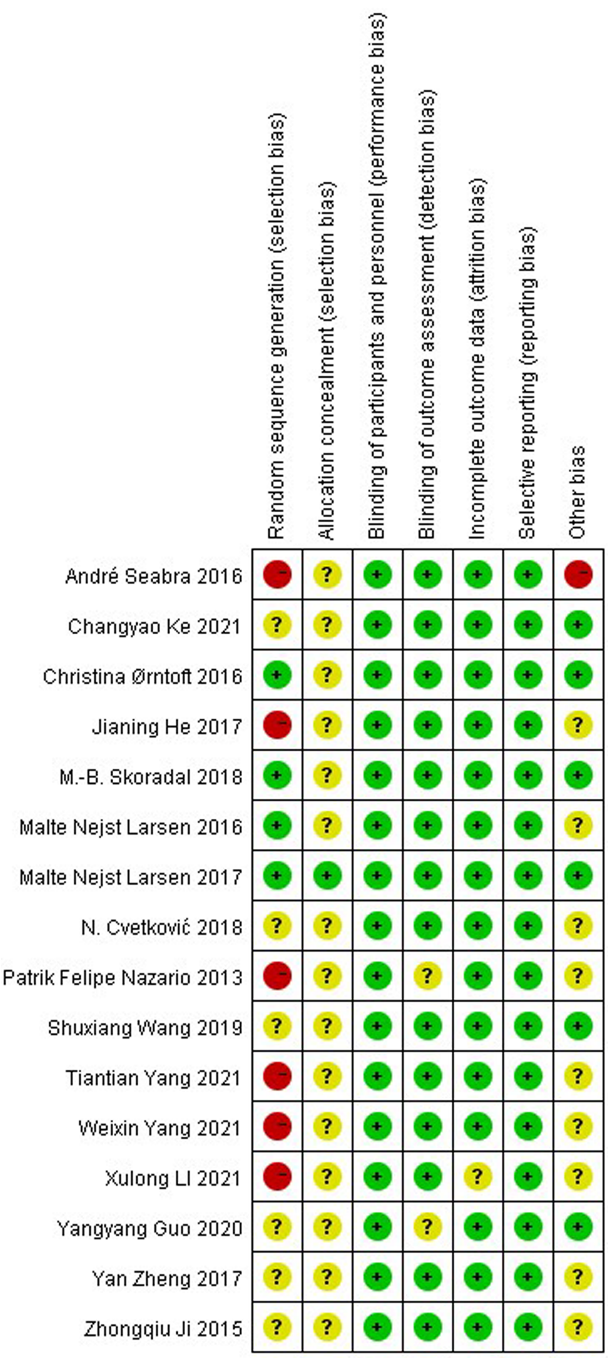

FIGURE 2
Risk of bias graph of the included studies.

indicating that the difference between the groups was not statistically significant. Pre and post intervention in the experimental group $\chi^2 = 3.73$, df = 2 ($P = 0.15$), $I^2 = 46\%$, SMD = −0.83, 95% CI: [−1.2, −0.45], $P < 0.0001$, |SMD| > 0.8, the small diamond-shaped square was located to the left of the null line and did not compare, indicating a significant change in the countermovement jump before and after the experimental group.

Meta-analysis of the effect of soccer on object control ability

From **Figure 7**, the effect of soccer on children's object control $\chi^2 = 71.47$, df = 11 ($P < 0.00001$), $I^2 = 85\%$, therefore, Meta-analysis was performed using a random effects model with SMD = 1.32, 95% CI: [0.80, 1.85], $P < 0.0001$, SMD > 0.8, indicating that the soccer intervention had a better facilitation effect on children's object control, and there were significant differences between subgroups.

In stationary dribbling, $\chi^2 = 1.42$, df = 1 ($P = 0.23$), $I^2 = 30\%$, there was homogeneity between the two groups, SMD = −0.03, 95% CI: [−0.56, 0.50], $P = 0.9$, |SMD| < 0.4, and the diamond-shaped small square intersected with the null line, indicating that the soccer sport intervention had no improvement effect on children's stationary dribbling.

In catching ability, $\chi^2 = 18, 71$, df = 1 ($P = 0.08$), $I^2 = 95\%$, there was heterogeneity between the experimental and control groups, SMD = 1.77, 95% CI: [−0.67, 4.21], $P < 0.0001$, SMD > 0.8, and the diamond-shaped cubes intersected the null line, indicating that the soccer sports intervention had no effect on the children's ball catching ability.

There was heterogeneity between the two groups of overhand throwing with $\chi^2 = 3.03$, df = 1 ($P = 0.08$), $I^2 = 67\%$, SMD = 1.41, 95% CI: [0.53, 2.28], $P = 0.02$, SMD > 0.8, and the diamond-shaped cube was located to the right of the null line and did not intersect, indicating that the soccer sport intervention had an improving effect on children's overhand throwing.

In the underhand rolling, $\chi^2 = 2.7$, df = 1 ($P = 0.1$), $I^2 = 63\%$, there was heterogeneity between the experimental and control groups, SMD = 1.42, 95% CI: [0.59, 2.24], $P = 0.0008$, SMD > 0.8, and the small diamond-shaped squares were located to the right of the null line and did not intersect, indicating that the soccer sport intervention had an improving effect on children's underhand rolling.

There was heterogeneity between the two groups of two-hand striking a stationary ball $\chi^2 = 8.25$, df = 1 ($P = 0.004$), $I^2 = 88\%$, SMD = 1.91, 95% CI: [0.31, 3.51], $P = 0.02$, SMD > 0.8, and the small diamond-shaped square was located to the right of the null line and did not intersect, indicating that the soccer practices had an improving effect on children's two-hand striking a stationary ball.

Kicking ability is an important manifestation of lower limb object control ability, $\chi^2 = 0.84$, df = 1 ($P = 0.36$), $I^2 = 0\%$, SMD = 1.59, 95% CI: [1.08, 2.1], $P < 0.0001$, SMD > 0.8 between the two groups, the small diamond-shaped squares were located to the right of the null line and did not intersect, indicating that there was a height effect and that the soccer practices

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TABLE 1 Characteristics of the experimental subjects included in the study.

Number	Author	Year	Experimental subjects		
			Crowd	Age (years)	Experimental group (male: female)/Control group (male: female)
1	A. Seabra (32)	2016	NC	8–12	9 (9 : 0)/8 (8 : 0)
2	C. Ørntoft (14)	2016	NC	10–12	386 (200 : 186)/140 (57 : 83)
3	M.B. Skoradal (31)	2018	NC	11.1 ± 0.3	292 (146 : 146)/100 (50 : 50)
4	M.N. Larsen (15)	2017	NC	10–12	829 (829 : 0)/439 (439 : 0)
5	M.N. Larsen (16)	2016	NC	EG:9.3 ± 0.4 CG:9.3 ± 0.3	91 (Unknown)/108 (Unknown)
6	N. Cvetković (33)	2018	NC	11–13	10 (10 : 0)/14 (14 : 0)
7	P. F. Nazario (12)	2013	NC	9 ± 1.0	16 (Unknown)/25 (Unknown)
8	Shuxiang Wang (17)	2019	NC	EG:9.2 ± 0.2 CG:9.2 ± 0.1	20 (20 : 0)/23 (23 : 0)
9	Yangyang Guo (13)	2020	NC	EG:8.80 ± 0.77 CG:8.85 ± 0.75	20 (20 : 0)/20 (20 : 0)
10	Changyao Ke (34)	2021	NC	10–11	60 (30 : 30)/60 (30 : 30)
11	Weixin Yang (18)	2021	NC	EG:9.37 ± 0.38 CG:9.27 ± 0.28	32 (Unknown)/32 (Unknown)
12	Xulong li (19)	2021	NC	EG:9.23 ± 0.45 CG:9.17 ± 0.45	38 (19 : 19)/38 (10 : 9)
13	Zhongqiu Ji (20)	2015	NC	9–11	58 (28 : 30)/60 (30 : 30)
14	Tiantian Yang (35)	2021	NC	8–9	50 (30 : 20)/50 (30 : 20)
15	Jianing He (36)	2019	NC	10–12	16 (8 : 8)/16 (8 : 8)
16	Yan Zheng (37)	2017	NC	7.13 ± 0.14	31 (Unknown)/30 (Unknown)

Note: NC is normally developing children; EG is the experimental group; CG is the control group.

had an effect on children's lower limb object control ability was improved.

Meta-analysis of the effect of soccer on stabilization ability

In this study, a total of seven included studies were conducted on children's stabilization ability. The closed-eye single-leg test and flamingo balance were used as an index. From **Figure 8**, $\chi^2 = 17.03$, df = 8 ($P = 0.03$), and $I^2 = 53\%$ between the two groups of the closed-eye single-leg test, which can be considered as heterogeneity between the two groups, and therefore a random-effects model was performed. The results showed that the sample size was 282 cases, SMD = 0.87, 95% CI: [0.48, 1.25], $P < 0.0001$, and the diamond-shaped small squares were located to the right of the null line and did not intersect, indicating that there was a high effect and that the soccer practices had a significant contribution to the children's stabilization ability. Also we can see that pre- and post-intervention of the experimental group $\chi^2 = 13.83$, df = 8 ($P = 0.09$), $I^2 = 43\%$, SMD = −0.83, 95% CI: [−1.07, −0.59], $P < 0.00001$, $|SMD| > 0.8$, the small diamond-shaped square was located to the left of the null line and did not intersect, it indicates that the level of standing on one foot with eyes closed was significantly higher in the experimental group after the intervention compared to before the intervention.

In **Figure 9**, $\chi^2 = 1.32$, df = 2 ($P = 0.52$), and $I^2 = 0\%$ between the two groups of the flamingo balance test, which can be considered homogeneous between the two groups, and the fixed effects model was performed. The results showed that the sample size was 829 cases, SMD = −0.16, 95% CI: [−0.31, −0.02], $P = 0.03$, and the small diamond-shaped squares were located to the left of the null line and did not intersect, indicating that there was a small effect and that the soccer practices promoted children's stabilization ability. We can see that pre- and post- intervention in the experimental group $\chi^2 = 4.56$, df = 2 ($P = 0.1$), $I^2 = 56\%$, SMD = 0.12, 95% CI: [−0.1, 0.35], $P = 0.28$ indicating that the difference in balance ability after the intervention in the experimental group was not statistically significant.

Subgroup analysis

It was difficult to conduct subgroup analysis of intervention intensity and content because most of the included studies had

TABLE 2 Status of interventions included in the study.

Number	Author	Interventions		
		Training content and ratio	Group: Total time/week frequency/sub-hour (week/time/min)	Training intensity
1	A. Seabra (32)	EG: 10–20 min warm-up, 40–60 min technical practice and competition,10 min relaxation CG: Unknown	EG:26 weeks*4 times*60–90 min CG:26 weeks	Unknown
2	C. Ørntoft (14)	EG: Warm-up, technical practice, competition CG: Not involved in sports	EG:12 weeks*2 times*45 min CG:12 weeks	Unknown
3	M.B. Skoradal (31)	EG: "FIFA 11 for Health"; Regular physical education courses CG: Normal physical education course	EG:13 weeks*2 times*45 min; 13 weeks CG:13 weeks	Unknown
4	M.N.Larsen (15)	EG:3v3 soccer training CG: Normal physical education course	EG:43 weeks*5 times*12 min CG:43 weeks	70%–90% HRmax
5	M.N. Larsen (16)	EG: 3v3 soccer training CG: Normal physical education course	EG:43 weeks*3 times*40 min CG:43 weeks	Unknown
6	N. Cvetković (33)	EG:10 min warm-up, 4*8 min soccer game, 10 min relaxation; normal physical education course CG: Normal physical education course	EG:12 weeks*3 times*60 min; 12 weeks*2 times CG:12 weeks	Unknown
7	P. F. Nazario (12)	EG: Soccer Practice; Physical Education Course CG: Physical Education Course	EG:25 weeks*2 times*90 min;25 weeks*2 times*50 min CG: 25 weeks*2 times*50 min	Unknown
8	Shuxiang Wang (17)	EG:8 min warm-up, 32 min soccer technique, physical exercise, 5 min relaxation CG: Normal physical education course	EG:12 weeks*3 times*45 min CG:12 weeks	Unknown
9	Yangyang Guo (13)	EG: Preparation part, ballistic exercise, ending part CG: Preparation section, fitness exercises, end section	EG:8 weeks*3 times*30 min CG: 8 weeks*3 times*30 min	Unknown
10	Changyao Ke (34)	EG: physical, technical, tactical, and general application skills training; normal physical education courses CG: Normal Physical Education Course	EG:16 weeks*5 times*45 min; 16 weeks CG:16 weeks	Unknown
11	Weixin Yang (18)	EG: 8 min warm-up, 8 min technical training, 9 min game, 10 min shooting; physical education class CG:7 min preparation activities, basic part, 23 min exercises, 5 min relaxation	EG:12 weeks*3 times*35 min; 12 weeks*1 time*35 min CG: 12 weeks*4 times*35 min	Unknown
12	Xulong li (19)	EG: Basic soccer skills, special quality CG: Normal physical education courses (no ball games)	EG:20 weeks*5 times*60 min CG: 20 weeks*5 times*60 min	60%–70% HR_{max}
13	Zhongqiu Ji (20)	EG: Inside foot passing is the main focus, supplemented by ballistic exercises and lower body strength exercises; CG: Normal physical education course (no soccer practice)	EG:12 weeks*2 times*40 min CG: 12 weeks*2 times*40 min	Unknown
14	Tiantian Yang (35)	EG:8 min warm-up, 32 min soccer training. 5 min relaxation stretch. CG:8 min warm-up, 32 min basic exercises The activity is relaxing for 5 min.	EG:16 weeks*3 times*45 min CG:16 weeks*3 times*45 min	Unknown
15	Jianing He (36)	EG: ball practice, technical practice CG: Normal teaching activities	EG:12 weeks*3 times*90 min CG:12 weeks	110–130 HR_{x-bar}
16	Yan Zheng (37)	EG:15 min warm-up, 15 min quality training, 60 min soccer technical training, 30 min game; normal sports course CG: Normal physical education course	EG:32 weeks*1 time*120 min CG:32 weeks	72.70% HRmax

*Represent multiplication.

the problem of not detailing the intensity of the intervention and the proportion of training content, while object control was not suitable for subgroup analysis because of the small number of included studies. Ultimately, this study subgroups three aspects of total intervention length, age (years), and gender for subgroup analysis.

