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Effects of intervention integrating physical literacy into active school recesses on physical fitness and academic achievement in Chinese children

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ABSTRACT

Background/Objective: The aim of this study was to examine the effects of school-based intervention integrating physical literacy (PL) into active school recesses (ASR) on physical fitness (i.e., body composition, 20-m shuttle run, 50-m run, rope skipping, sit and reach, handgrip) and academic achievement (i.e., academic result of Chinese and Mathematics) in Chinese children.

Methods: A total of 357 children (mean age: 7.8 ± 0.7 years; boys: 50.4%) were recruited from two schools and these two schools were randomly assigned as the intervention group (IG) and the control group (CG), respectively. The IG consisted of 155 children (mean age: 7.9 ± 0.7 years, boys: 51.0%), and 202 children (mean age: 7.8 ± 0.7 years; boys: 50%) were allocated to the CG. Children in the IG received a 10-week intervention integrating PL that was conducted during ASR. In the CG, children's regular school activity was remained during the intervention period. Generalized estimating equation was performed to compare the levels of physical fitness and academic achievement between the IG and the CG after intervention.

Results: Regarding physical fitness, there was a significant group × time interaction on 20-m shuttle run ($\beta = -3.89$, 95% CI [-5.08; −2.71], $p < 0.001$) and handgrip ($\beta = -0.70$, 95% CI [-1.20; −0.20], $p = 0.006$). After intervention, children in the IG had a greater increase than the CG ($p < 0.001$) in terms of 20-m shuttle run and handgrip. In addition, the post-test analysis indicated that performance of children in the IG was significantly greater than those in the CG (20-m shuttle run: $p < 0.001$, handgrip: $p = 0.002$). There was a significant group × time interaction on academic result of Chinese ($\beta = -1.21$, 95% CI [-1.91; −0.56], $p = 0.001$) and academic result of Mathematics ($\beta = 16.71$, 95% CI [15.14; 18.143], $p < 0.001$). Statistically significant positive difference in post-test was observed in academic result of Mathematics between the IG and the CG ($p = 0.012$).

Conclusion: The results of this intervention study indicate that intervention integrating PL into ASR could bring a promising effect on physical fitness and academic achievement in children. It is recommended that future studies are necessary to assess the effects of ASR-based PL intervention on physical and cognitive outcomes using a wide range of sample.

1. Introduction

Physical fitness refers to an individual's capacity to engage in physical activity, including cardiorespiratory fitness, muscular strength, power, endurance, flexibility, agility, speed, balance, coordination and body composition.[1] The level of physical fitness in children was regarded as a significant indicator of both current and future health status.[1,2] Elevated levels of health-related physical fitness, particularly in terms of cardiorespiratory fitness and muscular strength, were linked to a range of benefits on physical health, cognitive aspects and psychological well-being.[3,4] Prior study demonstrated positive association between inadequate cardiorespiratory fitness and mortality.[5] Moreover, other components of physical fitness were identified as important factors of children's health. Studies reflected that reduced muscular strength may

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contribute to increased risks of hypertension and type 2 diabetes,[6] as well as a factor of all-cause mortality.[7] Childhood flexibility was recognized as a predictor of adult health.[8] Furthermore, a study indicated the importance of maintaining physical fitness for promoting health throughout the lifespan.[9] However, a global decline in cardiorespiratory fitness among children has been observed.[10] For example, six consecutive national surveys conducted among Chinese children and adolescents revealed a decline in physical fitness levels.[11] In addition, physical fitness garnered growing research interest among scholars studying physical literacy (PL) in children and adolescents.[12] However, the relationship between physical fitness and PL remains yet fully investigated.[13]

Academic achievement is defined as the ways that students accomplish specific goals, deal with their studies as well as the outcome of different academic assessments.[14–16] Several studies demonstrated that exercise can promote children's physical, psychosocial and neurobiological development and also improved cognition and metacognition.[17,18] Cognitive skills were crucial for school readiness, intelligence and academic achievement.[19–21] Students' academic achievement might be a direct indicator of academic success in schooling education.[22] A study indicated that exercise duration, intensity and types may be factors of academic achievement.[23] However, the evidence regarding the effects of physical activity on academic achievement in children is still inconclusive.[24] Moreover, the relationship between physical activity and academic achievement in different subjects by teachers' assessment[25] has not been extensively investigated across various countries. Further studies are required to elucidate this relationship.[25,26]

Engaging in an active lifestyle during childhood offers advantages for physical, cognitive, and brain health.[27] Physical activity provides children with greater opportunities to strengthen their bones and muscles. Moreover, children who are more physically active tend to have better fitness levels. In comparison to unactive peers, more active children have exhibited superior academic achievement, improved classroom behavior, enhanced focus, and reduced absenteeism.[16] Many studies were conducted physical activity interventions in school settings, and the positive effects have been consistently demonstrated,[28,29] and even these benefits could extend into adulthood. Evidence has shown that physical activity intervention in physical education (PE) curriculum has limited impacts on behavior[30] and cognition.[31] Furthermore, physical activity interventions are typically implemented in classes or occasions that resemble formal classroom settings. In recent years, school recesses have become a potential opportunity for students to engage in physical activity during school days, providing a great avenue to promote physical and psychological outcomes in children.[32] There has been increasing interest in promoting children's physical activity during school recesses using various strategies.[33] Studies have shown that intervention conducted in active school recesses (ASR) have positive impacts on physical activity,[34] physical fitness and academic achievement.[35,36] However, A meta-analysis suggests that the evidence on recess interventions contributing to youth physical activity is limited, which is insufficient to determine conclusive intervention effects on children's physical activity during recess.[37] This could be attributed to the variations in recess periods and durations.[34] Therefore, there is a need for integrated intervention research to inform recess physical activity interventions. Numerous physical activity interventions have been developed based on theory or model of behavior change; but, the effectiveness of these interventions remain relatively small.[38–40] One potential solution to address the issue is to integrate theories (or models) from multiple disciplines (i.e., physical, and psychological) into intervention.[41] Moreover, employing an intervention grounded in PL, which has several philosophical foundations (i.e., monism),[42] represented spanning multiple disciplines in relation to physical activity participation. PL is a multidimensional concept[43] that included motivation, confidence, physical competence, knowledge and understanding necessary to maintain engagement in physical activity throughout life.[12,44] PL can contribute to improve physical and cognitive outcomes through participation in physical activity.[45] In a way, PL integrates previous theories and models from sport/exercise psychology and motor development. Conceptually, PL is associated with enhanced physical, mental, and social well-being through engagement in physical activity.[45] In addition, research showed that increasing opportunities for young people to interact with the environment through PL can not only increase physical activity, but also strengthen motivating children to participate in physical activity.[46] PL offers a theoretical framework to guide intervention design.[41] Meanwhile, PL has become an important research focus for implementing intervention in children and adolescents globally.[45,47,48] In 2016, among the top 10 research questions on PL research,[49] there were three questions around how to conduct PL related interventions.[50] Given the increasing emphasis on PL, a number of studies focused on blending PL into school-based activity in children and adolescents.

