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Physical exercise and metabolic health in children and adolescents

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Physical exercise and metabolic health in children and adolescents

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Editorial: Physical exercise and metabolic health in children and adolescents

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Editorial on the Research Topic
Physical exercise and metabolic health in children and adolescents

Introduction

The alarming rise in childhood obesity and related metabolic disorders represents a pressing global health challenge, with over 340 million children and adolescents aged 5–19 categorized as overweight or obese, according to the World Health Organization (1). This epidemic underscores the critical need for evidence-based strategies to promote metabolic health through physical activity. Regular engagement in structured exercise interventions, habitual physical activity, and innovative approaches has improved youth insulin sensitivity, lipid profiles, and overall metabolic function (2, 3). By examining diverse perspectives and methodologies, this Research Topic provides actionable insights into developing effective interventions and policies to combat this pervasive issue.

Contributions to the field

Nine compelling articles addresses the multifaceted relationship between physical activity and metabolic health, exploring various aspects of exercise science, from metabolic biomarkers to psychosocial outcomes. Together, they provide a comprehensive overview of current research and practical applications in the field through four thematic areas: (1) Exercise and metabolic biomarkers, (2) Exercise interventions and obesity management, (3) Psychosocial and cognitive benefits of physical activity, and (4) Policy recommendations for physical activity of the youngsters.

Exercise and metabolic biomarkers

In this Research Topic, Vasileva et al. highlight the effects of neuromuscular training on metabolic biomarkers (e.g., salivary high molecular weight adiponectin) and physical fitness parameters, linking exercise interventions to measurable physiological outcomes. These findings align with broader evidence that exercise modulates key metabolic pathways, reducing the risk of type 2 diabetes and cardiovascular diseases (4, 5).

Exercise interventions and obesity management

Several articles address the critical challenge of childhood obesity and explore strategies for its management. Aniśko et al. emphasized body mass composition as a key predictor of overweight and obesity, aligning with broader efforts to prevent and manage obesity through targeted interventions and regular monitoring. Their study revealed significant differences in body composition between ballet school students and their peers in traditional schools, suggesting that specialized physical training, such as ballet, can notably influence these metrics in children and adolescents. Similarly, Deng and Wang demonstrated that high-intensity interval training (HIIT) is an effective intervention for improving cardiorespiratory fitness in children and adolescents with overweight or obesity. Morgado et al. further highlighted the benefits of combining exercise with nutrition education to enhance children's health and wellbeing. Additionally, Ju et al. explored virtual reality-based exergaming as a structured intervention to improve cardiopulmonary fitness in children, aligning with targeted exercise strategies for managing obesity. Together, these studies underscore the importance of multi-component interventions in effectively addressing obesity in youth populations.

Psychosocial and cognitive benefits of physical activity

Beyond physical health, exercise has equally significant psychosocial and cognitive benefits. Zhao et al. systematically reviewed the health impacts, including psychosocial and cognitive outcomes, of adhering to movement guidelines encompassing physical activity, sedentary behavior, and sleep. Additionally, Joung et al. examined how perceived enjoyment and exercise commitment influence behavioral intentions, emphasizing the psychological and social dimensions of physical activity participation among adolescents. These findings highlight the holistic advantages of exercise, extending its impact on mental wellbeing and cognitive development.

Policy recommendations for physical activity of youngsters

The final section of this Research Topic emphasizes the necessity of systemic approaches to encourage physical activity among children and adolescents. Ruan and Tang provide longitudinal data and insights into changes in adolescent physical fitness, which can inform policies to improve youth activity levels and health outcomes. At the same time, Liao et al. offer insights that could inform guidelines promoting outdoor activities to enhance children's vision health. These findings are vital for shaping public health policies integrating physical activity into daily routines and institutional frameworks.

Conclusion

The nine articles on this Research Topic collectively reinforce physical activity's essential role in enhancing children's and adolescents' metabolic and psychosocial health. Future research should explore the long-term impacts of different exercise types and intensities and the integration of new technologies to promote activity. On the other hand, policymakers must prioritize equitable access to safe environments for physical activity, incorporating these into educational and community frameworks. Such actions will foster healthier generations and mitigate the burden of metabolic disorders worldwide.

Author contributions

SP: Conceptualization, Writing – original draft. GD: Writing – review & editing. NG-G: Writing – review & editing.

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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 "Football and Nutrition for Health" program on body composition, physical fitness, eating behaviours, nutritional knowledge, and psychological status among 7 to 10 years school children

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Introduction: Noncommunicable diseases and obesity are between the major health threat due to consumption of unhealthy foods and limited time spent on physical activities, a situation of particular concern among children. Since children spend most of their time at school, this study intends to investigate the effect of a school intervention program, which combines recreational football and nutrition education, on body composition, physical fitness, physical activity, blood pressure and heart rate, eating behaviours, nutritional knowledge, and psychological status in elementary school children.
Methods: A total of 67 children, between 7 and 10 years old, were allocated into three groups: the Football Group (FG) which held 2 weekly sessions of 60 min of recreational football, the Nutrition and Football Group (NFG) which held 2 sessions per week of 60 min of recreational football plus 60 min of nutritional education and the Control Group (CG) which maintained its usual curriculum. The intervention lasted 12 weeks. All measurements were collected before and after the intervention.
Results: Intervention groups significantly ($p < 0.05$) improved BMI Z-score, rest heart rate, horizontal jump and shuttle test, physical activity level, and psychosocial health. The NFG group significantly decreased ($p < 0.05$) waist-to-height ratio and blood pressure, and significantly increased ($p < 0.05$) nutritional knowledge, fruit, and fish consumption. While FG significantly decreased ($p < 0.05$) the percentage of fat mass and significantly increased ($p < 0.05$) muscle mass and performance in the 20 m sprint.
Discussion: The results have shown to improve nutritional status, explosive strength, aerobic and neuromuscular fitness, as well as increase the level of physical activity. The nutritional education sessions contributed to increase nutritional knowledge and to improve the consumption of healthy food groups in a ludic-educational way. The "Football and Nutrition for Health" program was able to induce short-term improvements in several health markers, highlighting the role of the school curriculum in children's health.

KEYWORDS

childhood obesity, physical activity, nutrition education, recreational football, public health, noncommunicable diseases

1. Introduction

In World Health Organization (WHO) European Region, non-communicable diseases are the major health threat due to consumption of unhealthy foods, and limited time spent on physical activities, a situation of particular concern among children (1). Obesity, cardiovascular disease, and type 2 diabetes are examples of high-prevalence non-communicable diseases which are also partly interconnected (1). In this sense, prevention, and control of noncommunicable diseases have been identified in the United Nations Sustainable Development Goals as one of the key global priorities for the next decade (1).

Regarding childhood obesity, although remains a major public health problem in the WHO European Region (2, 3), rates of childhood obesity seem to be plateauing in some European countries. In Portugal overweight and obesity levels remain cautious, with one in three children in school-age are overweight (2, 3). Research from the latest round of the WHO European Childhood Obesity Surveillance Initiative (COSI) carried out in 2018–2020 indicates that 29% of children aged 7–9 years in the participating countries were found to be living with overweight (including obesity—according to WHO definitions) (2).

In recent decades, changes in dietary patterns and physical activity behaviours have been identified as likely contributors to a rise in childhood obesity (4). Physical activity is widely recognized as an important factor for prevention and treatment of childhood obesity and its comorbidities (5, 6). Although the health benefits of regular physical activity are extensively documented, 3 in 4 children and adolescents worldwide (aged 11–17 years) do not currently meet the global recommendations for physical activity (6). Another important factor that contributes to protect against overweight, obesity and other noncommunicable diseases is a healthy diet (4). COSI data has previously found that most countries indicate that childreńs level of fruit and vegetable consumption in the WHO European Region is still poor (7–9), while sugar intake is too high, with children commonly consuming more than 10% of their daily calories from added sugars (8–10).

Since children are in a period with rapid physiological and behavioural change, it is a critical time for the formation and establishment of lasting adequate nutrition, physical activity, and healthy behaviours (9). Food preferences and eating habits established in childhood and adolescence tend to be maintained into adulthood, making nutrition in childhood an important public health issue (4).