Comparison of the effects of different total intervention durations

In this study, the total intervention period (weeks), weekly intervention frequency, and length of each lesson(min) were considered to be factors influencing the study results, and

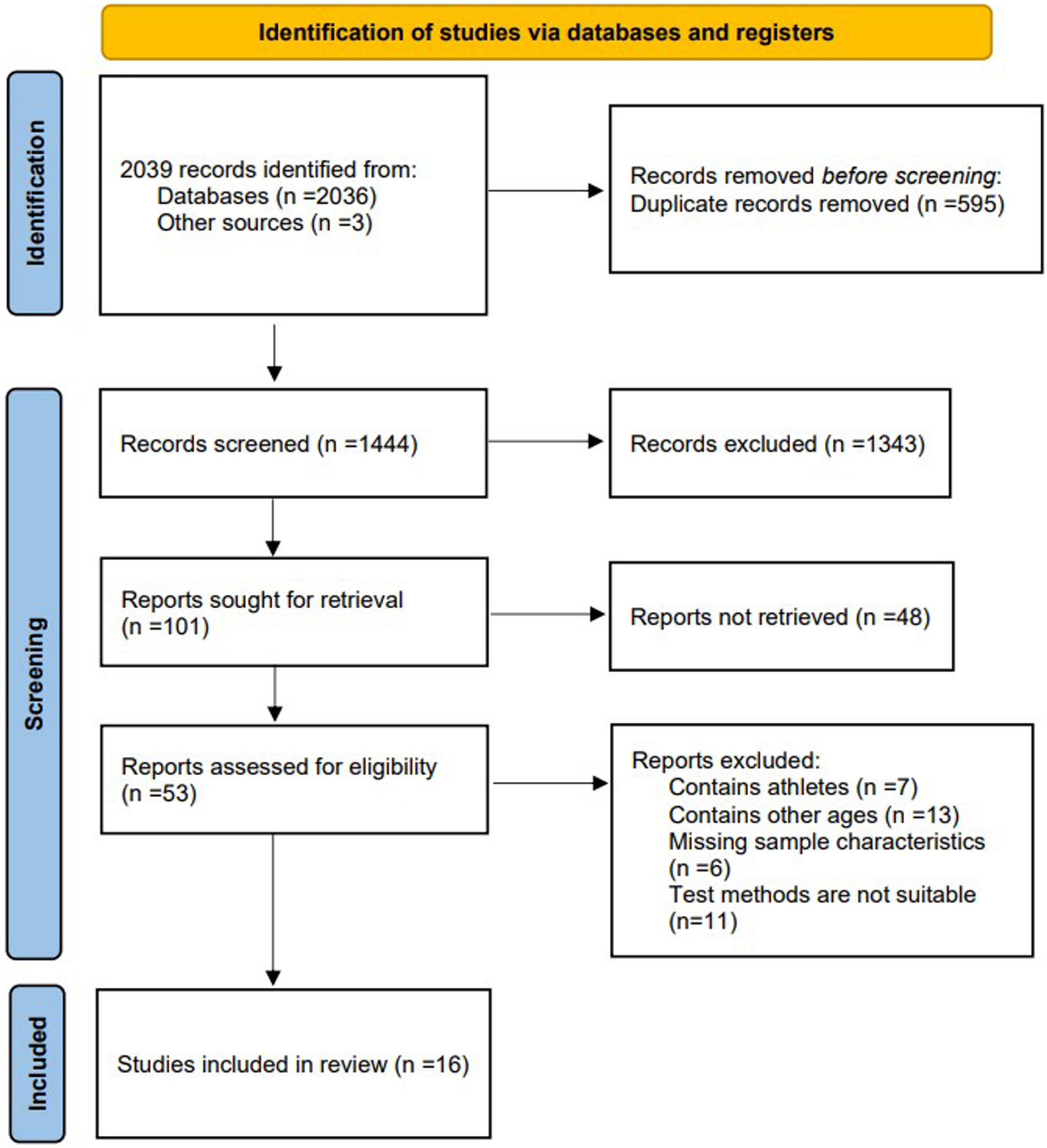

FIGURE 3
Flow diagram of the selected studies.

subgroup analysis of one of them alone would result in the study outcomes being confounded by the other two factors. Therefore the "total intervention period (weeks)" × "weekly intervention frequency" × "length of each lesson(min)" was used to obtain the total intervention duration, which was used to explore the relationship between intervention time and effect. In terms of the degree of distinction as well as the rationality of the intervention, "15 weeks * 3 times/week * 40 min/time = 1,800 min" was used as the dividing line. In **Table 3**, the $|SMD_{1,800\ min\ below}| < |SMD_{1,800\ min\ more}|$ of linear sprint ability and horizontal jump, the intervention above 1,800 min was a moderate and high effect, while below 1,800 min was a small effect, so the training effect above 1,800 min promoted the development of linear sprint ability and horizontal jump more. Flamingo balance had no statistically significant difference between groups below 1,800 min, while there was a large effect above 1,800 min. The duration of the closed-eye single-leg test intervention was below 1,800 min, and there was a high effect.

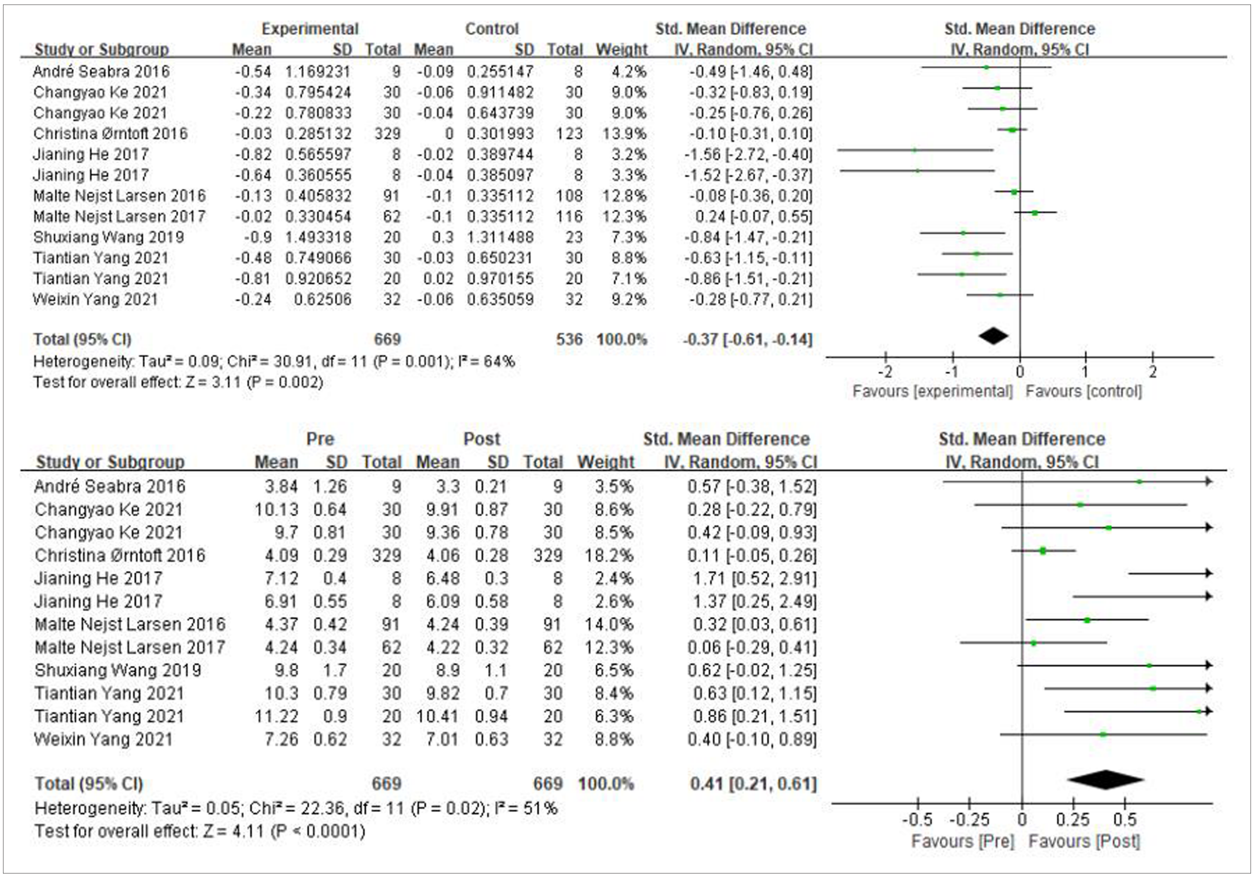

FIGURE 4
A meta-analysis of the results of linear sprint ability was conducted for comparisons between the control and experimental groups and for comparisons between the experimental groups pre- and post-intervention.

There was no statistically significant difference between groups above or below 1,800 min for the countermovement jump.

Comparison of effects by age group

In this study, the studies were divided into two subgroups based on age: 7–9 years old and 10–13 years old. In **Table 4**, there was no statistically significant difference between the groups of linear sprint ability and horizontal jump in children aged 10–13 years old, but there were medium and small effects in 7–9 years old, and it can be concluded that the effect of soccer practices on linear sprint ability and horizontal jump in children aged 7–9 years old was better than that in 10–13 years old, and there was no statistically significant difference between the groups of countermovement jump and flamingo balance in both 7–9 years old and 10–13 years old, while the eyes closed Closed-eye single-leg test $SMD_{7\text{–}9years} < SMD_{10\text{–}13years}$, indicating that children aged 10–13 years had better intervention effects on the ability to stand on one leg with eyes closed.

Comparison of effects by gender group

The study was divided into three subgroups: "male", "female", and "mixed" according to the gender of the intervention subjects. In **Table 5**, linear sprint ability and closed-eye single-leg test $|SMD_{female}| > |SMD_{male}|$ indicated that the soccer intervention was more effective for girls. There was a high effect of horizontal jump in boys, but no statistically significant effect in girls. There was no statistically significant effect for both subgroups of countermovement jump and flamingo balance.

Discussion

Soccer and children's locomotion

Locomotion is an indispensable ability in soccer, and linear sprint ability and jumping ability are the two main indicators to judge locomotion. The results of study have identified the facilitative effect of soccer practices on linear sprint ability,

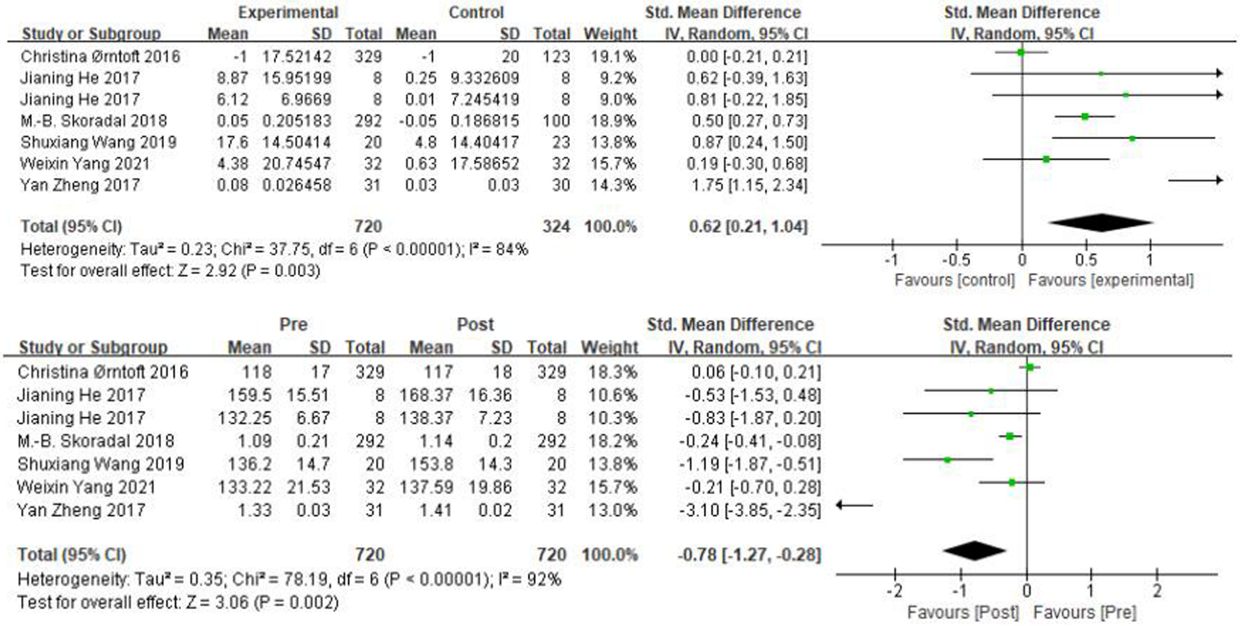

FIGURE 5
A meta-analysis of the results of horizontal jump was conducted for comparisons between the control and experimental groups and for comparisons between the experimental groups pre- and post-intervention.