One of the most recent review studies has showed a limited number of intervention research (only 38.6%) included all dimensions of PL, while the vast majority of interventions focused solely on a single component of physical competence when conducting PL-related interventions, neglecting the integration of other domains of PL.[13] Meanwhile, only 25% of the studies reported the relationship between PL and intervention content.[13] Moreover, one prior study revealed varying findings regarding the relationships between literacy, physical abilities, and cognition in different students.[51] This study also explored literacy predictors and associations with physical and cognitive outcomes in children.[51] Research has shown that PL-based intervention effectively improve health indicators such as cardiorespiratory fitness, overweight and obese on adolescents.[52] In addition, Clutterbuck et al. reported the improvements in cognitive-related outcomes through transition-focused sports training program,[53] but another study pointed that school-based physical activity programs did not affect cognitive performance.[54] The research on comprehensive interventions targeting the physical and cognitive development of school-age children is limited.[13] Therefore, this study carried out an intervention integrating PL into ASR (PL-ASR intervention) and assessed the effects on physical fitness and academic achievement.

The primary purpose of this study was to examine the effect of PL-ASR intervention on the physical fitness of Chinese children, compared to regular recess activities. We hypothesized that the intervention group (IG) would demonstrate greater effectiveness in improving physical fitness than the control group (CG). The second aim was to explore the effect of the IG compared to the CG on academic achievement in Chinese children. We hypothesized that improvements in academic achievement of children in the IG would be greater than the CG.

2. Methods

2.1. Study design

A quasi-experimental study was designed to compare the effects of activity after class on physical fitness and academic achievement during a 10-week intervention (Fig. 1) within two groups (IG and CG). This study was a part of the integrating *Physical Literacy into Exercises intervention on Physical Fitness and Health of Children Project*. Children in the IG participated in PL-ASR intervention for 10 weeks (Table 1). Children in the CG received regular school activities as same as the previous daily schedule. This intervention study was also by Institution of Review Board at Shanghai University of Sport (Number: 102772021RT084).

2.2. Sample size calculation

The sample size was determined by priori analysis in G*Power 3.1 software (Heinrich-Heine-Universität, Düsseldorf, Germany). According to one previous study,[41] the effect size was 0.6, alpha level = 0.05, power to 0.8. The total required sample size was calculated to be 90. A

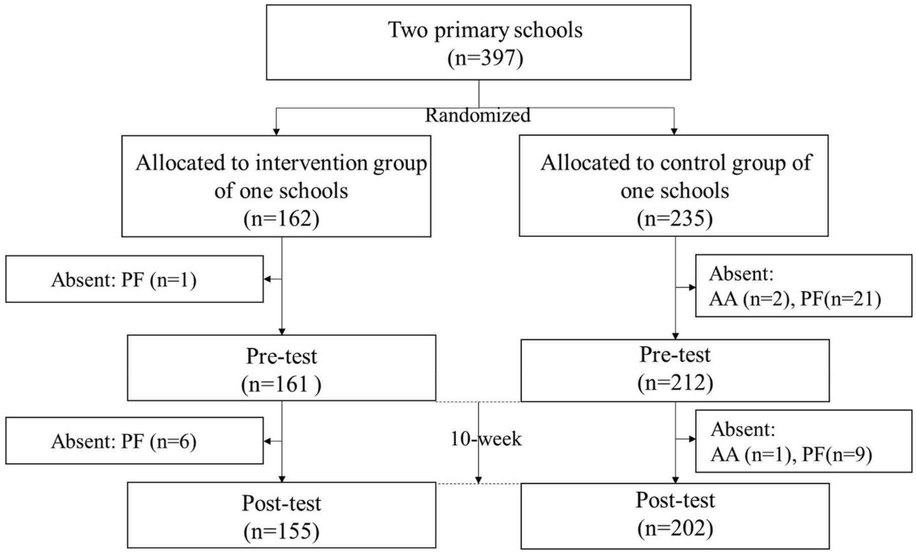

Fig. 1. Flow chart of recruitment, randomization, and participation of children in each group
Note: n, sample size; AA, academic achievement; PF, physical fitness.

Table 1
Activities plan of each group.

PL content*	Sessions	Intervention group	Control group	Frequency and duration
Physical competence	Morning exercise	Broadcast gymnastics	Broadcast gymnastics	10 ms/t, 5 ts/w
	20-mins active break	Sports/games (two)	Free arrangements	20 ms/t, 5 ts/w
	Active mini-breaks	Martial arts rhyme dance	Rhyme dance	5 ms/t, 5 ts/w
	Activity before PE class	Sports/games (one)	Free arrangements	10 ms/t, 4 ts/w
IPA and KPA	Classes in lunchtime-break	PL content through construct a situation for role play or Q&A interaction	None or classes of other subjects	15 ms/t, 1 t/w
Physical competence	Group activities	Jumping short rope, swinging shuttlecock, games	Free arrangements	30 ms/t, 1 t/w
IPA and KPA	School climate	PL content with boards and posters	Free arrangements	1 t/pp

Note: physical competence included physical fitness, motor skill and behaviour; IPA, intention of physical activity; KPA, knowledge and understanding of physical activity; *, Match with intervention group; Q&A, question and answer; PE, physical education; ms/t, mins/time; t(s)/w, time (s)/week; t/pp, time/per person; PL, physical literacy.

20% drop-out rate was estimated from pre-test to post-test and at lest 108 children were needed for study analysis. Moreover, this intervention was based on each class of school, the number of children in one class was around 30 according to the class size. Considering the number of children in each school class may vary, finally, two classes were randomly recruited in each grade of each school.

2.3. Recruitment

Participants from primary schools were recruited via online poster advertisements on WeChat APP and offline themed lectures. The recruitment poster included the study's aims, description, and measurement (i.e., pre-test, post-test). We utilized both the "Moment" and "Chat Group" features of WeChat for advertising. The chat group specifically targeted primary school physical education (PE) teachers who had received training from the Shanghai Teacher Institute. The recruitment period took place from December 2020 to February 2021. After the recruitment phase, seven primary school contacted us. WeChat, as a free mobile device application, emerged as a crucial and highly popular social media platforms for information dissemination in China. It offered various communication formats, including instant text, voice message, video, and graphics, making it an accessible means to share information to the public.[55]

2.4. Randomization

Simple random assignment with coin tosses was conducted by researcher who was responsible for the intervention. Two schools were selected as units from a pool of seven school and randomly assigned to the IG or the CG. Within each selected school, eligible children in the same class received an identical strategy to mitigate confounding influences, such as variations in activity types. Moreover, the details of the IG allocation were kept blinded from both children and teachers. Data entry involved blind processing, which was independently performed by two researchers for data proofreading.

2.5. Participant

A total of 397 children from level 1 (grade 1 and grade 2) of two schools in Shanghai were recruited for this study. Exclusion criteria for subjects' absence included: (1) children with cognitive barriers, (2) those who were ill or physically unfit to participate in sports activities, and (3) those who transferred or sustained injures during the intervention. All participants were requested to provide a written informed consent statement. Ultimately, 357 children (mean age: 7.8 ± 0.7ys, boys: 50.4%) were included in the analysis. Among them, the IG comprised 155 children (mean age: 7.9 ± 0.7ys, boys: 51.0%), while the CG included 202 children (mean age: 7.8 ± 0.7ys, boys: 50.0%) (Fig. 1).

2.6. Intervention

Previous research indicated that behavior can be modified, and the process of automation might require a minimum of 66 days.[56] Considering the inclusion of physical and cognitive variables, as well as the incorporation of complete semester timeframe (included pre-test, post-test and intervention phases), this study implemented a ten-week intervention duration.