The pilot project of "'FIFA 11 for Health' modified program for Europe was developed in Denmark and showed positive effects on blood pressure, fat percentage, social well-being, and health knowledge (relating to physical training, healthy diet, hygiene, and mental health) (11–13). The conclusions of the studies that investigated football training in schools are encouraging. Small-sided school-based football interventions improve physical fitness (12, 14–17), heart health (15, 18–23), bone health (16, 17), psychological status (13, 24), and learning (11, 13) in children aged 8–12 years. Changes in body fat percentage and blood pressure can be achieved through dietary manipulations, physical activity interventions and other lifestyle changes, reinforcing the potential of combined interventions (12). There are several intervention programs designed to increase children's physical activity or health knowledge, but only a few programs that attempt to increase both (13, 25, 26). Furthermore, to the best of the authors' knowledge, interventions that combine nutrition education and recreational football are unknown.

For all describe reasons mentioned above, it was created the "Football and Nutrition for Health" project, inspired in "FIFA 11 for Health" modified program for Europe, that integrates the two major determinants of health in children: physical activity and nutrition as a non-pharmacological strategy to prevent and treat lifestyle diseases. Thus, the aim of this study was to understand the effects and differences of a recreational football intervention a sole and the combined effect of nutrition education and recreational football in body composition, blood pressure, heart rate, physical fitness, eating attitudes, nutritional knowledge, and perceived psychological status, after 12-week on schoolchildren aged 7–10 years old.

2. Materials and methods

2.1. Study design and participants

The current study lasted 14 weeks: week 1 was used for the pre-tests; weeks 2 to 13 the intervention groups completed the "Football and Nutrition for Health" program, and in week 14, all groups completed post-testing with the same test battery as in week 1.

To be eligible for participation, boys and girls had to be between 7 and 10 years old and attend elementary schools in the municipality of Águeda. Children under the age of 7 were not included in the study, as well as those who were participating in any nutritional or weight loss programs. Moreover, individuals using any medication or having a pathology or clinical condition that could potentially influence the study outcomes or limit participation in physical activities were also excluded. BMI was not considered as an exclusion factor. A total of 72 Portuguese elementary school children, aged 7–10 years from three schools participated in this study and were cluster-randomized, with each school representing a cluster, into the Football Group ($n = 26$, school I), Football and Nutrition Group ($n = 21$, school II) or Control Group ($n = 25$, school III). From those, 67 children completed both pre- and post- testing. The participant selection flow chart is presented in **Figure 1**.

Sample size calculations were performed *a priori* for repeated measures analysis of variance (ANOVA) using the G*Power software version 3.1.9.6, considering an effect size 0.25, a statistical power of 0.95 at $p < 0.05$ (22, 27). A sample size of at least 19 in each group was required. All participants and their legal representatives were previously informed by oral and writing communication about the experimental procedures. The project was conducted in accordance with ethical procedures of

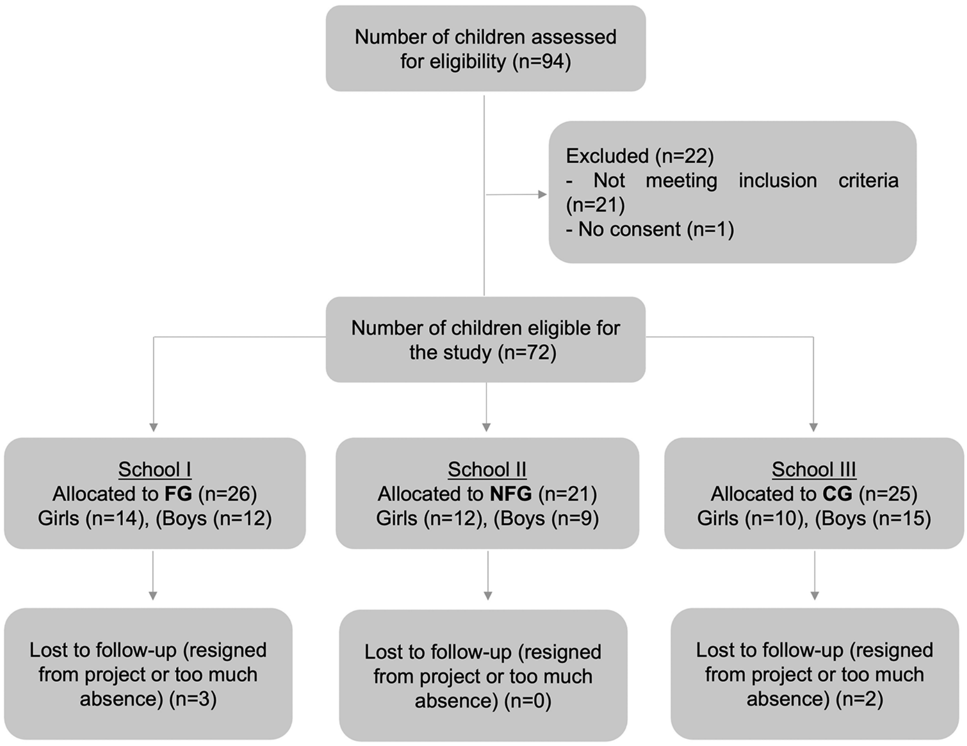

FIGURE 1
Participant flow chart of "nutrition and football for health". FG, football group; NFG, nutrition and football group; CG, control group.

the Declaration of Helsinki. The study was approved by the Ethical Committee of the Faculty of Sport of the University of Porto (nr. CEFADE 05 2019).

2.2. "Football and Nutrition for Health" program

In this study, the intervention groups completed the "Football and Nutrition for Health" program: Football Group (FG) performed 2 sessions per week of 60 min of recreational football and Nutrition and Football Group (NFG) performed 2 sessions per week of 60 min of recreational football plus 60 min of nutritional education, and Control Group (CG) continued their normal curriculum. It was incorporated physical activity based on recreational football practice and nutrition education in the school curriculum. The recreational football sessions were based on the structure, content, and implementation protocol for the "FIFA 11 for Health" program (13, 28) with adaptation to 12-week with 2 sessions of 60 min per week, each consisting of a play football period (i.e., teaching specific football skills, such dribbling, passing, shooting, and recreational small-sided football games). The nutrition education program consisted in a combination of six health and nutrition issues, on a weekly-basis 60 min during 12-week, based on the principles of the Portuguese food wheel rules and groups (29), consisted mostly in what are the calories, macro, and micronutrients; the nutritional traffic light label; how to prepare healthy meals; importance of fruits and vegetables; proof of the sea: choose fish, choose health.

2.3. Variables and measuring instruments

2.3.1. Anthropometric and body composition

Weight and height were collected according to the ISAK protocol (30). Height was measured with a mobile stadiometer (Seca 213, Germany). BMI (kg·m^{-2}) and percentile were calculated (31). The participants were weighed bare foot in light clothes, between 9:00 and 10:00, after having breakfast before 8:00. Waist circumference was measured at the superior border of the iliac crest, a metallic tape (Holtain Ltd.), according to the protocol of the National Health and Nutrition Examination Survey (NHANES) (32). The NHANES has proposed the 90th percentile as the cut-off for identifying central adiposity. To study the central fatness, it was used waist-to-height ratios (WtHr). WtHr was calculated by dividing waist circumference (in cm) by height (in cm). The ratio between waist circumference and height was calculated. The cut-off used to represent cardiovascular risk for WtHr was 0.500 (33). Body composition was measured using the classic unifrequency electrical bioimpedance method (Akern body composition analyser, Model BIA101) to measure weight and estimate percentage body fat and lean body mass, according to protocol (34). Participants were asked to not practice physical exercise in the previous 24 h, to be preferably fasted or at least 4 h without eating and drinking (but

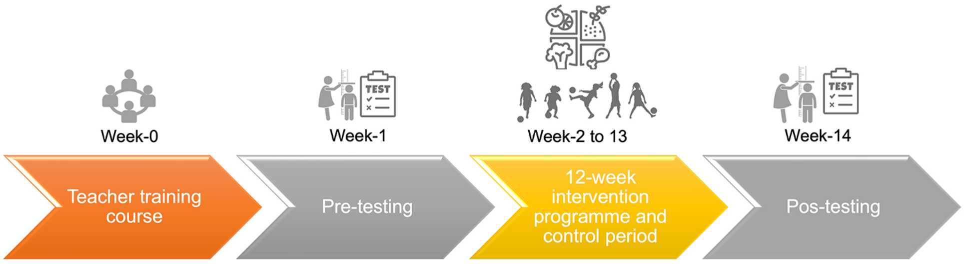

FIGURE 2
Timeline of the "Football and Nutrition for Health" program in elementary school children.

not dehydrated), not to ingest diuretics (tea or coffee), empty bladder and bowel, during the test remove all metal (bracelets, earrings, etc.) (35) (**Figure 2**).