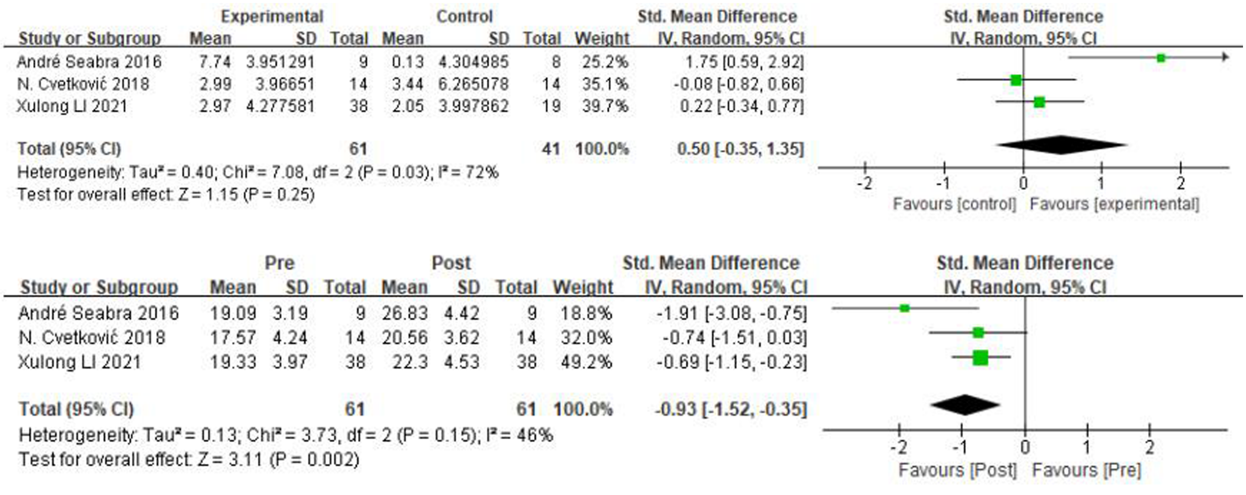

FIGURE 6
A meta-analysis of the results of countermovement jump was conducted for comparisons between the control and experimental groups and for comparisons between the experimental groups pre- and post-intervention.

and there are relevant studies that have demonstrated this (17, 35, 36). It is related to the soccer itself including running, kicking, and shifting movements, but the findings of M.N. Larsen (15) in 2017 diverge from the findings of this study, whose intervention period was 43 weeks long and with an exercise intensity of 70%–90% HRmax, but the weekly intervention duration was only 60 min, which may indicate that long-period, short-per-intervention methods are not effective in improving linear sprint ability. Jianing He (36) showed a more significant improvement in linear sprint ability after 12 weeks of soccer technique and ball handling intervention at 270 min per week, which may indicate that a

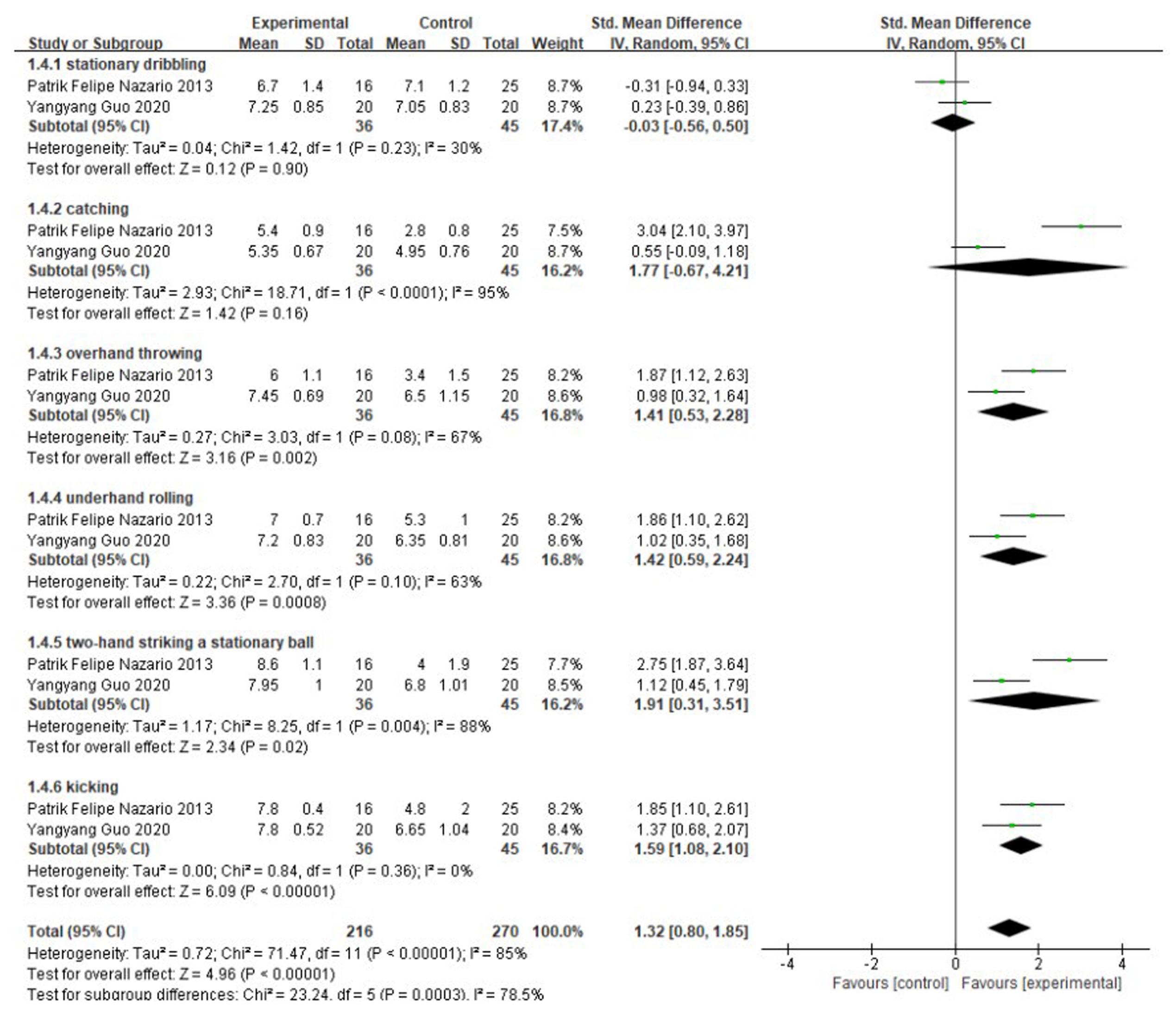

FIGURE 7
A meta-analysis of the results of object control was conducted for comparisons between the control and experimental groups.

longer weekly intervention duration can better promote linear sprint ability improvement. A subgroup analysis showed that interventions longer than 1,800 min were more effective than those below 1,800 min, that interventions were more effective in children aged 7–9 years than in those aged 10–13 years, and that interventions were more effective in girls than in boys, suggesting that soccer interventions should be conducted at ages 7–9 years to improve linear sprint ability. Meanwhile, it is difficult to compare the effects of factors such as the ratio of physical fitness training to soccer technique training, the ratio of different soccer technique training, and the ratio of aerobic to anaerobic training on linear sprint ability in the intervention because subgroup analysis of the intervention content was not conducted in this study.

Secondly, the results of the study showed that the soccer practices had a facilitating effect on horizontal jump, and Yan Zheng (37) showed a significant improvement in children's jumping ability after a 32-week * 1 time/week * 120 min/time intervention, which might indicate that long-term low-frequency high-intensity prolonged soccer sports have a better effect on jumping ability, while C. Ørntoft (14) showed that after a 12-week * 2 times * 45 min intervention, the intervention effect in the experimental group did not differ from the control group, considering its similarity to the intervention content of Yan Zheng (37), we therefore hypothesized that a low frequency, short duration intervention would be ineffective. The subgroup analysis of the study also proved the important role of intervention duration and age on horizontal jump ability,

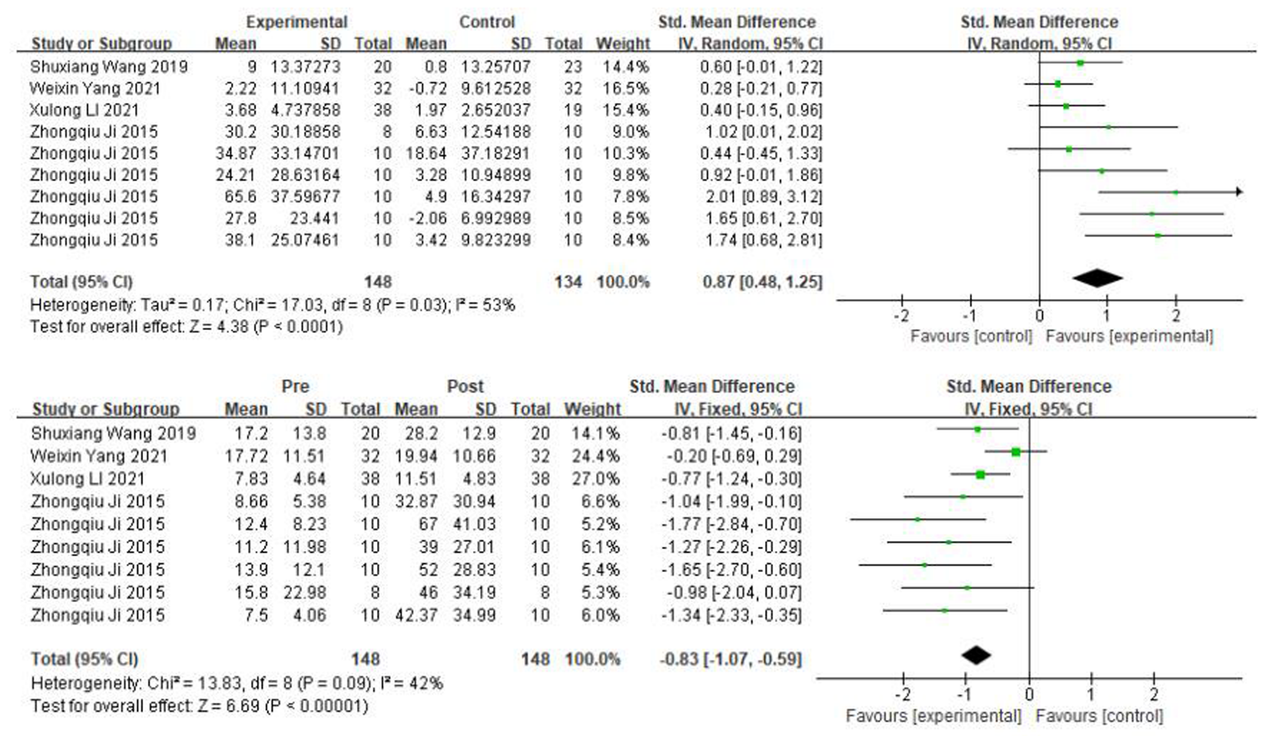

FIGURE 8
A meta-analysis of the results of closed-eye single-leg test was conducted for comparisons between the control and experimental groups and for comparisons between the experimental groups pre- and post-intervention.

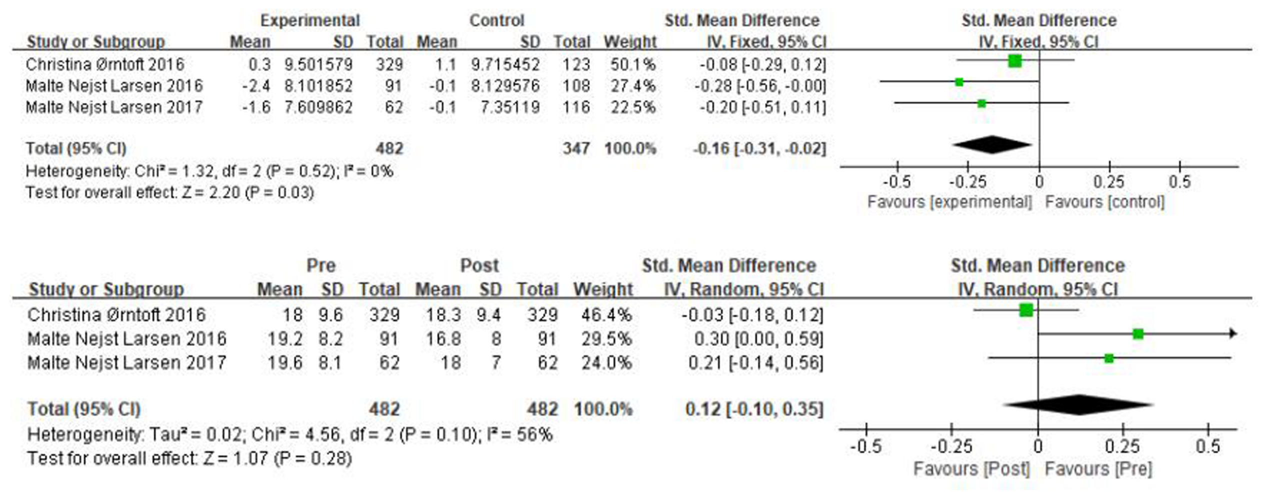

FIGURE 9
A meta-analysis of the results of flamingo balance was conducted for comparisons between the control and experimental groups and for comparisons between the experimental groups pre- and post-intervention.

as shown by the fact that the effect of intervention duration >1,800 min was better than that of <1,800 min, which also reminds us that the intervention duration should be extended in future interventions to improve the effect, while there was no significant difference between the intervention effect of boys and girls. Meanwhile, the effect

TABLE 3 Comparison of the effects of different total intervention times.