PL-ASR intervention content, based on PL theoretical framework, encompassed various aspects such as physical competence, intention of physical activity (including motivation and confidence), as well as knowledge and understanding of physical activity (Table 1). Each group participated in seven sessions of morning exercise, active 20-min-breaks, active mini-breaks, activity before PE class, classes during lunchtime-breaks, group activities and consideration of school climate. These intervention sessions were conducted over a period of 10 weeks. In addition, it was mandatory for participants in both groups to have a minimum attendance rate of 80% attendance (17/21) per week. The IG was specifically encouraged to engage in more physical activity within the school, while the CG had the freedom to engage in non-exercise related content (i.e doing homework).

The study conducted multiple sessions with varying frequencies and durations. Specifically, three sessions were held five times per week, one session was conducted four times per week, two sessions were carried out once per week, and one session occurred once per person. The content of these sessions included the following activities: (1) broadcast gymnastics of morning exercise, which was National Broadcast Gymnastics for Elementary and Middle School Students (serial of unified activities for Chinese students). (2) Martial arts rhyme dance during active mini-breaks, accompanied by music rhythm and involving kicking, punching, and horse squatting, etc. (3) sports/games during 20-mins active breaks in large recesses activities primarily focusing on running, jumping, throwing and catching. Examples of these activities include hopscotch, throwing and catching ball and playful replay running. (4) activity (sports/games) before PE classes also involving running, jumping, throwing, and catching, but with different durations. (5) PL content delivered through role play or Q&A interaction based on various topics, such as sports/sports event, exercise/Olympic knowledge, table games of knowledge and understanding, and Air Studio Class of sport). These content took place during lunchtime breaks and lasted for 15 min. Multimedia resources, including audio, videos, and images, were used by the teachers to facilitate the sessions. For example, *" in the table games, students play forest animal games where four animal group were required to complete the fragments of PL Q&A. (Q&A came from Chinese Assessment and Evaluation of PL. Each group was given a set of Q&A pieces of paper, which were cut into six parts. The groups had to complete the fragments and answer. Finally, the teacher revealed the answers and explanations using multimedia resources".* (6) Group activities involving jumping short rope, swinging shuttlecock or playing games for 30 min/time. (7) PL content displayed on boards and posters, with each student participating once. The children created boards and posters on specific PL topics during afterschool activities. After completing the posters, four of them were selected and displayed per week in school info column. The boards were only completed and displayed during sports culture theme week. The children in the CG participated in regular activities, such as morning exercise and class breaks, following the same schedule, frequency and duration as the IG (Table 1). However, they were prohibited from engaging in any normal physical education or exercise and were allowed to maintain their dietary habits. The sports/games they were involved in included hopscotch, throw and catch, jump the hula hoop, rope skipping, hoop game, tumble, 50-m run, "catch the piglets", standing long jump, plaster, kick shuttlecock, backwards, "drill caves", rhythmic exercises, jump the long rope, 20-m shuttle run, relay race.

Responses of activity plans were obtained from primary school teachers or experts. Two researchers conducted an interview to gather information on: (1) whether the plan of PL-ASR intervention was reasonable and easy to implement; and (2) any comments on improvements of PL-ASR intervention. The final intervention content reached a consensus with the school teacher. The validity of the factor structures underlying the intervention procedures was examined through consultations with other primary education teachers and pilot studies.

2.7. Preparing procedures

The intervention was carried out by school PE teacher. Prior to the formal intervention study, the teachers received eight lessons of PL training (including presentations and materials of intervention) which covered various aspects such as the concept, dimensions, development in different countries, association, assessment, application, and design micro-courses of PL. Additionally, a workshop and a pilot study were conducted to examine the contents and feasibility of the intervention. During the pilot study, the interventionist conducted the intervention and utilized a checklist provided by the researchers to provide feedback on the feasibility of the recesses based on different criteria, including time, content, frequency, and duration. An additional individual was assigned to the IG to monitor the quality of the intervention. Moreover, the researcher recorded any special cases that occur during the intervention. In addition, the communication between the intervention coordinator and the teachers was maintained through internet and cellphone contact. Any potential problems that arose during the study were promptly addressed by the research team.

2.8. Measurements and data collection

All participants from two primary school were assessed for outcomes at baseline (pre-test: March 2021) and the end of the intervention (post-test: June 2021).

2.8.1. Primary outcomes (physical fitness)

The study employed a battery test based on the Chinese National Student Physical Fitness Standard (CNSPFS) for young children.[57,58] The battery test included the following components (1) Body composition: Height was recorded to the nearest 0.1 cm using a portable stadiometer. Weight was measured without shoes, with participants wearing light clothing, using a portable digital scale to the nearest 0.1 kg. Body mass index (BMI) was calculated using the standard equation weight (kg)/height squared (m^2). (2) 50-m run(s) test: Participants were required to run from a standing start between two lines over a distance of 50 m. (3) Rope skipping (counts): Participants was asked to jump rope within 1 min, and the tester recorded the number of qualified jumps. (4) Sit and reach (cm): Participants were instructed to straighten their legs and place their feet flat on a longitudinal plate. They were then asked to gradually reach forward with their fingertips as far as possible. The measurement was recorded to one decimal place. The test was performed twice, and the best result was recorded.

The study measured two components of health-related physical fitness (cardiorespiratory fitness and muscular strength): (1) Cardiorespiratory fitness was assessed using the 20-m shuttle run test.[59] Participants were instructed to run back and forth between two lines over a 20-m distance within a specified time limit. The participants stood behind the starting line and ran with the rhythm of the music, which increased in speed. The test was concluded when a participant failed to reach the line for two consecutive shuttles. Scores were recorded as the level and shuttle reached, and these scores were converted to the number of 20-m laps completed to provide a continuous variable for analysis. (2) Muscular strength was assessed by handgrip strength test.[60] Participants were asked to grip the inner and outer handles of a grip tester with their dominant hand and exert maximum force until the display value stabilized. The test was performed twice, and the best result in kilograms (kg) was recorded.

2.8.2. Second outcomes (academic achievement)

Academic achievement, measured through standardized test scores, was assessed using the grades obtained from the school academic administration system's standardized begin and end-of-term tests. The subjects of Chinese and mathematics were evaluated using tests with a maximum score of 100. The test scores obtained before the intervention were compared to those obtained at the end of intervention. The academic achievement in both subjects was rated by teachers and then converted into four test levels: very good (A = 90–100), good (B = 80–89), general (C = 60–79), and under general (D = under 60). Based on their academic achievement level, the participants were divided into two groups: (1) those who was rated "good" and "very good" (high Level, coded = 2) and (2) those who was rated "general" and "under general" (low level, coded = 1).

2.8.3. Demographic information

Demographic characteristics included gender (1 = boys, 2 = girls), age and grade (1 = grade 1, 2 = grade 2) of participants were retrieved from the school information administration system.

2.8.4. Data collection

The pre-test and post-test were conducted by members of the project research group, who had no competing interests, and details of the intervention group allocation were not available to the testers. Before the test, all testers, who were graduate students majoring in physical education, participated in 1-h training session of physical fitness measurement at the university. The training session was conducted by professionals from a test equipment company to ensure the quality of the test. The workshop covered two main topics: (1) the development characteristics and special needs of children; and (2) the basic principle, testing procedures, and emergency plans for children at level 1.