2.3.2. Blood pressure and heart rate at rest

Resting blood pressure (mm Hg) was determined with the average of three measurements on the left upper arm by an automatic blood pressure monitor (36). Heart rate (bpm) was recorded using a digital blood pressure monitor (microlife BP A1 Easy, Switzerland) after subjects were seated for 10 min. (36). The average of 2 measures for systolic blood pressure (SBP) and diastolic blood pressure (DBP) was recorded. A third measurement was made if the difference between the previous two was higher than 5 mmHg. All blood pressure and heart rate measurements were conducted between 8:30 a.m. and 9:30 a.m. by the same investigator and the same automated monitor.

2.3.3. Physical fitness tests

After a standardized warm-up, the children performed a physical test battery which consisted of the maximal horizontal jump length test (37), the 20 m sprint test (38) and the shuttle run test (39). To evaluate the explosive strength of the lower limbs, the maximal horizontal jump length test was conducted, where the children aimed to achieve the maximum distance in a long jump (37). For measuring the acceleration capacity and speed of the students, the 20 m sprint was performed, aiming to complete it in the shortest time possible (38). The shuttle run test was used to assess aerobic fitness, and it involved completing the maximum number of 20 m courses at a predetermined cadence signaled by a sound (39). The subjects ran in groups of up to five children to simulate a competition and ensure maximal effort.

2.3.4. Physical activity monitoring

To estimate daily physical activity a tri-axial accelerometer (ActiGraph, model GT3X, Acticorp Co., Pensacola, FL, USA) was used at baseline and at the end of the study. ActiLife Software v6.13.4 was used for data processing. Before each data collection, the ActiGraph was initialized according to the manufacturer's specifications (40). Data collection by accelerometer started 1h after distribution to avoid increased physical activity (PA) results because of curiosity for device and study (40). The ActiGraph was attached to a flexible elastic belt that was fastened snugly around the waist of each child, to remain tight but not too tight. The ActiGraph was positioned on the right midaxilla line at the level of the iliac crest under or over clothing (may be in contact with the skin or over a piece of clothing). We advised that it is not visible so that other children were not tempted to touch (40). Children were asked to wear the accelerometer as soon as they got up in the morning (on waking up) and taken out at night to sleep. We also ask to only remove it for sleeping, bathing, during water-based activities and in exceptional cases like while performing contact sports such as martial arts, because of the risk of injury.

Accelerometer data files were collected in 15-s epochs according to the respectively cut point chosen to record the spontaneous and intermittent activities of children more accurately (41, 42). The accelerometers were used for 7 consecutive days and the records of physical activity performed in at least 4 days, of which 3 days a week and 1 day at the weekend, with at least 8 h of recording per day, were considered valid. Wear time validation was calculated using Troiano (43, 44) defaults and we considered days with ≥480 min of activity recordings as valid (45). Non-wear time was defined as 60 min of consecutive zeros allowing for 2 min of non-zero interruptions (46, 47). Average counts per minute (CPM) were used as a measure of total physical activity. Evenson cut-points (41), validated cut-points recommended for children, were used to estimate time spent in sedentary, light, moderate, and vigorous intensity activity in children: light (101 to ≥2,295), moderate (≥2,296 CPM), and vigorous intensity (≥4,012 CPM) physical activity (40, 42, 45, 46). The numbers of minutes per day in different intensities were determined by summing all minutes where the activity count was equal to and greater than the threshold for that intensity, divided by the number of valid days (45).

2.3.5. Dietary intake and eating behaviours

2.3.5.1. Dietary Intake

The collection and description of dietary intake was evaluated by a 24-hours recall using portion quantification methods with photography of home measurements (cups, bowls, and glasses) completed by the legal representatives (48). Detailed instructions were given to legal representatives to record the consumption of all foods and beverages consumed by the child, to represent the usual consumption. The instructions consist of discriminating the foods consumed, reporting the commercial name (if applicable) and the portion consumed (in weight, volume, or household measures). In the case of prepared dishes, an indication is given to provide details of the recipe, including ingredients and cooking methods. Information such as mealtime, name of meal, location of meal, and day of the week were also reported. At the end of each food record, it was asked if the registered day represents a day of usual consumption and if not, the reasons were asked. There was also an open section for comments. For nutritional data analysis, the ESHA's Food Processor Nutrition Analysis software, version 11.5 was used.

2.3.5.2. Food propensity questionnaire (FPQ)

To complement the 24h recall, a food propensity questionnaire (FPQ) was applied. Parents (or the main caregiver) of children were asked to report the frequency of consumption of food and fluids items in the last month. Following the protocols proposed by IAN-AF studies (48), a food frequency questionnaire was used, including a general list of food and drink supposedly common to the different European countries (e.g., bread, rice, pasta, potatoes, fruits, red and white meat, fish, milk, butter) and a list of specific Portuguese foods and beverages important for important for assessment (e.g., certain types of vegetables, specific fresh or canned fish, certain types of cheeses). Children's nutritional attitudes and eating behaviours regarding fruit and vegetables were measured with a fruit and vegetable preference questionnaire (IAN-AF) (48). To analyse the differences between consumption frequency over the intervention, two categories were stablished according to the amount of each food group consumed. The interpretation of the data requires some care since the methodology used allows identifying the number of times a food was consumed but not the total amount ingested.

2.3.5.3. Food and nutritional supplementation

The use of nutritional supplements was assessed through questions of propensity for habitual consumption, from a pre-defined list of different supplements, currently in use in the market, with the possibility of mentioning others not included in the initial list (48). The reference period to which the use of supplements refers was based on the previous month.

2.3.6. Nutrition knowledge questionnaire

The questionnaire was developed with 6 questions related to the Portuguese food wheel concepts and based on the educational activities performed in the intervention program (29). The instrument was reviewed by a panel of experts for clarity of wording and instructions and then reviewed again by a panel of elementary school teachers. Statements in the questionnaire were presented in different formats: statements eliciting responses of "yes", "no" or "do not know"; statements providing four response options (only 1 of which was correct); statements to classify foods and linking words game. Correct answers were scored with one point and incorrect and "do not know" answers were scored zero points (49–51). Each answer received a score. The scores were summed, so children received a knowledge score ranging from 0 to 20 points. Participants completed a preintervention and postintervention nutrition knowledge questionnaire to assess children's learning outcomes from the program. Higher scores indicated higher retention and understanding of the information presented in the nutritional education sessions and activities.

2.3.7. Perceived psychological status

2.3.7.1. Body image perception—Collins' child figure drawing scale

Body image was analysed with Collins' child figure drawing scale (52). This pictorial instrument included seven silhouette figures of boys and girls ranging from very thin to obese. Children were asked to select the silhouette figure that best represented how their body shape currently looked (perceived) during school time. To evaluate the discrepancy between the perceived weight status (feel figure) and the actual weight status assessed by means of BMI percentile, was calculated the index FAI (feel weight status minus actual weight status inconsistency) (53). This index uses the silhouette matching technique as a proxy to confirm if there was or was not a realistic weight status perception in the subject (54). The index FAI was calculated by subtracting the feel figure assigned to the actual weight status of the participant classified as normal weight, overweight or obese based on international age- and sex-specific BMI cut-off points (55)—code 1 for underweight status (<15th); code 2 for normal weight status (15th–85th); code 3 for overweight status (85th–95th) and code 4 for obese status (95th and above)—from the code assigned to the silhouette chosen as perceived according to the following correspondence (code 1 for silhouettes 1 and 2; code 2 for silhouettes 3, 4 and 5; code 3 for silhouette 6 and code 4 for silhouette 7) (53, 56). The FAI scores range from −3 to +3: a FAI score of 0 indicates no inconsistency in weight status perception with a realistic perception of one's weight status; a negative FAI score mean that weight status is underestimated; a positive FAI score mean that weight status is overestimated (53). In the last two cases, the extent of discrepancy represents the degree of dissatisfaction in body image perception (53, 54).