Test index	Subgroup	Number of articles	*Z*	*P*	SMD 95% CI
Linear sprint ability	1,800 min more	6	2.57	0.01	−0.43 [−0.76, −0.1]
	1,800 min below	3	1.64	0.1	−0.32 [−0.71, 0.06]
	Overall	9	3.11	0.002	−0.37 [−0.61, −0.14]
Horizontal jump	1,800 min more	2	2.96	0.003	1.16 [0.39, 1.93]
	1,800 min below	4	1.87	0.06	0.34 [−0.02, 0.7]
	Overall	6	2.92	0.003	0.62 [0.21, 1.04]
Countermovement jump	1,800 min more	2	0.85	0.4	0.78 [−1.02, 2.57]
	1,800 min below	1	0.77	0.44	0.22 [−0.34, 0.77]
	Overall	3	1.15	0.25	0.5 [−0.35, 1.35]
Closed-eye single-leg test	1,800 min more	0	–	–	–
	1,800 min below	4	4.38	<0.0001	0.87 [0.48, 1.25]
	Overall	4	4.38	<0.0001	0.87 [0.48, 1.25]
Flamingo balance	1,800 min more	2	2.32	0.02	−0.99 [−1.44, −0.55]
	1,800 min below	1	0.79	0.43	−0.08 [−0.29, 0.12]
	Overall	3	2.2	0.03	−0.16 [−0.31, −0.02]

TABLE 4 Comparison of the effect of different age groups.

Test index	Subgroup	Number of articles	*Z*	*P*	SMD 95% CI
Linear sprint ability	7–9 years old	4	2.74	0.006	−0.47 [−0.81, −0.13]
	10–13 years old	4	1.61	0.11	−0.3 [−0.66, 0.06]
	Overall	9	3.11	0.002	−0.37 [−0.61, −0.14]
Horizontal jump	7–9 years old	3	1.97	0.05	0.93 [0.01, 1.84]
	10–13 years old	3	1.73	0.08	0.35 [−0.05, 0.75]
	Overall	6	2.92	0.003	0.62 [0.21, 1.04]
Countermovement jump	7–9 years old	1	0.77	0.44	0.22 [−0.34, 0.77]
	10–13 years old	1	0.22	0.83	−0.08 [−0.82, 0.66]
	Overall	3	1.15	0.25	0.5 [−0.35, 1.35]
Closed-eye single-leg test	7–9 years old	4	3.15	0.002	0.46 [0.17, 0.74]
	10–13 years old	1	5.79	<0.00001	1.53 [1.01, 2.04]
	Overall	4	4.38	<0.0001	0.87 [0.48, 1.25]
Flamingo balance	7–9 years old	1	1.97	0.05	−0.28 [−0.56, 0]
	10–13 years old	2	1.37	0.17	−0.12 [−0.29, 0.05]
	Overall	3	2.2	0.03	−0.16 [−0.31, −0.02]

of practice intensity on horizontal jump was studied (40), and in the medium- and high-intensity soccer practice, soccer players who received the high-intensity intervention performed significantly better in the horizontal jump than those with moderate practice intensity, this is consistent with Fei Xin's conclusion. For the countermovement jump, the results showed no difference between the experimental and control groups after the intervention, perhaps caused by the same participation of the control group in the physical education program, which is consistent with the findings of Xulong Li (19) and N. Cvetković (33), in addition to the findings of some of the studies (15, 41) that could not be combined due to different data presentation, which supports the conclusion. Whereas there were differences before and after the intervention in the experimental group, indicating that the soccer practices were effective for children, but the effect did not differ from participation in a general physical education program, the results of the countermovement jump should be treated with caution due to the small number of included studies.

Soccer and children's object control

The present study found that soccer had a good promotion effect on children's object control in general, but there was no statistical significance between groups on stationary dribbling and catching. This is consistent with the conclusion reached

TABLE 5 Comparison of effects by gender.

Test index	Subgroup	Number of articles	Z	P	SMD 95% CI
Linear sprint ability	Male	6	2	0.05	−0.49 [−0.98, −0.01]
	Female	3	2.21	0.03	−0.73 [−1.39, −0.08]
	Mixed	3	1.42	0.15	−0.11 [−0.27, 0.04]
	Overall	9	3.11	0.002	−0.37 [−0.61, −0.14]
Horizontal jump	Male	2	2.94	0.003	0.8 [0.27, 1.34]
	Female	1	1.54	0.12	0.81 [−0.22, 1.85]
	Mixed	3	1.26	0.21	0.23 [−0.13, 0.59]
	Overall	6	2.92	0.003	0.62 [0.21, 1.04]
Countermovement jump	Male	2	0.85	0.4	0.78 [−1.02, 2.57]
	Female	0	–	–	–
	Mixed	1	0.77	0.44	0.22 [−0.34, 0.77]
	Overall	3	1.15	0.25	0.5 [−0.35, 1.35]
Closed-eye single-leg test	Male	3	4.26	<0.0001	0.91 [0.49, 1.33]
	Female	1	2.65	0.008	1.35 [0.35, 2.35]
	Mixed	2	1.87	0.06	0.73 [−0.03, 1.49]
	Overall	4	4.38	<0.0001	0.87 [0.48, 1.25]
Flamingo balance	Male	1	1.27	0.2	−0.2 [−0.51, 0.11]
	Female	–	–	–	–
	Mixed	2	1.81	0.07	−0.15 [−0.32, 0.01]
	Overall	3	2.2	0.03	−0.16 [−0.31, −0.02]

by Yangyang Guo (13), in which there was a significant improvement in two-hand striking a stationary ball and throwing ability, and slightly higher scores on stationary dribbling and catching than the control group but no significant difference, he concluded that kicking movements involve precision control of the limbs on the target, and long-term practice tends to improve proprioception to help develop object control in the upper limbs. In contrast, the results of the study by P.F. Nazario (12) yielded the same results in terms of the promotion of stationary dribbling, but with a significant increase in catching ability, and it concluded that the characteristics of the experimental subjects, the environment they were in, and the time of the intervention were all influential factors. Considering the small difference between the two in terms of age and that the intervention by Yangyang Guo (13) was not traditional soccer instruction but ball practice, this study hypothesized that when the intervention included passing and catching football, upper limb throwing and catching accuracy would also be enhanced, but when the intervention was only ball practice and lacked passing and catching football, the enhancement of all upper limb object control abilities would be limited. Since this study included less study on upper limb object control, the specific effect still needs to be verified in the future. And since soccer itself is a sport involving lower limb control, most FMS assessment tools use soccer as a test of lower limb object control, so the effect of soccer on lower limb object control is direct, and this study used kicking in TGMD-2 as a test item, and the results showed that soccer had a facilitating effect on the effect of lower limb intervention, and not only that, Xulong Li (19) found that children's ability to change direction and dribble was improved after the soccer intervention, which can also represent the improvement of children's lower limb object control ability, although the specific intervention effect can be affected by various aspects such as training content, time, and characteristics of the experimental subjects, but the appropriate intervention has a positive effect.

Soccer and children's balance

Balance is an important prerequisite for the development of motor skills, and examining children's balance will help future research and interventions that will lead to better overall movement skills (42). The results of the study point to differences in the results of the two different testing methods. In the four studies tested by Closed-eye single-leg test, the experimental group significantly improved compared to the control group, which is consistent with the study of Zhongqiu Ji (20), which concluded that movements such as running, paddling and dribbling have a helpful effect on stability, while the fatigue resistance of the calf muscles is also a major factor affecting balance, and soccer contains both aerobic and anaerobic exercises that promote fatigue resistance in the calves. And Xulong Li (19) and Shuxiang Wang (17) although there was no significant difference between the experimental and control groups, there was a significant difference between the posttest of the experimental group compared to the base test, as the balance ability can be effectively improved by practice can be improved (43), which may be related to the participation of the control group in the normal physical education program. The intervention effect was better in girls and 10–13 years old than in boys and 7–9 years old in the subgroup analysis, indicating that there are gender differences in FMS (44, 45) and it is more appropriate to intervene in soccer at the age of 10–13 years old in children, but the present findings do not coincide with the developmentally sensitive period of balance ability, and considering that the present study did not analyze factors such as practice content, ratio, and intensity, more research in this area is necessary in the future. However, the analysis results of the flamingo balance test showed that the balance ability was not improved significantly after the intervention, which can have an impact on the accuracy of the results due to the small amount of study, but it is worth noting that C. Ørntoft (32) in the present study performed an intervention with a total duration of 1,080 min, balance ability did not improve, while subgroup analysis, for >1,800 min study showed that the soccer practices had a better effect on the flamingo balance test, indicating that the increase in the total duration of the intervention was a major factor in improving the effect of the intervention. Secondly, related scholars (40) conducted flamingo balance tests for 11-year-old soccer players after medium- and high-intensity soccer interventions with regular children, and the results showed that the balance ability of soccer players was significantly better than that of regular children, and the balance ability of soccer players with high exercise intensity was better than that of athletes with medium intensity.

Limitations and shortcomings

The search terms in this study only included Chinese and English, and some of the studies could not be viewed in full text, resulting in fewer included study for the countermovement jump, object control ability, and flamingo balance tests, which had some impact on the reliability of the results. In the quality evaluation of the included study, most of the study failed to accurately state the principle of random assignment, and in some experiments where the subjectivity of the raters was relatively high, the scores were not blinded, and some of the literature did not report the withdrawal, resulting in a lower level of quality of the study. In the subgroup analysis, the small number of studies for some indicators and the difficulty in unifying the intervention intensity and proportion of experimental subjects across the study resulted in the inability to further analyze the interventions.

Conclusions and recommendations

The soccer practice was able to improve children's FMS, as evidenced by significant improvements in linear sprint ability [SMD 95% CI = −0.37 (−0.61,−0.14), $P = 0.002$], horizontal jump [SMD 95% CI = 0.22 (−0.34,0.77), $P = 0.003$], object control [SMD 95% CI = 1.32 (0.8,1.85), $P = 0.0003$], Closed-eye single-leg test [SMD 95% CI = 0.87 (0.48,1.25), $P < 0.0001$], and no improvement in countermovement jump, basketball shooting, flamingo balance test and catching test. The accuracy of the results needs to be verified in the future because of the small amounts of included studies in countermovement jump, upper limb object control ability, and flamingo balance test. Meanwhile, the subgroup analysis revealed that the intervention effects of linear sprint ability, horizontal jump and flamingo balance test were better than those of <1,800 min; the intervention effects of linear sprint ability and horizontal jump were better than those of 10–13 years old for children aged 7–9 years old, while the intervention effects of Closed-eye single-leg test were better for 10–13 years old than those of 7–9 years old; the intervention effects of linear sprint ability and Closed-eye single-leg test were better for girls. but the horizontal jump is better for boys to improve the effect.

It is suggested that when developing children with FMS in the future, the intervention effect can be increased by increasing the total length of intervention and selecting the appropriate age for timely development. The effects of different intervention components and the ratio of each component as well as the intensity of the intervention on FMS are lacking in the current study and need to be further explored in the future.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author/s.

Author contributions

XM and LF: conducted data analysis and summary. XM: wrote the first manuscript. LF: reviewed and edited the final manuscript. YL, JZ and YC: conducted the study search and quality evaluation. YL and JZ: supported data extraction. DM and LW provided valuable input in the revision of the paper and participated in the revision process. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Relationships between athletic ability and academic performance in primary school students: A 3-year follow-up study

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Background: The aim of this study was to examine whether academic performance is associated with students' athletic ability in primary school.

Methods: A 3-year follow-up study was conducted among 1,136 Chinese students. Sit-up and jump rope testers were used to measure 1-min sit-ups and 1-min jump ropes, respectively. Meanwhile, the Pittsburgh Sleep Quality Scale and the Beck Depression Inventory were used to estimate sleep quality and depression levels. The end-of-semester examinations were used to evaluate students' academic performance during the follow-up period.