2.9. Statistical analysis

Statistical analyses were conducted using SPSS Version 26.0 (IBM Corp., Armonk, NY, USA). To assess baseline differences, independent samples *t*-test and Chi-Square tests were used. Within-group change of each group was examined using paired-samples *t*-test. The effects of the intervention on primary and secondary outcomes were evaluated using a Generalized Estimating Equation (GEE) model with an unstructured correlation structure, represented as Y = A + B × Gender + C × Week + D × Group + E × Age + F × [Week × group]. The model included the group × time interaction term, and adjustments were made for gender and age in both groups.

3. Results

The baseline outcomes of participants were presented in Table 2. No significant baseline differences were observed, except for sit and reach and academic result of Chinese. Children in the IG demonstrated significantly better outcomes ($p < 0.001$) compared to those in the CG. Children in the CG were more likely to have higher academic result of Chinese ($p < 0.001$) than those in the IG.

3.1. Outcomes of physical fitness

A significant group × time interaction was observed for the 20-m shuttle run ($\beta = -3.89$, 95% CI [−5.08; −2.71], $p < 0.001$). Equation Y = −2.51 + 0.25 × Gender - 3.05 × Week +4.52 × Group +2.00 × Age - 3.89 × [Week × group] was used to analyze the data. Both groups showed a significant positive improvement ($p < 0.001$), with the IG demonstrating a greater increase compared to the CG. Furthermore, the post-test performance of children in the IG was significantly higher than that of those in the CG ($p < 0.001$).

A significant group × time interaction A significant on handgrip strength ($\beta = -0.70$, 95% CI [−1.20; −0.20], $p = 0.006$). Equation Y = −2.68 + 1.29 × Gender – 0.40 × Week +0.75 × Group +1.48 × Age – 0.70 × [Week × group] was utilized to analyze the data. Only the IG showed a significant positive change ($p < 0.001$). In addition, there was a significant positive difference in post-test handgrip strength between the IG and the CG (IG: 10.34, CG: 9.47, $p = 0.002$).

There was a significant group × time interaction observed for sit and reach ($\beta = 1.26$, 95% CI [0.22; 2.29], $p = 0.017$). Equation Y = 12.36–3.22 × Gender – 1.49 × Week +0.81 × Group - 0.10 × Age +1.26 × [Week × group] was utilized for analysis. However, no significant group × time interactions were found for BMI, the 50-m run and rope skipping (Table 3).

Table 2
Participants characteristic and outcomes of each group at baseline.

Items	Intervention group (Proportion/mean ± SD, n = 155)	Control group (Proportion/mean ± SD, n = 202)	*p*
Demographic			
Gender			0.92
Boys	51.0%	50.0%	/
Girls	49.0%	50.0%	/
Age (ys)	7.9 ± 0.7	7.8 ± 0.7	0.05
Height (cm)	126.2 ± 6.2	125.5 ± 6.1	0.29
Weight (kg)	26.7 ± 5.6	26.4 ± 5.6	0.61
Physical fitness			
BMI (kg/m^2)	16.7 ± 2.7	16.7 ± 2.6	0.90
Sit and reach (cm)	10.5 ± 5.3	8.5 ± 5.1	<0.001
50-m run (s)	11.5 ± 1.4	11.5 ± 1.2	0.89
Rope skipping (counts)	82.6 ± 37.8	76.2 ± 32.5	0.90
20-m shuttle run (laps)	10.9 ± 4.5	10.2 ± 4.4	0.11
Handgrip (kg)	9.2 ± 3.3	9.1 ± 2.8	0.60
Academic achievement			
Academic of Chinese			<0.001
High level	67.7%	90.1%	
Low level	32.3%	9.9%	
Academic of Mathematics			0.28
High level	95.5%	93.8%	
Low level	4.5%	6.2%	

Note: n, sample size; SD, standard deviation. BMI, Body mass index.

3.2. Outcomes of academic achievement

There was a significant group × time interaction on academic result of Chinese ($\beta = -1.21$, 95% CI [−1.91; −0.56], $p = 0.001$, Y = 7.00–0.04 × Gender – 0.25 × Week - 0.26 × Group – 0.57 × Age – 1.21 × [Week × group]). Similarly, a significant group × time interaction was found for the academic result of Mathematics ($\beta = 16.71$, 95% CI [15.14; 18.143], $p < 0.001$, Y = −2.78 + 0.02 × Gender – 0.67 × Week - 17.24 × Group - 0.05 × Age + 16.71 × [Week × group]). However, the intervention only resulted in a significant positive difference in the academic result of Mathematics between the IG and the CG ($p = 0.012$) (Table 4).

4. Discussion

The purpose of this study was to assess the effects of a 10-week PL-ASR intervention on physical fitness and academic achievement. The main finding supported the primary hypothesis and indicated that PL-ASR intervention can improve physical fitness, especially, cardiorespiratory fitness and muscular strength. These findings were consistent with prior research that recesses during school hours led to health benefits,[61,62] such as improving cardiovascular fitness.[63] These results also supported the second hypothesis and showed that PL-ASR intervention enhanced academic achievement. This study was in accordance with previous research, which suggested active class-breaks provided a valuable opportunity, not only to enhance physical competence, but also

Table 3
Effects on physical fitness of each group.

Items	Groups	Post-test		Changed over time		Group × time interaction[a]	
		Mean (SD)	*p*	Mean (SD)	*p*	*β* (SE)	*p*
BMI (kg/m^2)	IG	16.86 (2.46)	0.221	−0.17 (2.20)	0.332	0.38 (0.21)	0.074
	CG	17.21 (2.83)		−0.56 (1.70)	**< 0.001**		
Sit and reach (cm)	IG	10.76 (4.27)	0.169	−0.23 (4.97)	0.561	**1.26 (0.53)**	**0.017**
	CG	10.00 (5.87)		−1.49 (4.96)	**< 0.001**		
50-m run (s)	IG	11.02 (0.92)	0.955	0.50 (1.22)	**< 0.001**	−0.02 (0.12)	0.903
	CG	11.02 (0.84)		0.52 (1.03)	**< 0.001**		
Rope skipping (counts)	IG	104.98 (28.66)	**0.004**	−22.41 (28.77)	**< 0.001**	−3.14 (3.3)	0.342
	CG	95.48 (31.58)		−19.27 (33.80)	**< 0.001**		
20-m shuttle run (laps)	IG	17.85 (7.82)	**< 0.001**	−6.95 (6.30)	**< 0.001**	**−3.89 (0.60)**	**<0.001**
	CG	13.19 (5.55)		−3.05 (4.70)	**< 0.001**		
Handgrip (kg)	IG	10.34 (2.70)	**0.002**	−1.10 (2.40)	**< 0.001**	**−0.70 (0.36)**	**0.006**
	CG	9.47 (2.51)		−0.40 (2.40)	0.018		

Note: SD, standard deviation; BMI, Body mass index; IG: intervention group; CG: control group.
[a] Generalized estimated equations (GEE) coefficient (*β*) refers to the coefficient of the week * group in the GEE model, adjust gender, age, week, group; SE, standard error.

Table 4
Effects on academic achievement of each group.