2.3.7.2. Pediatric quality of life inventory

To assess health-related quality of life, the adaptation of the generic scale of the Pediatric Quality Life Inventory 4.0 (PedsQL 4.0), to the Portuguese population (57) was used. It is a self-report measure with 20 items, based on a modular approach with generic and disease-specific instruments. The instructions suggest that the respondent thinks about each of the problems pointed out in terms of their occurrence during the previous month, and the answers are organized/rated on a 5-point Likert scale, ranging from 0 (never) to 4 (almost always), to indicate how much the child has problems with each area of functioning. Scoring Procedure has two steps. Step 1 is about transforming score, where items are reversed scored and linearly transformed to a 0–100 scale as follows: 0 = 100, 1 = 75, 2 = 50, 3 = 25, 4 = 0. In the step 2 the scores are calculated by dimensions, the mean score is the sum of the items over the number of items answered. If more than 50% of the items in the scale are missing, the scale scores should not be computed; If 50% or more items are completed: Impute the mean of the completed items in a scale. Three summary scores were calculated for each of the four core scales: the analysis of the results can be performed through a total score and through two sub-results: a specific one of Physical Health (6 items;

corresponding to factor 1) and another one related to Psychosocial Health (emotional, social, and school functioning scales combined; 14 items; corresponding to factors 2, 3, 4). Both in the total score and in the sub-results, the values are obtained by the sum of the items divided by the number of items answered. So, total score is the sum of all the items over the number of items answered on all the Scales. The sub-result for Physical Health is the sum of the items of the physical functioning factor divided by the number of items answered. Psychosocial Health Summary Score is the sum of the items over the number of items answered in the Emotional, Social, and School Functioning Scales (57). The higher results are indicators of a better quality of life.

2.4. Statistical analysis

Descriptive statistics (mean values, standard deviations and percentages) were calculated for the groups at baseline and after the intervention. None of the variables analysed showed significant deviations from normal distributions (Kolmogorov-Smirnov normality test). Differences between groups at baseline and the effect of the football and nutritional intervention programmes relative to the CG was evaluated with a two-factorial repeated measures ANOVA. Percentage change (%Δ) between baseline and post-intervention was calculated for each variable. Effect size was calculated using eta-squared (η^2). The McNemar test was used for categorical variables. Significance level was set at 0.05. Statistical analyses were conducted using SPSS version 27.0.

3. Results

3.1. Anthropometry, body composition, resting blood pressure and heart rate, physical fitness, physical activity, and perceived psychological status

Participant characteristics, anthropometry, body composition, resting blood pressure and heart rate, physical fitness, physical activity, and perceived psychological status before and after the 12-week intervention in the three groups are summarised in **Table 1**.

TABLE 1 Anthropometry, body composition, blood pressure and heart rate, physical fitness, physical activity, and perceived psychological status before (pre) and after (post) the 12-week intervention in the three groups.

Variables	FG (*n* = 23)			NFG (*n* = 21)			CG (*n* = 23)		
	Pre[a]	Post[a]	%Δ	Pre[a]	Post[a]	%Δ	Pre[a]	Post[a]	%Δ
Age (y)	8.6 ± 0.8	8.9 ± 0.8		9.4 ± 0.3	9.7 ± 0.3		8.6 ± 0.7	8.9 ± 0.8	
Anthropometry and body composition									
Height (cm)	130.2 ± 8.3**	134.5 ± 9.5***	3.3***	137.5 ± 5.2	139.3 ± 6.0	1.3	133.3 ± 8.0	136.6 ± 7.1	2.5
Weight (kg)	31.9 ± 9.2	34.2 ± 10.5	7.2	36.4 ± 8.1	36.3 ± 8.1	0.2	32.8 ± 8.0	34.5 ± 6.8	4.9
BMI	18.7 ± 3.4	18.7 ± 3.4	0.1	19.3 ± 3.6	18.7 ± 3.4	−2.7	18.3 ± 2.8	19.4 ± 2.6	5.7
BMI Z-score	0.9 ± 0.9	0.7 ± 0.9***	−21.2***	0.7 ± 0.9	0.5 ± 0.9***	−30.5***	0.7 ± 0.9	0.7 ± 0.9	−3.1
WC (cm)	66.2 ± 10.8	67.1 ± 10.0	1.3	67.4 ± 9.0	64.2 ± 8.9***	−4.3***	63.7 ± 6.6	64.5 ± 6.7	1.4
WtHr	0.50 ± 0.07	0.50 ± 0.05	−0.4	0.50 ± 0.07	0.46 ± 0.06***	−6.5***	0.47 ± 0.05	0.48 ± 0.04	2.9
Body fat (%)	28.7 ± 8.1	25.5 ± 7.7***	−11.1***	24.8 ± 8.2	24.4 ± 7.9	−1.6	26.7 ± 7.5	26.9 ± 7.4	0.9
Muscle mass (kg)	14.6 ± 3.8**	16.2 ± 4.9***	11.6***	17.9 ± 3.0	17.6 ± 2.7	−0.4	16.0 ± 3.7	15.7 ± 2.6	−0.5
Fat free mass (kg)	22.5 ± 5.8**	25.3 ± 7.5***	12.4***	26.9 ± 4.1	27.0 ± 4.0	0.3	23.8 ± 2.5	23.4 ± 3.9	−1.9
Blood pressure and heart rate									
SBP (mmHg)	100.9 ± 8.2	99.9 ± 9.8	−0.9	105.5 ± 13.5	100.8 ± 10.4***	−4.5***	102.5 ± 19.2	103.0 ± 19.4	0.5
DBP (mmHg)	61.3 ± 5.7**	60.0 ± 5.0	−2.2	68.5 ± 12.4	61.7 ± 6.6***	−9.9***	64.4 ± 9.6	64.5 ± 6.4	0.2
rHR (bpm)	89.4 ± 10.8	84.1 ± 14.9***	−5.9***	85.7 ± 12.9	78.1 ± 11.7***	−8.9***	81.5 ± 10.4	83.2 ± 7.4	2.1
Physical fitness									
Horizontal jump length (m)	1.20 ± 0.23	1.28 ± 0.25***	6.5***	1.25 ± 0.19	1.39 ± 0.22***,*	11.1***	1.21 ± 0.15	1.23 ± 0.12	1.6
20 m sprint (s)	5.00 ± 0.59**	4.85 ± 0.45**,***	−2.9***	4.64 ± 0.34	4.53 ± 0.39	−2.3	4.68 ± 0.24	4.77 ± 0.23	2
Shuttle run (m)	428.6 ± 206.6	500 ± 214.2***	16.7***	444 ± 238	642 ± 298***,*	44.1***	410 ± 162	436 ± 170	1.5
Physical activity									
Sports club active (%)	52.2	65.2	13	66.7	66.7	-	73.9	73.9	-
MVPA (min/d)	50.17 ± 15.2	58.2 ± 18.2***	15.9***	61.4 ± 19.8	68.5 ± 29.2***	12.1***	54.9 ± 14.5	55.0 ± 14.6	0.2
Psychological measures									
Index FAI	−0.6 ± 0.7	−0.4 ± 0.6***	−41***,	−0.6 ± 0.8	−0.3 ± 0.6***	−42.1***	−0.5 ± 0.7	−0.4 ± 0.7	−10.4
Physical health	70.1 ± 9.8	72.5 ± 10.5	3.6	78.8 ± 14.7	74.3 ± 15.6	−5.6	75.9 ± 16.7	75.0 ± 17.8	−1.2
Psychosocial health	70.0 ± 14.1	76.6 ± 11.6***	9.4***	68.5 ± 13.4	82.5 ± 15.7***,*	20.5***	71.2 ± 15.4	71.1 ± 14.7	−0.1
Quality of life	69.9 ± 11.5	73.8 ± 10.2	5.6	71.6 ± 12.1	76.8 ± 13.8***	7.3***	72.6 ± 14.1	72.3 ± 14.2	−0.5

FG, football group; NFG, nutrition and football group; CG, control group.
[a]Data are presented as mean (±SD), except for the percentage of sports club active children (% of all).
*Significantly different from control at the same measuring moment ($p < 0.05$).
**Significant between-group difference ($p < 0.05$).
***Significant baseline to post difference within the group ($p < 0.05$).