Results: After adjusting for confounders, the mean change in Chinese language performance for participants stratified by 1-min sit-ups at baseline was 0.35 (95% CI: −0.37 to 0.76) for level 1 (slowest), 0.52 (95% CI: −0.54 to 1.08) for level 2, and 1.72 (95% CI: 1.14 to 2.30) for level 3 (fastest) (P for trend = 0.003); the mean change in math scores was 0.28 (95% CI: −0.50 to 0.95) for level 1 (slowest), 0.95 (95% CI: 0.38 to 1.52) for level 2, and 1.41 (95% CI: 0.82 to 1.99) for level 3 (fastest) (P for trend = 0.048). The mean change in foreign language scores was −0.45 (95% CI: −0.99 to −0.93) for level 1 (slowest), −0.14 (95% CI: −0.44 to 0.41) for level 2, and 0.69 (95% CI: 0.25 to 1.13) for level 3 (fastest) (P for trend = 0.004). The mean change in Chinese language performance for participants stratified by 1-min jump ropes at the baseline was 0.30 (95% CI: −0.16 to 0.76) for level 1 (slowest), 1.09 (95% CI: 0.42 to 1.76) for level 2, and 1.74 (95% CI: 1.14 to 2.35) for level 3 (fastest) (P for trend = 0.001). The mean change in math scores was 0.41 (95% CI: −0.11 to 0.92) for level 1 (slowest), 1.44 (95% CI: 0.69 to 2.19) for level 2, and 1.43 (95% CI: 0.76 to 2.10) for level 3 (fastest) (P for trend = 0.019). The mean change in foreign language performance was −0.71 (95% CI: −1.08 to −0.33) for level 1 (slowest), 0.95 (95% CI: −0.40 to 1.50) for level 2, and 0.91 (95% CI: 0.41 to 1.41) for level 3 (fastest) (P for trend $<$ 0.001).

Conclusion: This study suggests that participation in jump rope and sit-up exercises may positively affect students' academic performance.

KEYWORDS

athletic ability, academic performance, Chinese, middle school students, 3-year follow-up study, primary school students

Introduction

Under the current education system in China, students' academic performance is the key to their access to higher education opportunities and superior educational resources, placing the question of how to effectively improve students' academic performance at the center of attention among society, schools, and families.

With the benefits of physical activity on children's physical development being universally acknowledged, a large number of foreign epidemiological surveys in recent years have also shown significant positive correlations between the amount and frequency of physical activity that the adolescent children participated in and their school behavioral performance (1–3). This correlation can be evidenced by the finding of Chaddock et al. (4) who discovered that exercise reduced activation of the prefrontal cortex and improved behavioral performance on executive control tasks in children. This association was further heightened by Han (5) study, which demonstrated that students with higher levels of physical fitness tended to have higher academic achievement. Based on many research results, experts in China, as well as in other countries, hope to help students improve their academic performance by increasing their engagement in physical activities. However, an objective and accurate evaluation of the frequency with which students participate in physical activity can be difficult to achieve in practice. Compared with frequency measurement, a comprehensive exercise capacity measurement is not only more accurate but also easier and faster to conduct and, thus, can truly reflect the daily physical activity level.

While there is no shortage of studies investigating the association between physical activity and children's behavior, most studies on the relationship between athletic ability and academic performance have been conducted in foreign countries (4, 6). The populations are mostly secondary school and college students. In the meantime, studies have yet to be conducted among Chinese students. Therefore, the object of the evaluation was to broaden the empirical base with a focus on Chinese students in primary school. Through the test of sports ability and academic performance of 1,136 third-grade primary school students in Chengdu, this study explores the relationship between sports ability and academic performance to provide theoretical support for improving primary school students' academic performance.

Materials and methods

Study population

The initial study was conducted in June 2019 among school children in Cheng du, China. The initial sample consisted of 1,494 pupils from primary schools, aged 10–11 (mean 10.6) years. These children underwent an athletic ability examination and completed a self-administered questionnaire; this provided information on demographics, academic performance, anthropometrics, and lifestyle factors. The same methodology was used on a follow-up, which will

TABLE 1 Single item scoring table for boys' 1-min jump rope (unit: times).

Grade	Score	Third grade	Fourth grade	Fifth grade	Sixth grade
Excellent	100	126	137	148	157
	95	121	132	143	152
	90	116	127	138	147
Good	85	110	121	132	141
	80	104	115	126	135
Pass	78	97	108	119	128
	76	90	101	112	121
	74	83	94	105	114
	72	76	87	98	107
	70	69	80	91	100
	68	62	73	84	93
	66	55	66	77	86
	64	48	59	70	79
	62	41	52	63	72
	60	34	45	56	65
Fail	50	31	42	53	62
	40	28	39	50	59
	30	25	36	47	56
	20	22	33	44	53
	10	19	30	41	50

TABLE 2 Single item scoring table for girls' 1-min jump rope (unit: times).

Grade	Score	Third grade	Fourth grade	Fifth grade	Sixth grade
Excellent	100	139	149	158	166
	95	132	142	151	159
	90	125	135	144	152
Good	85	117	127	136	144
	80	109	119	128	136
Pass	78	102	112	121	129
	76	95	105	114	122
	74	88	98	107	115
	72	81	91	100	108
	70	74	84	93	101
	68	67	77	86	94
	66	60	70	79	87
	64	53	63	72	80
	62	46	56	65	73
	60	39	49	58	66
Fail	50	36	46	55	63
	40	33	43	52	60
	30	30	40	49	57
	20	27	37	46	54
	10	24	34	43	51

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be explained in detail in the following paragraphs. Each child's family, contacted by phone, was informed about the study's aim and invited to participate. Meanwhile, certain participants were excluded for the following reasons:

failure to provide written informed consent for analysis of their data ($n = 12$),
missing data for the assessment ($n = 133$) or other variables ($n = 65$),
existing contraindications to exercise ($n = 75$),
body deformity ($n = 10$) at the baseline, and
missing athletic ability assessment data for 2022 ($n = 63$).

Therefore, the follow-up study included 1,136 (634 male and 502 female) participants. Ethics approval was obtained from the Institutional Review Board of the College of Physical Education of Southwest University, and written parental consent for the minors was also received before the study began.

Measurement of athletic ability

Students' muscular endurance was assessed using 1-min rope skipping and 1-min sit-ups. The total duration of the assessment was 20 min, with rope skipping and sit-up assessment taking up 5 min and the follow-up questionnaire 15 min. The exercise ability of the investigated population was tested in June 2019, June 2021, and June 2022, respectively. The 1-min rope jumping test requires the subject to stand in the test area, start jumping rope after hearing the instructions in 3.2.1, and stop jumping rope after hearing the end instructions. The sensor would automatically record and save the test results, and this test uses the h5 tester. One-min setup requires the subject to lie on the mat, legs slightly apart, feet set on the padded instrument, knees at an approximately 90-degree angle, two fingers crossed on the back of the brain, and waist with a special electronic test belt. The participant begins to sit up when the instrument is heard to emit a "drop drop" chime. Sitting on the back must be coherent, and there is a tone. The instrument automatically counts 1. If one up and one sitting action are not in place, with no tone, then this sit-up would not count. The athlete ability of students is evaluated based on the physical health standards of Chinese students. The specific evaluation standards are as follows: During the test, we found that the number of failed students was small, and it was pointless to classify them separately for data analysis. Therefore, the passing grade and the failing grade were combined. Thus, in the subsequent data analysis, 1-min rope skipping and 1-min sit-ups were three classified variables. The evaluation criteria are shown in Tables 1–4.

Assessment of academic performance

This survey takes the students' Chinese, mathematics, and English scores in a 90-min examination at the end of the academic year as the core criterion for academic performance evaluation. The

TABLE 3 Scoring table of 1-min sit-ups for boys (unit: times).

Grade	Score	Third grade	Fourth grade	Fifth grade	Sixth grade
Excellent	100	48	49	50	51
	95	45	46	47	48
	90	42	43	44	45
Good	85	39	40	41	42
	80	36	37	38	39
Pass	78	34	35	36	37
	76	32	33	34	35
	74	30	31	32	33
	72	28	29	30	31
	70	26	27	28	29
	68	24	25	26	27
	66	22	23	24	25
	64	20	21	22	23
	62	18	19	20	21
	60	16	17	18	19
Fail	50	14	15	16	17
	40	12	13	14	15
	30	10	11	12	13
	20	8	9	10	11
	10	6	7	8	9

TABLE 4 Single score table of 1-min sit-ups for girls (unit: times).

Grade	Score	Third grade	Fourth grade	Fifth grade	Sixth grade
Excellent	100	46	47	48	49
	95	44	45	46	47
	90	42	43	44	45
Good	85	39	40	41	42
	80	36	37	38	39
Pass	78	34	35	36	37
	76	32	33	34	35
	74	30	31	32	33
	72	28	29	30	31
	70	26	27	28	29
	68	24	25	26	27
	66	22	23	24	25
	64	20	21	22	23
	62	18	19	20	21
	60	16	17	18	19
Fail	50	14	15	16	17
	40	12	13	14	15
	30	10	11	12	13
	20	8	9	10	11
	10	6	7	8	9

TABLE 5 The participants' baseline characteristics, according to categories of 1-min jump rope and 1-min sit-ups.

Characteristic		One min rope skipping				One minute sit ups			
		Lower ($N = 565$)	Middle ($N = 341$)	Upper ($N = 230$)	P for linear trend	Lower ($N = 391$)	Middle ($N = 400$)	Upper ($N = 340$)	P for linear trend
Sex	Male	313	176	145	0.005	235	197	197	0.045
	Female	252	165	85		156	203	143	
Age (years)		10.40 (10.36, 10.44)	10.35 (10.30, 10.40)	10.1 (10.23, 10.35)	0.014	10.32 (10.27, 10.37)	10.38 (10.34, 10.43)	10.40 (10.35, 10.45)	0.064
Only child	Yes	432	235	175	0.74	235	309	298	<0.001
	No	133	106	50		156	91	42	
Body mass index (kg/m2)		20.50 (19.88, 21.12)	19.42 (19.07, 19.77)	18.82 (18.57, 19.07)	0.000	20.97 (20.54, 21.39)	18.71 (18.43, 18.99)	18.20 (17.93, 18.47)	<0.001
Sleep quality		8.00 (7.74, 8.26)	7.77 (7.50, 8.04)	7.66 (7.32, 7.99)	0.26	8.01 (7.73, 8.31)	7.54 (7.27, 7.80)	8.06 (7.75, 8.38)	0.018
Depression level		12.16 (11.47, 12.85)	11.92 (11.15, 12.69)	11.42 (10.50, 12.34)	0.48	12.90 (12.03, 13.76)	11.95 (11.20, 12.71)	11.12 (10.37, 11.85)	0.008
Parents marital status	First marriage	371	255	158	0.87	268	269	247	0.23
	Divorce	80	39	26		53	49	43	
	Remarriage	114	47	41		70	82	50	
Father education	High school degree or below	467	293	193	0.19	336	328	289	0.68
	Bachelor degree or above	98	48	32		55	72	51	
Mather education	High school degree or below	456	286	186	0.73	319	311	280	0.091
	Bachelor degree or above	109	73	39		72	89	60	
Mobile phone usage (h/Day)	<1 h	413	259	189	0.02	310	313	238	0.001
	1–2 h	132	68	34		75	73	86	
	>2 h	20	14	2		16	14	6	
Left-behind children	Yes	57	35	21	0.001	42	36	35	0.841
	No	508	306	204		349	364	305	

Continuous variables without a normal distribution were log-transformed and are expressed as the estimated geometric means (95% confidence intervals). Linear trends were assessed using ANCOVA for continuous variables and logistic regression analyses for categorical variables.

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TABLE 6 Multivariable-adjusted relationships of 1-min jump rope with change in academic performance during the 3-year follow-up period.

	$n = 1{,}131$	Number of participants	Model 2[a]	Model 2[b]	Model 3[c]
Chinese	1 (slowest)	322	0.40 (−0.66, 0.86)	0.31 (−0.15, 0.78)	0.30 (−0.16, 0.76)
	2	260	1.09 (0.42, 1.76)	1.17 (0.50, 1.84)	1.09 (0.42, 1.76)
	3 (Fastest)	549	1.59 (0.98, 2.19)	1.67 (1.05, 2.28)	1.74 (1.14, 2.35)
	Pd		0.008	0.002	0.001
Maths	1 (slowest)	322	0.89 (−0.12, 0.90)	0.39 (−0.13, 0.89)	0.41 (−0.11, 0.92)
	2	260	1.13 (0.58, 2.06)	1.35 (0.61, 2.09)	1.44 (0.69, 2.19)
	3 (Fastest)	549	1.59 (0.92, 2.25)	1.48 (0.81, 2.15)	1.43 (0.76, 2.10)
	Pd		0.01	0.016	0.019
English	1 (slowest)	322	−0.72 (−1.09, −0.34)	−0.71 (−1.09, −0.34)	−0.71 (−1.08, −0.33)
	2	260	0.93 (0.38, 1.47)	0.92 (−0.39, 1.47)	0.95 (−0.40, 1.50)
	3 (Fastest)	549	0.93 (0.44, 1.43)	0.94 (0.44, 1.44)	0.91 (0.41, 1.41)
	P[d]		<0.001	<0.001	<0.001

[a]Model 1: Adjusted for sex (categorical variable) and age (continuous variable) at the baseline. [b]Model 2: Adjusted for the variables in model 1 and parents' educational level (categorical variable: high school degree or below and bachelor degree or above), parents' marital status (categorical variable: first marriage, divorce, or remarriage), BMI (continuous variable), only child (categorical variable: yes or no), and left-behind children (categorical variable: yes or no) at the baseline. [c]Model 3: Adjusted for the variables in model 2 and sleep quality (continuous variable), mobile phone usage (h/Day, categorical variable:<1 h, 1–2 h, and >2 h), depression level (continuous variable) at the baseline. [d]Linear trends were assessed using ANCOVA.

academic achievements of the survey population were collected in June 2019, June 2021, and June 2022, respectively. The grade was coded as follows: 4 outstanding (>90), 3 good (89–80), 2 passed (79–60), and a failure (<60).