Academic achievement	Groups	Post-test		Group × time interaction[a]	
		%	*p*	*β* (SE)	*p*
Academic of Chinese	IG	High: 89.7%, low: 10.3%	0.431	**−1.21 (0.36)**	**0.001**
	CG	High: 92.1%, low: 7.9%			
Academic of Mathematics	IG	High: 100.0%, low: 0	**0.012**	**16.77 (0.80)**	**< 0.001**
	CG	High: 96.0%, low: 4.0%			

Note: IG: intervention group; CG: control group.
[a] Generalized estimated equations (GEE) coefficient (*β*) refers to the coefficient of the week*group in the GEE model, adjust gender, age, week, group; SE, standard error.

to improve academic outcomes of children.[64] This development of a multicomponent (included four domains of PL) ASR intervention in this study led to benefits of physical and cognition aspects. Moreover, the intervention contributed to providing different activities and learning time in school settings, which helped create physical activity opportunity to promote the elements of PL.

4.1. Physical fitness

The results showed that PL-ASR intervention effectively improved physical fitness of children, especially the levels of cardiorespiratory fitness and muscular strength.[65] Compared with the CG, the activity and content within class-break of the IG fully utilized school recesses. Most of the activities involved run, jump and shoot movement. These movements engage the entire body and require a combination of cardiovascular endurance and muscular strength. Therefore, this may explain why intervention had an effective impact on cardiorespiratory fitness and muscular strength. Research has demonstrated that physical activity stimulates the body to recruit more muscle units to participate in exercise, thus improving muscle strength. Additionally, it accelerated the transition between excitation and inhibition, facilitating the rapid reception and transmission of information within the human body. This, in turn, enhanced physical competence and enabled quick response. Previous study revealed that school intervention promoted students to participate in physical activity.[66] Moreover, studies reported that structured sports activities for students, such as morning exercises and longer breaks, provide more opportunities for students to participate in sports activities, showcase their abilities, achieve higher step counts[67–70] and reach the daily physical activity levels.[66,67] Research indicated that an additional opportunity for exercise could have a significant impact on overall physical activity levels.[69,70] However, it should be noted that these interventions had limited effects on improving joint and muscle flexibility. Although the PL-ASR intervention content included dance activities, the movements primarily involved jumping and shooting in aerobic dances, with minimal focus on flexibility-related movements in children.

This program adjusted extracurricular activities for school-age children and improved the school climate by incorporating PL content, such as lunchtime classes and campus posters promoting PL. Research demonstrated that intervention enhanced all dimensions of PL, including physical competence.[71] A study conducted in Hong Kong[46] also supported the correlation between PL and physical competence among students. From an indirect perspective, activity of PL-ASR intervention increased opportunities for children to interact with the environment. Furthermore, children may have developed more confidence and motivation, which further encouraged their participation in activities and improved physical fitness. The integration of multimedia into school climate in this PL-ASR intervention may have an impact on activity participation. Content aligned with learning goals[72,73] or a sports activity from videos[74] could promote children's learning. In addition, the use of multimedia during lunch breaks provided opportunities to shape the school PL atmosphere and enhance children's knowledge of sports and health. Moreover, one previous study demonstrated the correlation between the internal dimensions of PL.[44] Regardless of whether healthy or obese children, motivation and confidence were important factors influencing their physical competence.[75] Research reflected sports activities[76] in after-class programs enriched fitness knowledge and developed children's competitive awareness. Regular class-break activities also contributed to the accumulation of physical activity time for children. Furthermore, organizing group sports activities could lead to schools providing more accessible sports equipment and resources, encouraging children to participate in various sports.[66] A research revealed that when children had access to sports resources in school, their physical activity increased threefold.[77]

4.2. Academic achievement

Studies presented controversial findings regarding the effectiveness of physical activity intervention and the acute effects of physical activity on brain function, brain structure and cognitive functions.[78] Moreover, it identified improvements in neurobiological factors like BDNF and IGF-1.[79] Another meta-analysis demonstrated that engaging in physically active tasks requiring higher cognitive involvement yielded positive effects.[80] The higher level of neural plasticity in children suggested that more physical exercise could enhance cognitive function.[31] A previous study indicated that the relationship between physical activity and academic achievement was supported by the activation of neural regions during motor tasks, which were associated with cognitive function.[81],[82] Furthermore, engaging in physical activity was found to promote cerebral blood flow, which could enhance academic achievement.[83] A review demonstrated that physical fitness and interventions involving physical activity had positive effects on children's cognitive function and academic achievement.[16] Recess activities, which encompassed physical activities of varying intensities, were found to influence a child's school aptitudes, creativity, and cognitive flexibility in children aged 8–12 [35]. Prior study have summarized that incorporating active class-recesses provides excellent opportunities to meet daily physical activity guidelines and offered benefits across multiple domains of cognition and metacognition in youth.[35,36] Studies have shown that students exhibit greater willingness to engage in academic tasks following active recess periods. This finding could be explained by the fact that exercise induced both general and specific physiological changes in the brain, leading to an immediate neurochemical response that may enhance academic achievement.[84]

A previous study indicated a positive correlation among all domains of PL.[75] PL-ASR intervention of the IG aimed to enhance the dissemination of knowledge and sports awareness of PL, potentially impacting children's understanding and knowledge levels. Moreover, children were inclined to participate in activities to develop positive self-perception and academic self-confidence, which may be associated with academic learning.[85] Intervention comprised diverse games and activities, offering children more opportunities for participation and facilitating their holistic learning potential.[86] Aerobic fitness and motor skills significantly contributed to cognitive development during childhood and young adulthood.[87] The use of situational and dramatic games in activities was found to be effective. Integrating these activities may enhance cognitive functioning,[88] attention[89] and understanding ability.[90] Specifically, different skills and activities require varying cognitive loads and involve sophisticated cognitive processes. For example, tasks like throwing, catching, and striking demand higher cognitive demands. Locomotor tasks, such as walking, running, and hopping, involve repetitive movements that engage automated cognitive processes.[91] Locomotor tasks, such as walking, running, and hopping, involve repetitive movements that engage automated cognitive processes.

5. Strengths and limitations

This intervention contributed to the development of an active class-break integrated all domains of PL among primary school children. The study strengthened opportunities to promote physical and cognitive abilities by the novel implementation of sessions during school recesses. However, there were several limitations in this study. Firstly, although the study was based on the PL framework, the assessment and results did not include all domains of PL, such as motivation, This limitation was also been reported in another study[92], which suggested that the underlying impact may not be specifically determined. In future research, it would be necessary to highlight the holistic nature of PL, and we planned to explore this in our future studies. Secondly, objective measures, such as polar monitors or accelerometers, were not used to monitor physical activity and heart rate levels during recesses, which may have led to inconsistency in activity intensity. For larger-scale interventions, more attention should be laid on the intensity of physical activity in school days between the IG and the CG. Thirdly, the study was conducted in two separate schools, one for the IG and the other for the CG. It is important to note that these schools may have been affected by various environmental factors. We planned to further promote and involve more schools in the future. Finally, the current study only tested the acute intervention effects using pre- and post-tests. It would be beneficial for future studies to understand the longer-term impacts of the intervention on young children.

6. Conclusion

This study indicated that intervention integrating PL into ASR can promote health-related physical fitness especially for aerobic fitness and strength. Also, such intervention is beneficial to enhance academic achievement. These findings suggest that blended PL framework based on school setting could be a potential approach to promote health and development for children. It is recommended that future studies evaluate the longer-term effects PL intervention.

Author statement

DQZ conducted the research, sorted data. YL designed and drafted the manuscript. LJS help conducted the intervention and XLZ proofed method, DQZ analyzed data and proofed methods, STC edited the original manuscript. All authors revised the manuscript. All authors read and approved the final manuscript.

Declaration of competing interest

All authors have declared that there are no any relevant financial interests related to the research, as well as all potential conflicts of interest.