In total, 67 children (boys: 35; girls: 32) in 3 schools completed the program and both the preintervention and postintervention testing; of those, 23 were from the FG (age: 8.6 ± 0.8 years), 21 were from the NFG (age: 9.4 ± 0.3) and 23 from the CG (age: 8.6 ± 0.7 years).

No significant differences were observed at baseline between groups in weight, BMI, waist circumference, WtHr, body fat mass, systolic bloop pressure and heart rate, horizontal thrust, shuttle run test, physical activity levels, body image, physical health dimension and quality of life. Whereas significant differences were found in height [$F_{(2.64)} = 5.53$, $p = 0.006$, $\eta 2 = 0.15$], muscle mass [$F_{(2.64)} = 4.95$, $p = 0.010$, $\eta 2 = 0.13$] and fat-free mass [$F_{(2.64)} = 4.24$, $p = 0.019$, $\eta 2 = 0.12$] between intervention groups at baseline. On average, height of the FG is 7.35 ± 2.22 cm lower than the heigh of the NFG, muscle mass is 3.31 ± 1.05 kg lower than NFG and the fat-free mass of the FG is 4,41 ± 1.55 kg lower than the lean body mass of the NFG. Significant differences in diastolic blood pressure were found between intervention groups at baseline [$F_{(2.64)} = 3.16$, $p = 0.049$, $\eta 2 = 0.09$]. On average the diastolic blood pressure of the FG is 7.22 ± 2.88 mmHg lower than NFG, but there is no difference between the intervention groups and the CG. Regarding physical fitness, a statistically significant difference on 20 m sprint test [$F_{(1.64)} = 6.01$, $p = 0.017$, $\eta 2 = 0.14$] between the intervention groups at baseline. On average, FG is 0.359 ± 0.125 s slower than NFG, but there is no difference between the intervention groups and the CG in 20 m sprint test at baseline.

Over the 12-week study period within-group improvements were observed in both intervention groups. The FG and NFG significantly decreased in BMI z-score [FG: $F_{(1.64)} = 8.35$, $p = 0.005$, $\eta 2 = 0.12$; NFG: $F_{(1.64)} = 8.97$, $p = 0.004$, $\eta 2 = 0.12$], and resting heart rate [FG: $F_{(1.64)} = 6.22$, $p = 0.015$,, $\eta 2 = 0.09$; NFG: $F_{(1.64)} = 11.81$, $p = 0.001$ $\eta 2 = 0.16$] and significantly increased in horizontal jump length [FG: $F_{(1.64)} = 25.54$, $p < 001$, $\eta 2 = 0.29$; NFG: $F_{(1.64)} = 74.13$, $p < 001$, $\eta 2 = 0.54$], shuttle run [FG: $F_{(1.64)} = 11.45$, $p = 0.001$, $\eta 2 = 0.15$; NFG: $F_{(1.64)} = 79.16$, $p < 001$, $\eta 2 = 0.55$], Index FAI [FG: $F_{(1.64)} = 8.94$, $p = 0.004$, $\eta 2 = 0.12$; NFG: $F_{(1.64)} = 6.80$, $p = 0.011$, $\eta 2 = 0.10$], psychosocial health dimension [FG: $F_{(1.56)} = 6.81$, $p = 0.012$, $\eta 2 = 0.11$; NFG: $F_{(1.56)} = 40.82$, $p < 001$, $\eta 2 = 0.42$], and moderate to vigorous physical activity (MVPA) (FG: $F_{(1.64)} = 10.13$, $p = 0.002$, $\eta 2 = 0.14$; NFG: $F_{(1.64)} = 7.87$, $p = 0.007$, $\eta 2 = 0.11$] over the 12-week intervention), while CG maintain constant values.

In the intervention groups, BMI z-score reduced on average 0.19 ± 0.07 scores in FG (21.2%) and 0.21 ± 0.07 scores in NFG (30.5%), resting heart rate reduced on average 5.28 ± 2.12 bpm in FG (5.9%) and 7.62 ± 2.22 bpm in NFG (8.9%), horizontal jump length improved 0.08 ± 0.02 m (6.5%) in FG and 0.14 ± 0.02 m (11.1%) in NFG, with differences between NFG and CG [$F_{(2.64)} = 0.19$, $p = 0.016$, $\eta 2 = 0.12$], Shuttle run test improved 72 ± 21 m (16.7%) in FG and 198 ± 22 m (44.1%) in NFG, with differences between NFG and CG [$F_{(2.64)} = 5.29$, $p = 0.007$, $\eta 2 = 0.14$], Index FAI (values closer to 0 represent consistent weight status perception) reduce 0.26 ± 0.87 scores in FG and 0.24 ± 0.91 scores in NFG, psychosocial health dimension improved on average 6.58 ± 2.42 scores in FG (9.4%) and 14.07 ± 2.20 scores in NFG (20.5%), with differences between NFG and CG [$F_{(2.56)} = 3.42$, $p = 0.40$, $\eta 2 = 0.11$], and regarding MVPA, FG increase 8.00 ± 2.51 min/d (15.9%) the time spent in MVPA and NFG increase 7.38 ± 2.63 min/d (12.1%), with 39.1% and 57.1% of the children reaching the guideline of MVPA, respectively.

After the 12-week, the NFG significantly decreased in DBP [$F_{(1.64)} = 14.81$, $p < 001$, $\eta 2 = 0.19$], SBP [$F_{(1.64)} = 5.94$, $p = 0.018$, $\eta 2 = 0.09$], WC [$F_{(1.64)} = 26.71$, $p < 001$, $\eta 2 = 0.29$], and WtHr [$F_{(1.64)} = 20.22$, $p < 001$, $\eta 2 = 0.24$], and significantly increased in quality of life [$F_{(1.56)} = 6.87$, $p = 0.011$, $\eta 2 = 0.11$] while the FG and CG maintain constant values between baseline and post. These differences in NFG are the result of a reduction about 6.81 ± 1.77 mmHg in DBP (9.9%), 4.71 ± 1.94 mmHg in SBP (4.5%), 2.88 ± 0.56 cm in WC (4.3%), 0.03 ± 0.01 scores in WtHr (6.5%) and an improvement around 5.22 ± 1.99 scores in quality of life (7.3%).

The FG, significantly decreased in % body fat mass [$F_{(1.64)} = 13.31$, $p < 001$, $\eta 2 = 0.17$], significantly increased in height [$F_{(1.64)} = 11.25$, $p = 0.001$, $\eta 2 = 0.15$], MM [$F_{(1.64)} = 6.58$, $p = 0.013$, $\eta 2 = 0.09$], and FFM [$F_{(1.64)} = 9.49$, $p = 0.005$, $\eta 2 = 0.12$], and significantly improved in 20 m sprint test [$F_{(1.64)} = 6.39$, $p = 0.014$, $\eta 2 = 0.09$], while the NFG and CG maintain constant values between baseline and post. In the FG, these significant differences are the result of a reduction on average about 3.20 ± 0.88% in body fat mass percentage (11.1%), and improvements around kg 1.60 ± 1.19 kg in muscle mass (11.6%), 2.80 ± 0.96 kg in fat-free mass (12.4%), 4.29 ± 1.28 cm in height (3.3%) and 20 m sprint test by reducing on average 146 ± 58 milliseconds (2.9%), with significant differences between FG and NFG [$F_{(2.64)} = 4.11$, $p = 0.021$, $\eta 2 = 0.11$].