Confounding variables

Demographic variables and lifestyle factors were assessed using a self-administered questionnaire. Variables and factors assessed by the questionnaire included: sex (males or females), age (continuous variable), only child (yes or no), self-reported body mass index (continuous variable), parents' marital status (first marriage, divorce, or remarriage), mobile phone usage (h/day) (<1 h, 1–2 h, or >2 h), and left-behind children (which means children who grow up away from their parents) (yes or no) with established reliability and validity for assessing subjective sleep quality and quantitative sleep–wake parameters in the previous month (from self-reported measurements of sleep latency, duration, and efficiency). The answers to the 19 questions in PSQI are divided into seven parts in proportion, with a total score of 0–21. The higher the score, the worse the sleep (7). The Beck Depression Inventory (BDI) (8) was used to examine the severity of depression. It consists of 21 items. A higher score means a more severe depressive state.

Statistical analysis

All statistical analyses were performed with SPSS software (version 20.0; SPSS, Chicago, IL, USA). For the baseline characteristics of participants, continuous variables are expressed as means and 95% confidence intervals, and categorical variables are expressed as percentages. Continuous data with skewed distributions, as determined using the Kolmogorov–Smirnov test, were logarithmically transformed. Analysis of covariance (ANCOVA) and logistic regression analysis were used to compare the baseline characteristics of the categorized group after adjustment for sex and age. One-min rope skipping and 1-min sit-ups were considered independent variables, and baseline variables were considered dependent variables. ANCOVA was also used to estimate the change in academic performance based on the categories of 1-min rope skipping and 1-min sit-ups. Model 1: adjusted for sex (categorical variable) and age (continuous variable) at the baseline. Model 2: adjusted for the variables in Model 1 and parents' educational level (categorical variable: high school degree or below and bachelor degree or above), parents' marital status (categorical variable: first marriage, divorce, or remarriage), BMI (continuous variable), only child (categorical variable: yes or no), and left-behind children (categorical variable: yes or no), at the baseline. Model 3: adjusted for the variables in Model 2 and sleep quality (continuous variable), mobile phone usage (h/day, categorical variable: <1 h, 1–2 h, and >2 h), and depression level (continuous variable) at the baseline.

Results

The participants' baseline characteristics, according to categories of 1-min rope skipping and 1-min sit-ups, are shown in Table 5. Participants who reported higher levels of 1-min jump rope were generally younger, had lower body mass index, spent less time on their phones, and consisted of a higher proportion of males and a lower proportion of left-behind children (*P* for trend: 0.014, <0.001, 0.02, and 0.001, respectively). Other baseline characteristics did not differ significantly between categories. Similarly, participants with higher levels of 1-min sit-ups were reported to have higher proportions of males and only children, lower body mass index, better sleep quality, lower levels of depression, and less cell phone usage (P for trend: 0.05, <0.001, <0.001, 0.018, 0.008, and <0.001, respectively). Table 6 shows the relationship between a 1-min jump rope grade at the baseline and a change in academic performance during the 3-year follow-up. After adjusting for all covariates, the higher the 1-min jump rope grade, the higher the improvement in test scores. In Model 3, the mean change in Chinese language

TABLE 7 Multivariable-adjusted relationships of 1-min sit-ups with change in academic performance during the 3-year follow-up period.

	$n = 1{,}131$	Number of participants	Model 2[a]	Model 2[b]	Model 3[c]
Chinese	1 (slowest)	276	0.38 (−0.34, 1.11)	0.29 (−0.44, 1.02)	0.35 (−0.37, 0.76)
	2	436	1.09 (−0.12, 1.13)	0.53 (−0.39, 1.10)	0.52 (−0.54, 1.08)
	3 (Fastest)	419	1.59 (1.07, 2.24)	1.75 (1.16, 2.33)	1.72 (1.14, 2.30)
	Pd		0.008	0.002	0.003
Maths	1 (slowest)	276	0.66 (−0.65, 0.78)	0.20 (−0.52, 0.93)	0.28 (−0.50, 0.95)
	2	436	0.99 (0.41, 1.55)	0.97 (0.40, 1.54)	0.95 (0.38, 1.52)
	3 (Fastest)	419	1.48 (0.89, 2.06)	1.40 (0.82, 1.99)	1.41 (0.82, 1.99)
	Pd		0.011	0.045	0.048
English	1 (slowest)	276	−0.38 (−0.91, 0.16)	−0.46 (−1.00, 0.84)	−0.45 (−0.99, −0.93)
	2	436	0.22 (−0.45, 0.40)	−0.12 (−0.44, 0.42)	−0.14 (−0.44, 0.41)
	3 (Fastest)	419	0.65 (0.21, 1.08)	0.69 (0.25, 1.13)	0.69 (0.25, 1.13)
	P[d]		0.009	0.004	0.004

[a]Model 1: Adjusted for sex (categorical variable) and age (continuous variable) (categorical variable) at the baseline. [b]Model 2: Adjusted for the variables in model 1 and parents' educational level (categorical variable: high school degree or below and bachelor degree or above), parents' marital status (categorical variable: first marriage, divorce, or remarriage), BMI (continuous variable), only child (categorical variable: yes or no), and left–behind children (categorical variable: yes or no) at the baseline. [c]Model 3: Adjusted for the variables in model 2 and sleep quality (continuous variable), mobile phone usage (h/Day, categorical variable: <1h, 1–2h, and >2h), and depression level (continuous variable) at the baseline. [d]Linear trends were assessed using ANCOVA.

performance in the 1-min jump rope grade was 0.30 (95% CI: −0.16 to 0.76) for level 1 (slowest), 1.09(95% CI: 0.42 to 1.76) for level 2, and 1.74 (95% CI: 1.14 to 2.35) for level 3 (fastest) (*P* for trend = 0.001); the mean change in mathematics performance in the 1-min jump rope grade was 0.41 (95% CI: −0.11 to 0.92) for level 1 (slowest), 1.44 (95% CI: 0.69 to 2.19) for level 2, and 1.43 (95% CI: 0.76 to 2.10) for level 3 (fastest) (*P* for trend = 0.019). The mean change in foreign language performance in the 1-min jump rope grade was −0.71 (95% CI: −1.08 to −0.33) for level 1 (slowest), 0.95(95% CI: −0.40 to 1.50) for level 2, and 0.91 (95% CI: 0.41 to 1.41) for level 3 (fastest) (*P* for trend <0.001).

Table 7 shows the relationship between 1-min sit-ups grade at the baseline and change in academic performance during the 3-year follow-up. After adjusting for all covariates, the higher the 1-min sit-ups grade, the higher the improvement in testing score. In Model 3, the mean change in Chinese language performance in the 1-min jump rope grade was 0.35 (95% CI: −0.37 to 0.76) for level 1 (slowest), 0.52 (95% CI: −0.54 to 1.08) for level 2, and 1.72 (95% CI: 1.14 to 2.30) for level 3 (fastest) (*P* for trend = 0.003); the mean change in mathematics performance in the 1-min jump rope grade was 0.28 (95% CI: −0.50 to 0.95) for level 1 (slowest), 0.95 (0.38 to 1.52) for level 2, and 1.41 (95% CI: 0.82 to 1.99) for level 3 (fastest) (*P* for trend = 0.048). The mean change in foreign language performance in the 1-min jump rope grade was −0.45(95% CI:−0.99 to−0.93) for level 1 (slowest), −0.14 (95% CI: −0.44 to 0.41) for level 2, and 0.69 (95% CI: 0.25 to 1.13) for level 3 (fastest) (P for trend = 0.004).

Discussion

This 3-year longitudinal study examined the relationship between 1-min jump rope and sit-up grades with academic performance over time in Chinese students. These results showed that higher baseline grades of 1-min jump rope and sit-up were significantly associated with increased academic performance after adjusting for confounding factors These results showed that the better performance of these two tests at the baseline is associated with better academic achievement in the follow-up. Our findings suggest that performing 1-min jump rope and sit-up exercises has a positive effect on the academic performance of Chinese students.

The results of this longitudinal study support the hypothesis that higher levels of 1-min jump rope and 1-min sit-ups at the baseline were significantly associated with improved academic performance among Chinese children at 3 years of follow-up. The result of the study is generally consistent with the results of previous studies, such as Liao et al. (9) who found a significant positive correlation between curl scores and students' academic performance in a curl test administered to Taiwanese high school students. The result is also in line with that of Kim et al. (10) study showing that 12 weeks of skipping rope training was effective in improving the academic self-efficacy of obese female students, which in turn led to a boost in academic performance. Chen et al. (11) found that jump rope training was effective in improving cardiovascular fitness, muscular endurance, flexibility and strength, and cognitive function in a 12-week exercise intervention with obese adolescents. The 1-min rope skipping mainly tests the children's muscular endurance level, which can also reflect the students' coordination and speed quality to a certain extent. On the other hand, the 1-min sit-ups mainly test the students' abdominal flexor and hip muscle endurance levels. The results of this study infer that levels of muscular endurance may affect students' academic performance. This result is consistent with previously reported findings in children and adolescents, which suggest that adding muscular endurance training to our daily exercise routine may help to improve academic performance in elementary school students. Bass et al. (12) study found that male middle school students with higher levels of muscular endurance were 2–5 times more likely to pass math and reading tests than students with lower levels.

However, it is worth mentioning that some studies have shown no significant correlation between students' academic performance and muscle function. This may be due to differences in the age of the respondents, as well as differences in muscle function testing methods and test content. For the relationship between muscular endurance and academic performance, we infer that the reason may be due to the fact that levels of muscular endurance were in several aspects related to cognitive function, such as attention, memory, and reaction speed, a finding supported by Shigeta et al. (13). Therefore, students with higher levels of muscular endurance are normally better than students with low levels of muscular endurance, which may be one of the reasons for the difference in their academic performance; second, students with higher muscular endurance may do more muscle exercises or physical activities that require muscles in daily life. Kobilo et al. (14) found that treatment with the adenylate-activated protein kinase activator AICAR significantly enhanced the spatial memory of aged mice, whereas skeletal muscle-specific AMPKα2 subunit knockdown inhibited this effect, suggesting a strong link between the skeletal muscle and brain. Nearly 10 years of research found that the skeletal muscle is an endocrine organ that can produce and release cytokines and peptides that affect brain metabolism during muscle contraction. For example, exercise can modulate brain-derived neurotrophic by stimulating skeletal muscle BDNF (brain-derived neurotrophic factor), isrisin (Iris), interleukin-6 (IL-6) (CTSB), Exercise can modulate, for example, brain-derived neurotrophic by stimulating skeletal muscle BDNF (brain-derived neurotrophic factor), isrisin (Iris), interleukin-6 (IL-6) (CTSB), muscle growth inhibitor (MSTN), insulin-like growth factor-1 (IGF-1), vascular endothelial growth factor (VEGF), and myostatin (MSTN), level. After entering the blood circulation, the related muscle factors can cross the blood–brain barrier (BBB) and are involved in maintaining neuronal structure and function structure and function, improving synaptic plasticity, reducing central inflammation, and increasing cerebral angiogenesis. Brain-derived neurotrophic factor (BDNF) is a member of the neurotrophic factor family and is currently the most studied neurotrophic factor involved in the regulation of adult neurogenesis and synaptic plasticity muscle factors involved in the regulation of neurogenesis and synaptic plasticity in adults. Studies have shown that circulating BDNF crosses the blood–brain barrier and can stimulate the production of the hippocampus to stimulate central trophic factor production and improve short-term cognitive performance and long-term morphological adaptation in the brain. Longitudinal studies have shown that during exercise, skeletal muscle secretes a transcriptional co-activator called PGC-1α of which FNDC5 is a downstream protein. During exercise, FNDC5 is broken down into irisin in the exercising muscle (15). Irisin is associated with neural differentiation, crosses the blood–brain barrier, acts on endothelial cell receptors or brain BDNF receptors, and directly regulates hippocampal gene expression. Brain-derived neurotrophic factor (BDNF) promotes neurotic proliferation, growth, differentiation, and synaptic regeneration, which are key functions related to learning, memory, and biological regeneration (16). Thus, frequent muscle activity may improve brain metabolism by enhancing the production of cytokines and peptides. This study shows that regular participation in rope skipping and sit-ups can effectively improve the academic performance of primary school students.

One limitation of this study, inherited from previous morpheme studies, is that the subjects of this survey are primary school students in Chengdu, which means that the findings are not wholly generalizable to students in other areas and whether the research results can be applied to other regions and populations need further research. Second, although the survey is conducted through the authoritative scale, the subjective factors of participants may still affect the research results.