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References

1. Ortega FB, Ruiz JR, Castillo MJ, et al. Physical fitness in childhood and adolescence: a powerful marker of health. *Int J Obes*. 2008;32:1–11. https://doi.org/10.1038/sj.ijo.0803774.
2. Ruiz JR, Castro-Piñero J, Artero EG, et al. Predictive validity of health-related fitness in youth: a systematic review. *Br J Sports Med*. 2009;43:909. https://doi.org/10.1136/bjsm.2008.056499.
3. Ortega FB, Ruiz JR, Castillo MJ. Physical activity, physical fitness, and overweight in children and adolescents: evidence from epidemiologic studies. *Endocrinol Nutr*. 2013;60:458–469. https://doi.org/10.1016/j.endonu.2012.10.006.
4. Smith JJ, Eather N, Morgan PJ, et al. The health benefits of muscular fitness for children and adolescents: a systematic review and meta-analysis. *Sports Med*. 2014;44:1209–1223. https://doi.org/10.1007/s40279-014-0196-4.
5. Han M, Qie R, Shi X, et al. Cardiorespiratory fitness and mortality from all causes, cardiovascular disease and cancer: dose-response meta-analysis of cohort studies. *Br J Sports Med*. 2022;56:733–739. https://doi.org/10.1136/bjsports-2021-104876.
6. Mainous 3rd AG, Tanner RJ, Anton SD, et al. Grip strength as a marker of hypertension and diabetes in healthy weight adults. *Am J Prev Med*. 2015;49:850–858. https://doi.org/10.1016/j.amepre.2015.05.025.
7. Leong DP, Teo KK, Rangarajan S, et al. Prognostic value of grip strength: findings from the prospective urban rural epidemiology (pure) study. *Lancet*. 2015;386:266–273. https://doi.org/10.1016/s0140-6736(14)62000-6.
8. Mikkelsson L, Kaprio J, Kautiainen H, et al. School fitness tests as predictors of adult health-related fitness. *Am J Hum Biol*. 2006;18:342–349. https://doi.org/10.1002/ajhb.20498.
9. García-Hermoso A, Izquierdo M, Ramírez-Vélez R. Tracking of physical fitness levels from childhood and adolescence to adulthood: a systematic review and meta-analysis. *Transl Pediatr*. 2022;11:474–486. https://doi.org/10.21037/tp-21-507.
10. Tomkinson GR, Léger LA, Olds TS, et al. Secular trends in the performance of children and adolescents (1980-2000): an analysis of 55 studies of the 20m shuttle run test in 11 countries. *Sports Med*. 2003;33:285–300. https://doi.org/10.2165/00007256-200333040-00003.
11. Dong Y, Lau PWC, Dong B, et al. Trends in physical fitness, growth, and nutritional status of Chinese children and adolescents: a retrospective analysis of 1·5 million students from six successive national surveys between 1985 and 2014. *The Lancet. Child & adolescent health*. 2019;3:871–880. https://doi.org/10.1016/s2352-4642(19)30302-5.
12. Chen S-T, Tang Y, Chen P-J, et al. The development of Chinese assessment and evaluation of physical literacy (caepl): a study using delphi method. *Int J Environ Res Publ Health*. 2020;17. https://doi.org/10.3390/ijerph17082720.