In contrast, CG showed no significant changes over 12-week ($p > 0.05$).

3.2. Nutritional knowledge and eating behaviours

Nutritional knowledge and analysis of 24-hour recall before and after the 12-week intervention are represented in **Table 2**. All children consumed a minimum of five meals per day, consisting of breakfast, a morning snack, lunch, an afternoon snack, and dinner. No significant differences at baseline were observed between groups in the nutritional knowledge and eating behaviours.

Between baseline and post, both intervention groups showed significant reduction in CHO intake [FG: $F_{(1.64)} = 17.48$, $p < 001$, $\eta 2 = 0.22$; NFG: $F_{(1.64)} = 7.39$, $p = 0.008$, $\eta 2 = 0.10$], and in sodium intake [FG: $F_{(1.64)} = 12.89$, $p < 001$, $\eta 2 = 0.17$; NFG: $F_{(1.64)} = 11.64$, $p = 0.001$, $\eta 2 = 0.15$], while CG maintain constant values. In the intervention groups, CHO intake reduced on average 47.9 ± 0.9 g in FG (16.9%) and 32.1 ± 23.6 g in NFG (7.9%), and sodium intake reduced on average 401.4 ± 34.8 mg (18%) in FG and 399.2 ± 337.9 mg (10.7%) in NFG.

Significant differences between intervention groups and control group were found in CHO [$F_{(2.64)} = 4.02$, $p = 0.023$, $\eta 2 = 0.11$] and in sodium intake [$F_{(2.64)} = 8.03$, $p < 001$, $\eta 2 = 0.20$] after the 12-week intervention.

TABLE 2 Analysis of 24-hour recall: daily mean nutritional intake of the participants.

	FG ($n = 23$)			NFG ($n = 21$)			CG ($n = 23$)		
	Pre[a]	Post[a]	%Δ	Pre	Post[a]	%Δ	Pre[a]	Post[a]	%Δ
NQK	10.8 ± 2.9	10.7 ± 3.4	−0.5	12.7 ± 2.5	15.3 ± 2.3*,**,***	24***	11.6 ± 2.3	11.5 ± 2.3	−0.1
24-hour recall									
Energy (kcal)	1,796.2 ± 295.2	1,751.1 ± 328.1	−1.1	1,959.9 ± 390.3	1,810.3 ± 407.1***	−6.1***	2,027.3 ± 328.6	1,998.3 ± 288.4	−1.1
Energy/Kg	55.9 ± 12.0	54.1 ± 14.2	−3.4	57.6 ± 17.5	52.7 ± 18.4***	−7.8***	65.7 ± 13.2	62.5 ± 13.0	−4.8
Protein (g)	89.0 ± 14.9	97.6 ± 13.9	11.8	99.8 ± 23.6	92.5 ± 20.0	−2.6	94.5 ± 23.4	93.9 ± 21.1	−0.1
Carbohydrate (g)	250.8 ± 66.8	202.8 ± 67.7***,*	−16.9***	252.9 ± 72.6	220.3 ± 49.1***,*	−7.9***	250.3 ± 64.5	253.5 ± 65.2	1.3
Fiber (g)	17.0 ± 7.3	14.8 ± 6.1	−10.1	16.6 ± 10.4	14.2 ± 3.9	4.5	17.9 ± 7.1	18.1 ± 7.1	1.3
Sugar (g)	93.0 ± 43.5	69.2 ± 41.0***,*	−18.7***	80.7 ± 30.9	71.7 ± 22.8*	−1.4	102.0 ± 40.3	98.1 ± 35.6	−2.1
Fat (g)	49.6 ± 13.7*	61.4 ± 17.5***	29.9***	62.5 ± 18.1	62.5 ± 22.9	3.9	74.7 ± 24.6	75.1 ± 24.2	0.7
Saturated fat (g)	17.0 ± 4.8*	20.3 ± 5.0***	24.1***	19.8 ± 7.8	21.7 ± 9.8	15.9	25.0 ± 11.5	25.1 ± 11.4	0.6
Sodium (mg)	1,992.8 ± 572.7	1,591.4 ± 607.5***,*	−18.0***	2,112.4 ± 744.7	1,713.3 ± 406.8***,*	−10.7***	2,134.3 ± 431.0	2,147.5 ± 434.5	0.6

Data are presented as mean (±SD). FG, football group; NFG, nutrition and football group; CG, control group. NKQ, Nutritional Knowledge Questionnaire.
*Significantly different from control at the same measuring moment.
**Significant between-group difference.
***Significant within-group difference.

Over the intervention, the NFG was the only group that significantly increase in nutritional knowledge [$F_{(1.60)} = 47.06$, $p <$ 001, $\eta2 = 0.44$], while FG and CG maintain constant values, with between group differences [$F_{(2.60)} = 17.05$, $p < 001$, $\eta2 = 0.36$], and significantly decrease the total energy intake [$F_{(1.64)} = 5.09$, $p =$ 0.028, $\eta2 = 0.07$] and consequently the energy intake/body weight [$F_{(1.64)} = 6.51$, $p = 0.013$, $\eta2 = 0.09$] over the intervention. On average, NFG increase 2.58 ± 0.15 scores (24%) in the nutritional knowledge and decrease 149.6 ± 16.8 Kcal in the total energy intake (6.1%) and 5.0 ± 0.9 Kcal/Kg (7.8%).

The FG increased in total fat intake [$F_{(1.64)} = 11.47$, $p = 0.001$, $\eta2 = 0.15$] and saturated fat intake [$F_{(1.64)} = 8.73$, $p = 0.004$, $\eta2 =$ 0.12], and decreased sugar intake [$F_{(1.64)} = 11.00$, $p = 0.002$, $\eta2 =$ 0.15] between baseline and post, while NFG and CG maintain constant. Differences between groups were found for sugar intake [$F_{(2.64)} = 4.98$, $p = 0.010$, $\eta2 = 0.14$] over the intervention. On average, FG increase 11.8 ± 3.8 g of fat intake (29.9%) and 3.3 ± 0.1 g of saturated fat (24.1%), while decreased 23.8 ± 2.5 g of sugar (18.7%).

Children's food frequency questionnaire identifies the number of times a particular food or food group was consumed during the previous month, but not the total amount ingested. The analysis of the frequency of food and drink consumption reported by the children's guardians showed that only the NFG children significantly improved the daily fruit frequency consumption [Baseline = 28.6% vs. Post = 61.9%; $\chi^2(_1) = 5.143$; $p = 0.016$] and the frequency of fish consumption greater than or equal to 3 times a week [Baseline = 52.4% vs. Post = 85.7%; $\chi^2(_1) = 5.143$; $p = 0.016$] over the intervention.. In addition, we observed that children from NFG tend to increase the daily consumption of vegetables [Baseline = 4.8% vs. Post = 28.6% $\chi^2(_1) = 3.200$; $p = 0.063$] and the daily intake of soup [Baseline = 28.6% vs. Post = 57.1% $\chi^2(_1) = 3.125$; $p = 0.070$], with no significant difference. Tables 3, 4 show the consumption frequencies in the

TABLE 3 Estimated differences in frequency of fruit and vegetable consumption at baseline and after 12-weeks of intervention in the three groups.

	FG ($n = 23$)			NFG ($n = 21$)			CG ($n = 23$)		
	Baseline	Post	P-value[a]	Baseline	Post	P-value[a]	Baseline	Post	P-value[a]
Fruit (%)									
≤6 times/week	26.1	39.1	0.375	71.4	38.1	0.016b[b]	39.1	47.8	0.500
Daily	73.9	60.9		28.6	61.9		60.9	52.2	
100% fruit juice (%)									
≤6 times/week	87.0	100.0	0.250	81.0	85.7	1.000	91.3	91.3	1.000
Daily	13.0	0		19.0	14.3		8.7	8.7	
Soup (%)									
≤6 times/week	26.1	30.4	1.000	71.4	42.9	0.070	34.8	43.5	0.727
Daily	73.9	69.6		28.6	57.1		65.2	56.5	
Vegetable (%)									
≤6 times/week	52.2	56.5	1.000	95.2	71.4	0.063	65.2	73.9	0.625
Daily	47.8	43.5		4.8	28.6		34.8	26.1	

Data are presented as percentage.
[a]χ^2 test (McNemar); FG, football group; NFG, nutrition and football group; CG, control group.
[b]Significant within-group difference.