Conclusion

In conclusion, after adjusting many covariates, this study found that higher levels of 1-min jump rope and 1-min sit-ups at the baseline were significantly associated with improved academic performance among Chinese children at 3 years of follow-up. This study suggests that participation in jump rope and sit-up exercises may positively affect the improvement of students' academic performance. Further intervention studies are needed to explore the causality between 1-min jump rope and sit-up grades with academic performance.

Data availability statement

The original contributions presented in the study are included in the article/supplementary files, further inquiries can be directed to the corresponding author.

Ethics statement

Ethics approval was obtained from the Institutional Review Board of the College of Physical Education of Southwest University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

HJ, CB, and YY have given substantial contributions to the conception or the design of the manuscript. QY, WP, ZM, ZX, GZ, XL, ZF, WJ, and LK contributed to the acquisition, analysis and interpretation of the data. TY made an important contribution to the polishing of the manuscript. HJ had critically revised the manuscript. All authors participated to drafting the manuscript, read, and approved the final version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Effectiveness of Brainball program on physical fitness of primary school pupils in Vietnam. A longitudinal study

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Objective: The present study aimed to evaluate the effectiveness of the Brainballs on the physical fitness of 2nd-grade students at a primary school in Vietnam during and eight months after the experiment.

Methods: The study included 55 pupils (23 boys and 32 girls) aged seven years. The study design was a pedagogical experiment with a parallel-group technique, including experimental and control groups. The examination was carried out in 2019/2020 in three terms pre- (September 2019), post- (January 2020), and follow-up (September 2020). Physical fitness was tested with the use of the International Physical Fitness Test. The Brainball program, conducted twice a week for 35 minutes, combined physical education (PE) with subject-related content, utilizing 100 balls with painted letters, numbers, and signs.

Results: Results show that the fitness level was not increased significantly after 20 weeks of the intervention program, neither in experimental nor control groups. However, it significantly improved eight months later at the follow-up examination. The analysis of covariance indicated that pupils from the experimental group improved significantly on most physical fitness as compared to the control group, specifically on the following tests: 50-meter running ($p = 0.0044$), toe touch ($p = 0.0137$), standing long jump ($p = 0.0076$), 4 × 10 m sprint ($p = 0.0333$), hand strength ($p = 0.0233$).

Conclusions: These results have shown long-term positive effects of the use of "Brainball" educational balls in physical education classes on the physical fitness development of students, especially in the qualities of speed, strength, and flexibility.

KEYWORDS

Brainball, educational balls, physical education, 2nd-grade students, integrated teaching

1. Introduction

Evidence (1) proves that physical activity (PA) plays a fundamental role in stimulating a sound development of a growing child. It supports optimal biological growth, physical development, and psychological health (1). Researchers and education experts agree that PA and spontaneous play remain essential in a child's overall development (2). The PA in childhood may have numerous benefits on health, brain and emotional functioning (3, 4). Findings from research (5–7) indicate that PA if taken regularly, enhances the strength of bones and muscles. It also improves the cardiovascular system with better blood circulation, thus reducing the risk of chronic diseases such as (obesity, cancer, cardiovascular disease, diabetes, and metabolic syndrome) (7). In addition, the World Health Organization (WHO) recommends that children and adolescents aged 5–17 should take at least 60 min of moderate to vigorous-intensity PA daily to improve cardiorespiratory and muscular fitness, bone health and reduce symptoms of anxiety and depression (8).

For children and adolescents, PA includes games, sports, recreation, physical education (PE), or planned exercise as part of the family, school, and community activities (8). However, recent research shows that schools are ideal environments to encourage long-term regular physical activity (9, 10) and that physical education provides students with the opportunity to engage in enjoyable physical activity, become physically fit, and learn general motor and behavioral skills (11). The importance of physical education in child and adolescent development has been demonstrated by many researchers around the world (9, 10, 12, 13). These authors agree that an appropriate physical education program that focuses on fun games and exercise can help students have more significant opportunities to participate in physical activity and has many physical and mental health benefits. In a study aimed at determining the effectiveness of using Ringo games in physical education classes (14), the authors showed that after an experimental semester, students in the game-based program demonstrated higher fitness than those in the traditional exercise group program. Other research, in Italy (15), interwoven 2 h of intervention scheduled into regular school curricula, where the contents was designed and supervised by professional PE experts. The findings of the study after 8 months of implementation indicated that studying PE in the school settings can be very helpful with school-aged children to foster their physical, mental, and psychological health.

In an effort to find a new teaching method to improve teaching and learning for students, researchers at the Wroclaw University of Health and Sports Science, Poland, have created an active teaching method called Eduball/Brainball. The primary teaching method of the program is to use games and exercises designed with educational balls to integrate the contents of other subjects into physical education classes (16, 17). After years of research, researchers have proven that using fun games and exercises along with educational balls in physical education classes has positively impacted children's physical fitness (16, 18), motor skills (19–22), eye-hand coordination, and spatial awareness (23–26). Children who participated in pedagogical experiments with Eduball significantly improved their language skills and achieved better math scores than children in the control group (16, 27–29).

The idea of the educational balls was coined in 2002 in the Department of Team Sports Games at the Wroclaw University of Health and Sport Sciences, Poland. The first name of educational balls was "Edubal." After 10 years of experience and research with Edubals, the set was modified and the next edition of educational balls, called "Eduball," was prepared. In 2018, the English edition of education balls called "Brainball" started; although the name is different, the idea of Edubal/Eduball/Brainball is the same; children learn while playing! (30).

Researchers have found that physical activities with balls are the favorite forms for children. They designed the educational balls by adding numbers, letters, and mathematical symbols on the balls' surface and adjusting the balls' size to fit the children's body size (from 6 to 9 years old) (31). The set of Brainball consists of 100 balls for mini team sports games (basketball and soccer) in five colors (yellow, green, blue, red, and orange) with painted (black) letters of the alphabet (uppercase and lowercase letters); numbers (from 0 to 9); and signs of mathematical operations [addition (+), subtraction (–), multiplication (*), division (:), greater than (>), less than (<), parentheses (), and the at sign (@)] (30). The numbers, letters, signs, and colors of the educational balls make their extensive use possible in almost all school subjects. They can be used to teach native languages (Polish or English), foreign languages (English or Spanish), mathematics, history, biology, geography, etc. (30). The games and exercises of Brainball are based on natural forms of movement (running, jumping, throwing, catching, etc.) combined with physical activity so that students can easily acquire and improve basic motor skills and develop physical and academic fitness achievements (27, 32).

Eduball/Brainball has been implemented in the official list of teaching aids for elementary schools in Poland. They were accredited and approved by the Polish National Ministry of Education. Eduball/Brainball has also been launched and confirmed its benefits in Germany, Portugal, Finland, Greece, the USA, Singapore, and Taiwan (China) (28). However, there are no scientific studies evaluating Eduball/Brainball program in Vietnam. This study aimed to investigate whether teaching PE with Brainball can have similar impact and significance on the physical fitness levels of elementary pupils in Vietnam.

2. Methods

2.1. Participants

The research sample was students from two second-grade classes in a primary school in the center of An Giang province, a province located in the Mekong Delta region of Southern Vietnam. A total of 55 students (23 boys and 32 girls, ages: 7) participated in the study. The study was conducted during the 2019–2020 academic year. The study design included pedagogical experiments using parallel grouping techniques under natural conditions. Participants were randomly divided into a control group of 27 students (11 boys and 16 girls) and an experimental group of 28 students (12 boys and 16 girls). The teaching process of both groups (experimental group and control group) was conducted according to the same curriculum prescribed by the Ministry of Education and Training of Vietnam. The only difference is the introduction of Brainball into the teaching and learning in the experimental group. All participants' parents and guardians signed informed consent for their children to participate in this study. The study was approved by the local Ethics Committee for Research Involving Human Subjects (Senate Committee on Ethics of Scientific Research at the Wroclaw University of Health and Sport Sciences on September 22, 2010). It was conducted according to the principles of the Declaration of Helsinki.

The experimental factor was a PE program combined with Brainball games and exercises (Table 1). The experimental group participated in physical education classes twice a week for 35 min

TABLE 1 Physical education of experimental and control groups.

Experimental group	Control group
- Warm up	- Warm up
- PE unit	- PE unit
- Brainball games and exercises	- Drills
- Cool down	- Cool down

each and integrated with Brainballs for 5 months (one semester). Each class includes warm-up periods (5 min), Brainball games and exercises (15 min), physical education lessons (10 min), and cool down (5 min). The teacher guides the students to perform movement exercises at the warm-up stage. At the Brainball games and exercises stage, the teacher teaches students to play 2–3 games or exercises. Most games and activities involve movement, such as running, jumping, throwing, catching, etc.

In the control group, physical education classes also took place twice a week for 35 min and were conducted using traditional styles (without Brainballs). The same PE teacher with 10 years of experience, taught physical education in both groups (experimental group and control group). Due to the experiment the teacher was trained in the Brainball method to organize and perform games and exercises with these balls.

2.2. Research tool

The International Physical Fitness Test (33) was used to assess the physical fitness level of students. Seven of the eight tests of the International Fitness Test were performed, including the 50-meter sprint, standing long jump, hand strength, bent arm hang, 4 × 10 m sprint, sit-ups, and forward bend. The 600 m sprint test was rejected for lack of parental consent.

2.2.1. 50-meter sprint

At the command "on your marks," the pupil doing the exercise stands still in front of the starting line with one leg put forward (a so-called standing start). Then, at the "start" signal, he runs to the finish as quickly as possible. Time is measured with an accuracy of 0.1 s.

2.2.2. Standing long jump

The subject stands with legs extended; naturally, toes are placed close to the boundary line; when jumping and landing, both feet do it simultaneously. The jump length is measured from the setline (beam) to the nearest footstep left by the jumper's heel. The result is the longest distance jumped, the best of two attempts.

2.2.3. Hand strength

The subject stands with feet shoulder-width apart. The dominant hand holds the dynamometer toward the palm and extends straight along the body. The subject performed the exercise by reducing the dynamometer to maximum power. The result is the highest of two attempts.

2.2.4. Bent-arm hang

The task is to remain as long as possible, hanging with arms bent in elbow joints. Upon starting the test, the person doing the exercise holds the bar with fingers directed downwards and the thumb from the bottom upwards, at the shoulders' breadth, so that his chin would be above the bar. The test starts when the person doing the exercise hangs on the bar unaided and ends when his eyes go below the bar. Time is measured in 0.1-s units.

2.2.5. Sit-ups

The subject lies supine on a mattress, knees bent, hands clasped on the neck, and performs sit-ups, feet held firmly by an assistant. The result is the exact number of sit-ups in 30 s.

2.2.6. 4 × 10 m sprint

The subject stands with one foot forward (standing start) in front of the starting line. On signal, the subject runs to the finish line to pick up a block, runs back, and places the block behind the start line. The subject then runs back to the finish line, picks up a second block, and runs back to put it behind the start line. If the block is thrown and not placed behind the starting line, the test is considered invalid and must be repeated. Time is measured with an accuracy of 0.1 s.

2.2.7. Forward bend

The subject was not wearing shoes, stood on a stool or bench, toes placed close to the edge of the stool, feet together, and knees straight. From this position, the person doing the exercise bends forward with a continuous movement to reach the furthest with his fingers. Such a position of a maximum bend must be kept for 2 s. If the person doing the exercise reaches the level he is standing on while bending with a continuous movement, he scores 0. He scores a plus point for every centimeter below the surface of the stool. Otherwise, he scores a minus point for every centimeter above the surface of the stool. The test is invalid if, during bending, the legs are bent in knee joints. Any vigorous movements during bends are not permitted, either. The result is the best of two attempts.

All measurements were taken in September 2019 (marking the beginning of academic year), and in January 2020 (20 weeks later, at the end of the first semester). The final, third examination took place in September 2020 (8 months after the end of the Brainball Intervention Program) to estimate the long-term impact. Technical researchers conducted fitness tests on the training ground during physical education classes. Measurements were carried out in a natural environment with the help of teachers and students. Additionally, principals, teachers, and parents approved information on testing procedures before testing.

2.3. Data analysis

Statistica software version 13.0 (Statsoft Polska Sp. z o.o., Krakow, Poland) was used for statistical analysis. The main dependent variables were the scores on the physical fitness test obtained by testing students in the control and experimental groups. First, the Shapiro-Wilk test confirmed the normal distribution of the physical fitness test. Then, the students' *t*-tests for the dependent variables were used to compare the differences in the mean parameters of the tests performed between the experimental and control groups. Next, to determine the statistically significant differences between the experimental and control groups after 1 year of study, an analysis of variance (ANOVA) was performed. Partial eta squared (ηp^2) was used to quantify the effect size (small effect = 0.01; medium effect = 0.06; large effect = 0.14) (34). Newmana-Keulsa's *post-hoc* test was used to confirm the importance of the differences between groups. Statistical significance was set at $p < 0.05$.

TABLE 2 The mean and standard deviation (SD) of the fitness test obtained by pupils from the experimental and control groups in the pre, post, and follow-up tests.