13. Carl J, Barratt J, Töpfer C, et al. How are physical literacy interventions conceptualized? – a systematic review on intervention design and content. *Psychol Sport Exerc*. 2022;58, 102091. https://doi.org/10.1016/j.psychsport.2021.102091.
14. Oguguo BC, Ajuonuma JO, Azubuike R, et al. Influence of social media on students' academic achievement. *Int J Eval Res Educ*. 2020;9:1000. https://doi.org/10.11591/ijere.v9i4.20638.
15. Ricarda Steinmayr AM, Anne F. *Weidinger, Linda Wirthwein*. Academic Achievement, (Obo in Education; 2014.
16. Donnelly JE, Hillman CH, Castelli D, et al. Physical activity, fitness, cognitive function, and academic achievement in children: a systematic review. *Med Sci Sports Exerc*. 2016;48:1197–1222. https://doi.org/10.1249/mss.0000000000000901.
17. Alvarez-Bueno C, Pesce C, Cavero-Redondo I, et al. Academic achievement and physical activity: a meta-analysis. *Pediatrics*. 2017;140. https://doi.org/10.1542/peds.2017-1498.
18. Sibley BA, Etnier JL. The relationship between physical activity and cognition in children: a meta-analysis. *Pediatr Exerc Sci*. 2003;15:243–256. https://doi.org/10.1515/ijsl.2000.143.183.
19. Best JR, Miller PH, Naglieri JA. *Relations between Executive Function and Academic Achievement from Ages 5 to 17 in a Large, Representative National Sample*. vol. 21. Learning & Individual Differences; 2011:327–336. https://doi.org/10.1016/j.lindif.2011.01.007.
20. Shaul S, Schwartz M, Shaul S, et al. The role of the executive functions in school readiness among preschool-age children. *Read Writ*. 2014;27:749–768. https://doi.org/10.1007/s11145-013-9470-3.
21. Alloway TP, Alloway RG. Investigating the predictive roles of working memory and Iq in academic attainment. *J Exp Child Psychol*. 2010;106:20–29. https://doi.org/10.1016/j.jecp.2009.11.003.
22. Han G-S. The relationship between physical fitness and academic achievement among adolescent in South Korea. *J Phys Ther Sci*. 2018;30:605–608. https://doi.org/10.1589/jpts.30.605.
23. Gallotta MC, Emerenziani GP, Franciosi E, et al. Acute physical activity and delayed attention in primary school students. *Scand J Med Sci Sports*. 2015;25:e331–e338. https://doi.org/10.1111/sms.12310.
24. Singh AS, Saliasi E, Van Den Berg V, et al. Effects of physical activity interventions on cognitive and academic performance in children and adolescents: a novel combination of a systematic review and recommendations from an expert panel. *Br J Sports Med*. 2019;53:640–647. https://doi.org/10.1136/bjsports-2017-098136.
25. Syvaoja HJ, Kantomaa MT, Ahonen T, et al. Physical activity, sedentary behavior, and academic performance in Finnish children. *Med Sci Sports Exerc*. 2013;45:2098–2104. https://doi.org/10.1249/MSS.0b013e318296d7b8.
26. Syvaoja HJ, Kankaanpaa A, Kallio J, et al. The relation of physical activity, sedentary behaviors, and academic achievement is mediated by fitness and bedtime. *J Phys Activ Health*. 2018;15:135–143. https://doi.org/10.1123/jpah.2017-0135.
27. Chaddock-Heyman L, Hillman CH, Cohen NJ, et al. The importance of physical activity and aerobic fitness for cognitive control and memory in children. *Monogr Soc Res Child Dev*. 2014;79:25–50. https://doi.org/10.1111/mono.12129.
28. Lind RR, Geertsen SS, rntoft C, et al. Improved cognitive performance in preadolescent Danish children after the school-based physical activity programme "fifa 11 for health" for europe - a cluster-randomised controlled trial. *Eur J Sport Sci*. 2018;18:130–139. https://doi.org/10.1080/17461391.2017.1394369.
29. Martínez Vizcaíno V, Salcedo Aguilar F, Franquelo Gutiérrez R, et al. Assessment of an after-school physical activity program to prevent obesity among 9- to 10-year-old children: a cluster randomized trial. *Int J Obes*. 2008;32:12–22. https://doi.org/10.1038/sj.ijo.0803738.
30. Crotti M, Rudd J, Roberts S. Physical activity promoting teaching practices and children's physical activity within physical education lessons underpinned by motor learning theory (Sample-Pe). *PLoS One*. 2022;17, e0272339. https://doi.org/10.1371/journal.pone.0272339.
31. Fisher A, Boyle JM, Paton JY, et al. Effects of a physical education intervention on cognitive function in young children: randomized controlled pilot study. *BMC Pediatr*. 2011;11:97. https://doi.org/10.1186/1471-2431-11-97.
32. Erwin HE, Ickes M, Soyeon A, et al. Impact of recess interventions on children's physical activity-a meta-analysis. *Am J Health Promot*. 2014;28:159–167.
33. Ridgers ND, Stratton G, Fairclough SJ. Physical activity levels of children during school playtime. *Sports Med*. 2006;36:359–371. https://doi.org/10.2165/00007256-200636040-00005.
34. Suga ACM, Silva A a DP D, Brey JR, et al. Effects of interventions for promoting physical activity during recess in elementary schools: a systematic review. *J Pediatr*. 2021;97:585–594. https://doi.org/10.1016/j.jped.2021.02.005.
35. Ruiz-Ariza A, Suárez-Manzano S, Mezcua-Hidalgo A, et al. Effect of an 8-week programme of active breaks between classes on cognitive variables in secondary school. *Educ Stud*. 2022:1–19. https://doi.org/10.1080/03055698.2022.2128992.
36. Pedro ngel L-R, Beatriz B-A, Jerónimo A-V, et al. Effects of a 10-week active recess program in school setting on physical fitness, school aptitudes, creativity and cognitive flexibility in elementary school children. A randomised-controlled trial. *J Sports Sci*. 2021:1–10.
37. Parrish AM, Okely AD, Stanley RM, et al. The effect of school recess interventions on physical activity : a systematic review. *Sports Med*. 2013;43:287–299. https://doi.org/10.1007/s40279-013-0024-2.
38. Hagger MS, Chatzisarantis NL. An integrated behavior change model for physical activity. *Exerc Sport Sci Rev*. 2014;42:62–69. https://doi.org/10.1249/jes.0000000000000008.
39. Rhodes RE. The evolving understanding of physical activity behavior: a multi-process action control approach. In: *Advances in Motivation Science*. San Diego, CA, US: Elsevier Academic Press; 2017:171–205.
40. Rhodes RE, Janssen I, Bredin SSD, et al. Physical activity: health impact, prevalence, correlates and interventions. *Psychol Health*. 2017;32:942–975. https://doi.org/10.1080/08870446.2017.1325486.
41. Bremer E, Graham JD, Cairney J. Outcomes and feasibility of a 12-week physical literacy intervention for children in an afterschool program. *Int J Environ Res Publ Health*. 2020;17. https://doi.org/10.3390/ijerph17093129.
42. Pot N, Whitehead ME, Durden-Myers EJ. Physical literacy from philosophy to practice. *J Teach Phys Educ*. 2018;37:246–251. https://doi.org/10.1123/jtpe.2018-0133.
43. Whitehead M. Definition of physical literacy and clarification of related issues. *International Council of Sport Science and Physical Education (ICSSPE) Bulletin*. 2013;65.
44. Edwards LC, Bryant AS, Keegan RJ, et al. Definitions, foundations and associations of physical literacy: a systematic review. *Sports Med*. 2017;47:113–126. https://doi.org/10.1007/s40279-016-0560-7.
45. Cairney J, Dudley D, Kwan M, et al. Physical literacy, physical activity and health: toward an evidence-informed conceptual model. *Sports Med*. 2019;49:371–383. https://doi.org/10.1007/s40279-019-01063-3.
46. Ma RS, Sum RK. Association between physical literacy and physical activity: a multilevel analysis study among Chinese undergraduates. *Int J Environ Res Publ Health*. 2020;17. https://doi.org/10.3390/ijerph17217874.
47. Lane C, Naylor P-J, Predy M, et al. Exploring a parent-focused physical literacy intervention for early childhood: a pragmatic controlled trial of the playshop. *BMC Publ Health*. 2022;22:659. https://doi.org/10.1186/s12889-022-13048-5.
48. Giblin S, Collins D, Button C. Physical literacy: importance, assessment and future directions. *Sports Med*. 2014;44:1177–1184. https://doi.org/10.1007/s40279-014-0205-7.
49. Longmuir PE, Tremblay MS. Top 10 research questions related to physical literacy. *Res Q Exerc Sport*. 2016;87:28–35. https://doi.org/10.1080/02701367.2016.1124671.
50. Gleddie DL, Morgan A. Physical literacy praxis: a theoretical framework for transformative physical education. *Prospects*. 2021;50:31–53. https://doi.org/10.1007/s11125-020-09481-2.
51. Tabacchi G, Battaglia G, Alesi M, et al. Food literacy predictors and associations with physical and emergent literacy in pre-schoolers: results from the training-to-health project. *Publ Health Nutr*. 2019;23:356–365. https://doi.org/10.1017/S1368980019002404.
52. Nezondet C, Gandrieau J, Bourrelier J, et al. The effectiveness of a physical literacy-based intervention for increasing physical activity levels and improving health indicators in overweight and obese adolescents (capacites 64). *Children*. 2023;10(6):956. https://doi.org/10.3390/children10060956.
53. Clutterbuck GL, Auld ML. Sports stars: a practitioner-led, peer-group sports intervention for ambulant, school-aged children with cerebral palsy. Parent and physiotherapist perspectives. *Disabil Rehabil*. 2022;44:957–966. https://doi.org/10.1080/09638288.2020.1785558.
54. Demetriou Y, Bachner J, Reimers AK, et al. Effects of a sports-oriented primary school on students' physical literacy and cognitive performance. *J Funct Morphol Kinesiol*. 2018;3. https://doi.org/10.3390/jfmk3030037.
55. Wang Y, Li C, Zhang J, et al. Using social media for health education and promotion: a pilot of wechat-based prize quizzes on China national malaria day. *Malar J*. 2022;21:381. https://doi.org/10.1186/s12936-022-04404-2.
56. Lally P, Van Jaarsveld CHM, Potts HWW, et al. How are habits formed: modelling habit formation in the real world. *Eur J Soc Psychol*. 2010;40:998–1009. https://doi.org/10.1002/ejsp.674.
57. Zhu Z, Yang Y, Kong Z, et al. Prevalence of physical fitness in Chinese school-aged children: findings from the 2016 physical activity and fitness in China-the youth study. *J Sport Health Sci*. 2017;6:395–403. https://doi.org/10.1016/j.jshs.2017.09.003.
58. Wu H, Eungpinichpong W, Ruan H, et al. Relationship between motor fitness, fundamental movement skills, and quality of movement patterns in primary school children. *PLoS One*. 2021;16, e0237760. https://doi.org/10.1371/journal.pone.0237760.
59. Léger LA, Mercier D, Gadoury C, et al. The multistage 20 metre shuttle run test for aerobic fitness. *J Sports Sci*. 1988;6:93–101. https://doi.org/10.1080/02640418808729800.
60. Xu Y, Mei M, Wang H, et al. Association between weight status and physical fitness in Chinese mainland children and adolescents: a cross-sectional study. *Int J Environ Res Publ Health*. 2020;17:2468. https://doi.org/10.3390/ijerph17072468.
61. Pellegrini AD, Huberty PD, Jones I. The effects of recess timing on children's playground and classroom behaviors. *Am Educ Res J*. 1995;32:845–864. https://doi.org/10.3102/00028312032004845.
62. Barros RM, Silver EJ, Stein RE. School recess and group classroom behavior. *Pediatrics*. 2009;123:431–436. https://doi.org/10.1542/peds.2007-2825.
63. Strong WB, Malina RM, Blimkie CJ, et al. Evidence based physical activity for school-age youth. *J Pediatr*. 2005;146:732–737. https://doi.org/10.1016/j.jpeds.2005.01.055.
64. Egger F, Benzing V, Conzelmann A, et al. Boost your brain, while having a break! The effects of long-term cognitively engaging physical activity breaks on children's executive functions and academic achievement. *PLoS One*. 2019;14, e0212482. https://doi.org/10.1371/journal.pone.0212482.
65. Larouche R, Boyer C, Tremblay M, et al. Physical fitness, motor skill, and physical activity relationships in grade 4 to 6 children. *Appl Physiol Nutr Metabol*. 2014;39:553–559. https://doi.org/10.1139/apnm-2013-0371.
66. Mandic S, Bengoechea EG, Stevens E, et al. Getting kids active by participating in sport and doing it more often: focusing on what matters. *Int J Behav Nutr Phys Activ*. 2012;9:86. https://doi.org/10.1186/1479-5868-9-86.