TABLE 4 Estimated differences in frequency of food and drink consumption at baseline and after 12-weeks of intervention in the three groups.

	FG ($n = 23$)			NFG ($n = 21$)			CG ($n = 23$)		
	Baseline	Post	P-value[a]	Baseline	Post	P-value[a]	Baseline	Post	P-value[a]
Bread (%)									
<3 times/week	13.0	8.7	1.000	4.8	9.5	1.000	17.4	8.7	0.500
≥3 times/week	87.0	91.3		95.2	90.5		82.6	91.3	
Cereal (%)									
<3 times/week	30.4	47.8	0.219	42.9	42.9	1.000	47.8	47.8	1.000
≥3 times/week	69.6	52.2		57.1	57.1		52.2	52.2	
Cookies (%)									
<3 times/week	39.1	43.5	1.000	19.0	38.1	0.219	34.8	39.1	1.000
≥3 times/week	60.9	56.5		81.0	61.9		65.2	60.9	
Fish (%)									
<3 times/week	17.4	26.1	0.625	47.6	14.3	0.016[b]	47.8	56.5	0.688
≥3 times/week	82.6	73.9		52.4	85.7		52.2	43.5	
Meat (%)									
<3 times/week	8.7	21.7	0.375	14.3	14.3	1.000	21.7	21.7	1.000
≥3 times/week	91.3	78.3		85.7	85.7		78.3	78.3	
Eggs (%)									
<3 times/week	56.5	43.5	0.453	47.6	57.1	0.688	52.2	52.2	1.000
≥3 times/week	43.5	56.5		52.4	42.9		47.8	47.8	
Milk (%)									
<3 times/week	0.0	4.3	1.000	9.5	14.3	1.000	30.4	30.4	1.000
≥3 times/week	100.0	95.7		90.5	85.7		69.6	69.6	
Cheese (%)									
<3 times/week	47.8	30.4	0.219	42.9	42.9	1.000	56.5	56.5	1.000
≥3 times/week	52.2	69.6		57.1	57.1		43.5	43.5	
Yogurt (%)									
<3 times/week	4.3	26.1	0.063	19.0	33.3	0.250	30.4	30.4	1.000
≥3 times/week	95.7	73.9		81.0	66.7		69.6	69.6	
Sweet snacks (%)									
<3 times/week	78.3	82.6	1.000	57.1	76.2	0.125	65.2	65.2	1.000
≥3 times/week	21.7	17.4		42.9	23.8		34.8	34.8	
Salty snacks (%)									
<3 times/week	100.0	95.7	1.000	85.7	95.2	0.500	87.0	91.3	1.000
≥3 times/week	0.0	4.3		14.3	4.8		13.0	8.7	
Soft drinks (%)									
<3 times/week	87.0	82.6	1.000	71.4	66.7	1.000	69.6	73.9	1.000
≥3 times/week	13.0	17.4		28.6	33.3		30.4	26.1	

Data are presented as percentage.
[a]χ^2 test (McNemar); FG, football group; NFG, nutrition and football group; CG, control group.
[b]Significant within-group difference.

three groups at baseline and after the intervention. Children's guardians reported not consuming any food and nutritional supplementation.

4. Discussion

To the best of our knowledge, this study is the first to examine the effects of a 12-week football and nutrition intervention program on several health markers, nutritional status, and fitness profiles.

The significant differences observed at baseline in muscle mass and fat-free mass between the intervention groups suggest that NFG was more active than FG before the intervention. Furthermore, differences in body composition, may be associated with an advanced maturity in the children.

The present findings showed a significant reduction in BMI z-score in the FG and NFG children, in accordance with a 6-month intervention with obese boys (22). Previous interventions focused on school-based physical activity have shown potential for yielding positive effects on body composition. Specifically, these interventions have led to reductions in BMI (58) and slight improvements in BMI z-scores (59).

The significantly increase of muscle mass and fat free mass in FG, with a greater change score, 11.6% and 13% respectively, is similar to reported in previous studies (12, 15, 22). The increase in muscle mass could additionally indicate muscle hypertrophy as a result of additional exercise (15, 17). A possible explanation for muscle mass in NFG does not significantly increase over the intervention is that this group started the intervention with a significant greater muscle mass contribution than FG.

In the present study, only the FG experienced significant reductions in body fat mass percentage, with no differences between groups. These findings are in accordance with other school-based physical activity interventions with 11-week (12, 15, 60), 12-week (23), and 6-month intervention (22). The reduction in the percentage of body fat mass in the NFG was not significant after the intervention, possibly because the participants started the study with a lower percentage compared to the other groups.

Nevertheless, we found a positive influence of school-based physical intervention on modulating the central-adiposity markers of the NFG, the only group that significantly decreased waist circumference (−4.2%) and WtHr (−6.2%), specific markers of upper body fat accumulation in children and able to predict cardiovascular disease risk factors (33, 61, 62). These findings concur with a 12-week recreational football program with obese adolescents (23), and with a 6-month intervention with obese boys (18, 22). In the present study, 56.8% of the intervention participants had a mean value of WtHr greater than 0.500 at baseline, meaning this population should be considered as at high-risk of developing cardiometabolic comorbidities (33). The decrease in waist circumference and WtHr verified in the NFG participants demonstrates that school-based physical intervention with recreational football and nutritional education contributes to reducing the risk of developing cardiovascular comorbidities. WtHr is more closely linked to childhood morbidity than BMI and it should be used as an additional or alternative measure to BMI in children as well as adults (33).

Paediatric obesity and lifestyle patterns have an important influence on the overall risk of cardiovascular diseases (63) and the prevalence of paediatric hypertension has been observed to rise concurrently with the increase in childhood obesity rates (18, 64). In the present investigation, both intervention groups improved their resting heart rate. Notably, the NFG significantly improved both DBP and SBP. These findings highlight the positive impact of the program on blood pressure, aligning with prior research that reinforces the favourable effects of physical activity interventions in reducing systolic and diastolic blood pressure (65).

The observed improvements concerning DBP and SBP in the NFG are similar to or even larger than reported in other comparable football intervention studies with 11 weeks (12, 15, 20). In a 12-week recreational football program with obese adolescents, significant reductions in SBP were found, but no changes were found for DBP (23). In contrast, in a 10-week football training intervention for school children aged 9–10 years no changes were observed in none of the cardiovascular parameters (20).

For adults, the risk of cardiovascular mortality and morbidity is reduced by 13% for every 5 mm Hg reduction in SBP (66). Although no equivalent risk calculations have been made in children, a reduction in blood pressure of this magnitude is associated with less arterial stiffness and a decrease in the rate of progression of atherosclerosis in adulthood (12, 67, 68). The significant reduction of 4.7 mmHg in SBP that we found in NFG is a good indicator that a multidisciplinary program with physical activity and nutritional education could reduce the risk of cardiovascular diseases.

Children with higher blood pressure are more likely to become hypertensive adults, and the observed decrease in resting blood pressure and resting heart rate in the intervention groups is an important finding, as in normotensive children, no clear link has been established between physical activity and blood pressure (21, 63). These results suggest that physical activity programs inserted in a school environment are feasible to reduce blood pressure in normotensive children, and the potential of such interventions for the primary prevention of hypertension and cardiovascular diseases clearly warrants further study.

Cardiovascular disease risk factors have been demonstrated to be associated with children level of physical activity and was highly associated with a lower level of fitness (69). Moreover, it is important to note that interventions focusing on physical activity within a school-based setting can potentially enhance both physical activity and fitness among healthy young individuals (59, 70).