Variables		Evaluation stage				
		Pre-test	Post-test	*p*	Follow-up	*p*
50-meter running (s)	C	13.22 ± 0.30	13.08 ± 0.32	ns	12.42 ± 0.25	0.000
	E	13.40 ± 0.30	13.20 ± 0.31	ns	11.91 ± 0.24	0.000
	p-value	ns	ns		ns	
Toe touch (cm)	C	5.33 ± 0.63	6.08 ± 0.49	ns	8.22 ± 0.48	0.000
	E	3.54 ± 0.61	5.38 ± 0.48	ns	8.31 ± 0.47	0.000
	p-value	0.036	ns		ns	
Standing long jump (cm)	C	100.12 ± 2.35	100.36 ± 2.60	ns	113.70 ± 167	0.000
	E	101.29 ± 2.29	105.48 ± 2.54	ns	123.69 ± 1.63	0.000
	p-value	ns	ns		0.018	
4 × 10 m sprint (s)	C	16.30 ± 0.35	15.77 ± 0.23	ns	14.89 ± 0.23	0.000
	E	16.41 ± 0.33	15.48 ± 0.23	ns	14.22 ± 0.22	0.000
	p-value	ns	ns		ns	
Hand strength (kg)	C	10.41 ± 0.54	10.48 ± 0.45	ns	11.70 ± 0.33	0.000
	E	9.30 ± 0.53	9.86 ± 0.44	ns	11.67 ± 0.33	0.000
	p-value	ns	ns		ns	
Bent arm hang (s)	C	2.17 ± 0.17	2.56 ± 0.14	ns	3.83 ± 0.12	0.000
	E	2.37 ± 0.17	2.84 ± 0.14	ns	3.97 ± 0.12	0.000
	p-value	ns	ns		ns	
Sit-ups (num.)	C	8.31 ± 0.69	10.17 ± 0.53	ns	17.34 ± 0.72	0.000
	E	9.04 ± 0.67	11.35 ± 0.51	ns	17.40 ± 0.70	0.000
	p-value	ns	ns		ns	

C, Control group; E, Experimental group; ns, lack of statistical differences at $p < 0.05$.

3. Results

Table 2 presents data on the physical fitness level of pupils before and after the experiment in each group.

The results in Table 2 showed that there were no significant differences between the two groups (experimental and control groups) at the beginning of the experiment. Pupils of the experimental and control groups had no significant improvement in their physical fitness level after 20 weeks of the experiment (pre to post-test). However, the physical fitness level of pupils from the two groups improved significantly at the follow-up test, $p < 0.001$.

A repeated-measures analysis of variance ANOVA (2 × 2) was performed to compare the effectiveness of the Brainballs program on pupil physical fitness. The analysis showed that after 1 year of study, there were significant differences in the level of physical fitness improvement between the groups. Pupils in the experimental group were significantly better than those in the control group in most tests, especially the 50-meter run [$F_{(2,102)} = 5.72$, $p = 0.004$] and toe touch [$F_{(2,102)} = 4.47$, $p = 0.014$], standing long jump [$F_{(2,102)} = 5.11$, $p = 0.008$], 4 × 10-meter sprint [$F_{(2,102)} = 3.52$, $p = 0.033$], and hand strength [$F_{(2,102)} = 3.90$, $p = 0.023$; Table 3, Figure 1].

TABLE 3 Analysis of variance for physical fitness levels by group condition.

Variables	SS	MS	*F*	*p*	ηp^2
50-meter running (s)	3.98	1.99	5.72	0.004	0.101
Toe touch (cm)	23.86	11.93	4.47	0.014	0.081
Standing long jump (cm)	521	260	5.11	0.008	0.091
4 × 10 m sprint (s)	4.00	2.00	3.52	0.033	0.064
Hand strength (kg)	7.87	3.93	3.90	0.023	0.071
Bent arm hang (s)	0.15	0.08	0.38	ns	0.007
Sit-ups (num.)	8.54	4.27	0.59	ns	0.011

ns, lack of statistical difference at $p < 0.05$; SS, Sum of Squares; MS, Mean square; ηp^2, partial eta square.

4. Discussion

The main objective of this study was to evaluate the effectiveness of Brainball program on the physical fitness of 7-year-old children in a primary school in Vietnam. The Brainball program is an innovative, comprehensive educational program that encourages and provides

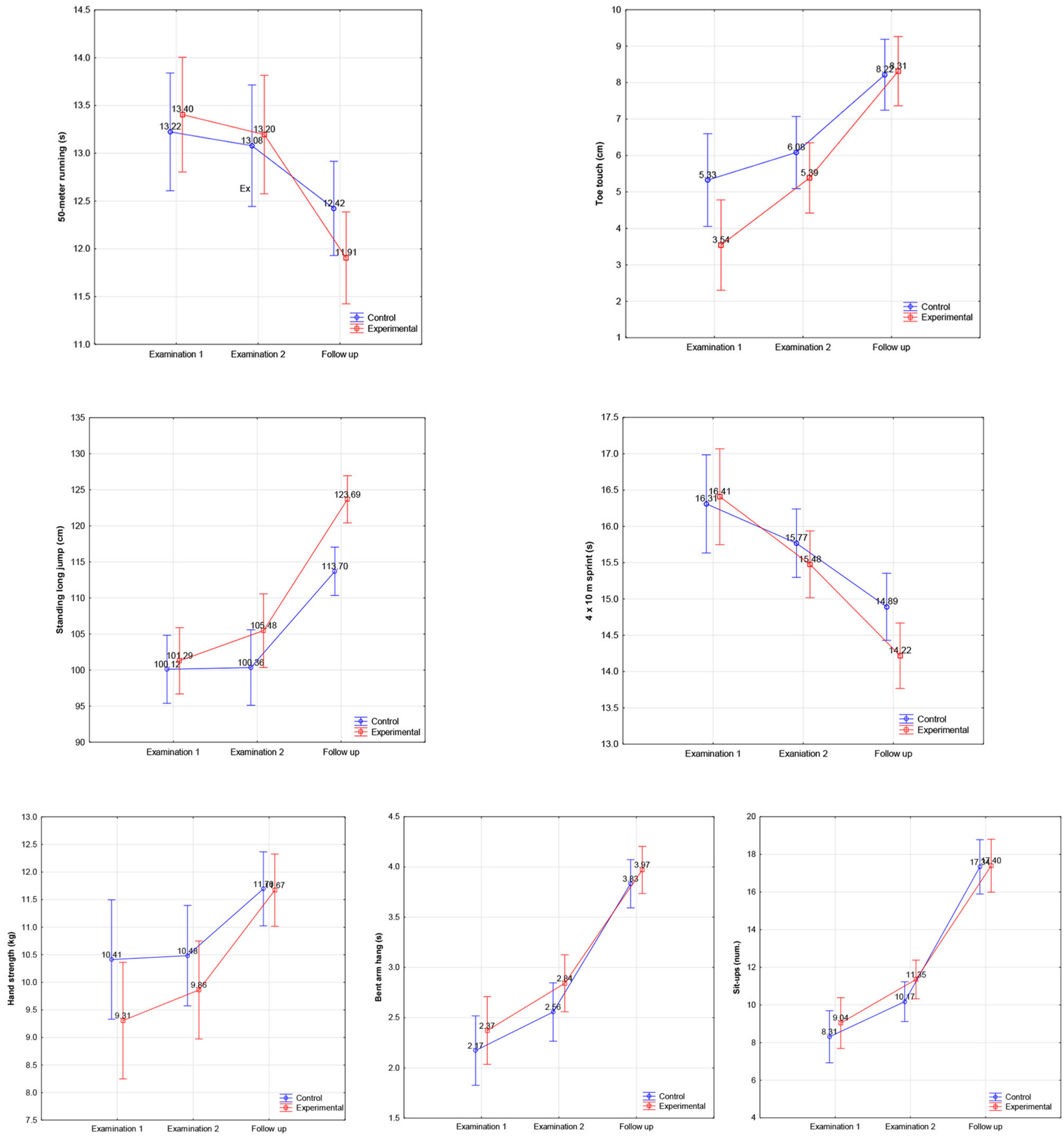

FIGURE 1
Physical fitness levels of pupils in the experimental and control groups at the first, second, and follow-up tests.

opportunities for intensive activities to improve health-related fitness and motor performance skills and enhance achievement learning to improve academic performance in comprehensive content. The study showed that after 20 weeks of the experiment, there was no significant difference in the level of physical development of the pupils in both groups (experimental and control groups). However, after a year of study, there were significant differences between the two groups. The improvement in physical fitness of the pupils in the experimental group was significantly better than that of the pupils in the control group, especially in 50-meter running ($p = 0.004$), toe touch ($p = 0.014$), standing long jump ($p = 0.008$), 4 × 10 m sprint ($p = 0.033$), and hand strength ($p = 0.023$) tests. These findings indicated that the Brainball program did not positively affect the pupils' physical fitness development in the experimental period, however, it showed progress in the follow-up, which may indicated long-term positive effects on the pupils' physical fitness development.

Previous studies found similar physical development results when using educational balls in PE classes for Polish preschool and primary school students (16, 18, 35, 36). Rokita (16) led a 3-year study (2004–2007) to assess the usefulness of the "Edubal" educational ball in engaging in physical activity combined with subject content (reading and writing). The study sample was students in grades 1–3 at two elementary schools. Each school has an experimental group and a control group. This is a longitudinal study with a total of six assessments of students' physical fitness (always at the beginning and end of each consecutive school year). The results of the study showed that the physical fitness development of the students was not affected by their participation in physical activities using the "Edubal" educational balls (16). Cichy and Rzepa (36) got similar results on the relationship between pupils' physical development and the use of educational ball in PE. Pupils participating in physical activities with educational balls do not adversely affect the change and development of their physical fitness. The authors concluded that lessons using educational balls could impact pupils' motor development as much as traditional lessons (36). Cichy (35) conducted a year-long study comparing the physical development, physical coordination, and learning abilities of first graders in traditional physical education classes compared to non-traditional classes. The findings suggest that a non-traditional curriculum using educational balls in physical education did not result in adverse changes in physical ability and general physical coordination but contributed to the more effective achievement of learning goals at this stage (35).

In this study, the application of the Brainball program to PE classes during the experiment did not affect the fitness of the pupils in the experimental group. One of the reasons can be provided by the relatively short practice time with Brainball (twice a week, 35 min each time). Compared with previous studies, when educational balls were applied in Poland (3 times a week, 45 min each time) in case of Vietnamese intervention the time duration (2 times a week 35 min) might have been an issue. Exciting physical activities with colorful balls (Brainball) could help pupils actively participate in movement, improve coordination, and develop motor skills, but did not impact level of fitness so significantly as the operational time was too short for pupils to absorb and develop fitness. Explanation may come from Rink (37), who states that fitness can only be developed when specific workload, movement duration and intensity standards are met (37).

The follow-up test results showed that after 1 year of study, the physical fitness of the pupils in the experimental group was significantly improved compared to the pupils in the control group, especially in terms of speed, strength, and flexibility. This suggests an association between the use of Brainballs in physical education classes and the physical development of pupils in the experimental group. Games and exercises with Brainball can be the cause of this relationship. Exciting activities with educational balls have made the class lively and attractive, students actively participate in and acquire knowledge (38). All these factors may help increase cognitive and emotional involvement in PE, which are the most important factors linked to further development and improvement of PA and physical fitness. The researchers also observed that the development of students' physical fitness and health was strongly related to improving the quality of physical education lessons. During the practice, attention should be paid to increasing the range of motion and intensity of movement for students (10, 39–41).

Researchers have previously demonstrated that the development of physical fitness is not only influenced by physical activities and sports, but also by factors such as genetics, environment (42); socioeconomic status of parents (43, 44); parental education (45); eating behavior (46). Therefore, with the present study's findings, it is impossible to conclude with certainty that the Brainball program has a positive long-term impact on the development of physical fitness for second-grade students in Vietnam. It is necessary to have further analyzes in the future about the aspects that can affect the physical development of students after the experimental period.

There are limitations to our study. Firstly, this is the first study to apply for the Brainballs program in physical education classes for students in Vietnam. Teachers and students are very interested in this new method of teaching and learning, but sometimes they are confused and unfamiliar with how to organize and perform exercises. Secondly, the study sample is relatively small, so it is difficult to generalize the research results. Despite its limitations, the study has many advantages. The study used an experimental pedagogical design with two parallel groups conducted in a natural environment. The students voluntarily participated in this study and received special attention from principals, teachers, and parents. During the implementation, classroom and physical education teachers coordinated rhythmically in the content of the curriculum, which is a new thing in the Vietnamese education system. The findings provide further insight into the effectiveness of using educational balls to promote healthy physical development in Vietnamese 7-year-olds' physical education classes. As for the pupils, they had the opportunity to experience new ways of learning and participate in exciting sports activities with Brainballs. This helped increase their interest while learning and fostering the absorption of knowledge. In addition, the results of this study will be the premise for further studies with a broader and deeper scope of research to precisely evaluate the impact of Brainball on the physical fitness development of students.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Resolution of the Senate Committee on Ethics of Scientific Research at the Wroclaw University of Health and Sport Sciences in Wroclaw. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

VP, AR, and MB developed ideas, managed the project, provided critical scholarly guidance for the drafting and interpretation of the manuscript, and critically revised the intellectual content of the manuscript. VP, SW, IC, and MB researched background literature, analyzed data, and wrote the manuscript. All authors approved the final version of the manuscript, ensured the accuracy of the work, and agreed to take responsibility for all aspects of the work.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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