67. Trost SG. *Active Education: Physical Education, Physical Activity and Academic Performance*. 2007.
68. Gibson CA, Smith BK, Dubose KD, et al. Physical activity across the curriculum: year one process evaluation results. *Int J Behav Nutr Phys Activ*. 2008;5:36. https://doi.org/10.1186/1479-5868-5-36.
69. Erwin HE, Beighle A, Morgan CF, et al. Effect of a low-cost, teacher-directed classroom intervention on elementary students' physical activity. *J Sch Health*. 2011; 81:455–461. https://doi.org/10.1111/j.1746-1561.2011.00614.x.
70. Erwin HE, Abel MG, Beighle A, et al. Promoting children's health through physically active math classes: a pilot study. *Health Promot Pract*. 2011;12:244–251. https://doi.org/10.1177/1524839909331911.
71. Kriellaars DJ, Cairney J, Bortoleto M a C, et al. The impact of Circus arts instruction in physical education on the physical literacy of children in grades 4 and 5. *J Teach Phys Educ*. 2019;38:162–170. https://doi.org/10.1123/jtpe.2018-0269.
72. Pill S. Promoting physical activity and health in schools. *Prof Educat*. 2006;5:36–41.
73. Pangrazi RP, Beighle A, Pangrazi D. *Promoting Physical Activity & Health in the Classroom*. San Francisco, CA, USA: Benjamin Cummings; 2009.
74. Carson RL, Lima M. *Play on!: Playground Learning Activities for Youth Fitness*. Amer Alliance for Health Physical; 2008.
75. Nystrom CD, Traversy G, Barnes JD, et al. Associations between domains of physical literacy by weight status in 8-to 12-year-old Canadian children. *BMC Publ Health*. 2018;18. https://doi.org/10.1186/s12889-018-5898-3.
76. Beighle A, Erwin H, Morgan CF, et al. Children's in-school and out-of-School physical activity during two seasons. *Res Q Exerc Sport*. 2012;83:103–107. https://doi.org/10.1080/02701367.2012.10599830.
77. Haug E, Torsheim T, Sallis JF, et al. The characteristics of the outdoor school environment associated with physical activity. *Health Educ Res*. 2010;25:248–256. https://doi.org/10.1093/her/cyn050.
78. Gunnell KE, Poitras VJ, Leblanc A, et al. Physical activity and brain structure, brain function, and cognition in children and youth: a systematic review of randomized controlled trials. *Ment Health Phys Act*. 2019;16:105–127. https://doi.org/10.1016/j.mhpa.2018.11.002.
79. Cabral DF, Rice J, Morris TP, et al. Exercise for brain health: an investigation into the underlying mechanisms guided by dose. *Neurotherapeutics*. 2019;16:580–599. https://doi.org/10.1007/s13311-019-00749-w.
80. De Greeff JW, Hartman E, Mullender-Wijnsma MJ, et al. Long-term effects of physically active academic lessons on physical fitness and executive functions in primary school children. *Health Educ Res*. 2016;31:185–194. https://doi.org/10.1093/her/cyv102.
81. Stoodley CJ, Valera EM, Schmahmann JD. Functional topography of the cerebellum for motor and cognitive tasks: an fmri study. *Neuroimage*. 2012;59:1560–1570. https://doi.org/10.1016/j.neuroimage.2011.08.065.
82. Mcpherson A, Mackay L, Kunkel J, et al. Physical activity, cognition and academic performance: an analysis of mediating and confounding relationships in primary school children. *BMC Publ Health*. 2018;18:936. https://doi.org/10.1186/s12889-018-5863-1.
83. Querido JS, Sheel AW. Regulation of cerebral blood flow during exercise. *Sports Med*. 2007;37:765–782. https://doi.org/10.2165/00007256-200737090-00002.
84. Best JR. Effects of physical activity on children's executive function: contributions of experimental research on aerobic exercise. *Dev Rev*. 2010;30:331–351. https://doi.org/10.1016/j.dr.2010.08.001.
85. Broh BA. Linking extracurricular programming to academic achievement: who benefits and why? *Sociol Educ*. 2002;75:69–95. https://doi.org/10.2307/3090254.
86. Castelli DM, Ward K. Physical activity during the school day. *J Phys Educ Recreat Dance*. 2012;83:20–29. https://doi.org/10.1080/07303084.2012.10598791.
87. Haapala EA, Poikkeus AM, Tompuri T, et al. Associations of motor and cardiovascular performance with academic skills in children. *Med Sci Sports Exerc*. 2014;46:1016–1024. https://doi.org/10.1249/mss.0000000000000186.
88. Reed JA, Einstein G, Hahn E, et al. Examining the impact of integrating physical activity on fluid intelligence and academic performance in an elementary school setting: a preliminary investigation. *J Phys Activ Health*. 2010;7:343–351. https://doi.org/10.1123/jpah.7.3.343.
89. Caterino MC, Polak ED. Effects of two types of activity on the performance of second-, third-, and fourth-grade students on a test of concentration. *Percept Mot Skills*. 1999;89:245–248. https://doi.org/10.2466/pms.1999.89.1.245.
90. Uhrich TA, Swalm RL. A pilot study of a possible effect from a motor task on reading performance. *Percept Mot Skills*. 2007;104:1035–1041. https://doi.org/10.2466/pms.104.3.1035-1041.
91. Alesi M, Battaglia G, Pepi A, et al. Gross motor proficiency and Intellectual functioning: a comparison among children with down syndrome, children with borderline Intellectual functioning, and typically developing children. *Medicine (Baltim)*. 2018;97, e12737. https://doi.org/10.1097/md.0000000000012737.
92. Caldwell H a T, Spencer RA, Joshi N, et al. Impact of an outdoor loose parts play intervention on nova scotian preschoolers' physical literacy: a mixed-methods randomized controlled trial. *BMC Publ Health*. 2023;23:1126. https://doi.org/10.1186/s12889-023-16030-x.