Over the "Football and Nutrition for Health" program, both intervention groups improved horizontal jump length and shuttle run test performance during the program with no differences between intervention groups. Improvements in explosive strength in the transition from childhood to adolescence are associated with positive changes in bone mineral density (71). Additionally, and more generally, explosive strength is inversely related to risk factors for cardiometabolic diseases (71). This result in horizontal jump length performance is similar to 11 weeks intervention (15), to 6-month small-sided football intervention (72), and to 10-month intervention of small- sided games (17). On the other hand, studies with 8 weeks of football training sessions found that is not sufficient to result in between-group differences (14) and with a lasting 11–12 weeks (12, 60, 73) found no significant effects on horizontal jump length performance.

Shuttle run test improved in both intervention groups, revealing a better aerobic fitness after the 12-week intervention, being associated with a lower risk of cardiometabolic diseases, obesity, diabetes, and other health problems during the entire life cycle (74). Other studies have reported similar effects of recreational football programs on aerobic fitness performance in children after 6 weeks (16, 75), 11 weeks (12, 15) and 10 months (17). The high-intensity football training is associated with high-intensity intermittent aerobic exercise capacity and can be effective in improving aerobic fitness (11, 15, 19, 76).

Both intervention groups improved the performance in the 20 m sprint test, but only the FG had a significant difference between baseline and post intervention. Although, on average, the NFG was faster (4.53″) than FG (4.85″) to complete the 20 m sprint test in the post-intervention, the FG reduced they time in 2.5%, a good indicator of bone tissue health and is inversely related to risk factors for cardiometabolic diseases (77). Improvements in the 20 m sprint test are in accordance with a study with modified "FIFA 11 for Health" program for non-communicable diseases (12). On the other hand, a study with 8 weeks of football training sessions was not sufficient to result in between-group differences in sprint (14).

The most recent results from Portugal's 2021 Report Card on Physical activity for Children and Adolescents shows that less than 30% of children and adolescents achieve physical activity guidelines (78). In our study, both intervention groups improved the moderate to vigorous physical activity (MVPA) from baseline to post intervention, approaching or reaching the WHO recommendations for children (5). In a 6-month studies with overweight children, no differences in the average minutes of MVPA per day were found (18, 22).

Prior research indicates that engagement in physical activity has a noteworthy positive impact on the moods of children and adolescents (79). Concerning the psychological status, the present intervention was effective in improving scores for the sub-result of psychosocial health status (emotional, social, and school functioning dimensions) in FG and NFG. These findings provide additional support for the previously reported benefits of physical activity programs in promoting the well-being of children (11, 13, 80).

In a comparable study, scores for the PedsQL questionnaire also identified significant improvements in the social and school dimension of well-being for the intervention group (13). Likewise, other study examining the effects of a comparable program on well-being demonstrated positive enhancements in both physical and psychological well-being (80). Moreover, in previous programs with obese boys was observed an improvement on perceived psychological status, showing that recreational football as a team-based activity has the potential to promote teamwork, sharing and social interactions that offer opportunities to improve perceived psychological status (22, 81, 82).

Intervention groups also showed an improve in the Index FAI score, revealing a more consistent body image and weight status perception. Children with overweight were more likely to underestimate their actual weight status and in obesity prevention such underestimation may be a barrier for behavioural change (83). Our results are in accordance with previous 5-month (24) and a 6-months intervention programs based on the practice of football (22, 82).

The positive influence of the "Football and Nutrition for Health" program on children's perceived psychological status underscores the significance of school-based initiatives in promoting mental health. It aligns with the goals outlined in the European Mental Health Action Plan, which advocates for impactful measures to enhance mental health and well-being. Specifically, this involves implementing comprehensive mental health promotion programs within schools (84).

The implementation of interdisciplinary and playful educational health interventions within school environments has been shown to enhance knowledge of topics related to eating and nutrition. This approach proves effective in promoting healthier habits among children, as it fosters an improved understanding of dietary concepts through comprehensive education (26, 85).

Differences between the baseline and post-intervention nutritional knowledge questionnaire in the NFG revealed significant increases in children's nutritional knowledge and significant differences between groups. NFG improved the nutritional knowledge in 2.6 scores (24%) after the 12 sessions. Likewise, in a 9-weeks school-based intervention the mean total nutrition knowledge increase by 1.1 scores (49). In a 5-month educational health intervention increased children's knowledge of eating and nutrition (26). In addition, the Program Obesity Zero, revealed that the children's knowledge concerning healthy diet, increased (5.8 scale point) after 6 months (A. Rito et al., 2012). Finally, in MUN-SI, a study about the Mediterranean Diet knowledge, was observed values between +12.1% to 21.1%, between 2016 and 2019 (86).

Dietary records revealed differences in the total energy intake and in the ratio kcal/body weight from the baseline to post-intervention in NFG. Children from NFG decreased carbohydrate, and sodium intake. Children from FG decreased carbohydrate, sugar, and sodium intake, but increased total fat, and saturated fat. These changes observed in the intake of carbohydrates, fats and sodium remained within the reference values (87, 88). Although sugar intake was reduced in the FG, it remained above the recommendations (87).

Surprisingly, the FPQ revealed that children from NFG had a low frequency of fruit, soup and vegetable consumption in the pre intervention compared with FG and CG. After realizing that the school is the environment where this consumption is most frequent (through the lunch meal), we noticed a difference in relation to other schools: the lack of a supervisor who encourages the consumption of these foods. At the end, the FPQ reported by the guardians, revealed an increase of fruit similar to FG frequency consumption. We believe that nutrition education classes, focusing on the role of fruits and vegetables in children's health and growth, influenced their consumption after the intervention.

Similarly, MUN-SI program showed a positive behavioural change in the preference for including fruit and vegetables in home brought to school lunches (+2.3% in 2015/2016) and at breakfast (+16% in 2014/2015 and +11.9% in 2017/2018) (86). In Program Obesity Zero, after 6 months, there was also an improvement in children's attitudes regarding healthy foods such as brown bread, fruits and vegetables, fish, milk, and yoghurt (89). In "CHILDREN study", after a 12-month school-based nutrition and physical activity intervention program the intervention group also revealed higher daily consumption of fruits (90).

Moreover, we speculate that the School Fruit Scheme (91), a national strategy for the supply of fruit implemented since 2009, associated with positive messages from nutrition educational classes could encourage the consumption of fruit among children. To school-based programs, we suggest combined nutritional education sessions (through positive messages and ludic environment) with programs that offers healthy food consumption in order to achieve a positive impact on eating behaviour.

In summary, the program revealed improvements in horizontal jump length, shuttle run performance, and MVPA, induced multiple effects on cardiorespiratory health, promoted a consistent body image and weight status perception (index FAI), and improved the psychosocial health status after 12-week. Furthermore, the intervention resulted in muscle mass and fat-free mass increases and reductions in BMI z-score, body fat mass percentage and rHR in the FG. While NFG decreased BMI z-score, waist circumference and WtHr, it improved DBP, SBP and rHR, increased fruit daily consumption and revealed an increase in nutritional knowledge. The "Football and Nutrition for Health" program confirmed the hypothesis that a combination of recreational football training and nutritional education classes are capable to induce short-term improvements in body composition, physical fitness, physical activity, eating habits, nutritional knowledge, and psychological status among children aged 7–10 years.

5. Strengths and limitations

The present study has limitations that should be acknowledged. The children were not randomly assigned to their respective groups. Furthermore, the dietary intake data relied on dietary records reported by parents, which may result in under-report or over-report of habitual nutritional intakes or changes in nutritional-intake patterns. Nevertheless, dietary records are widely used methods for the assessment of dietary intake valid in child populations. On the other hand, it is important to acknowledge the strengths of this study. It contributes to the existing knowledge by exploring the potential of a school-based intervention involving nutrition education and football, which, to the best of our knowledge, has not been previously undertaken. Moreover, the three groups were similar at baseline in the major characteristics. The utilization of accelerometers, an objective measure, further strengthened the design of our study. Overall, these strengths contribute to the robustness and credibility of our study's findings.

6. Conclusion

This study highlights the role of the school-based programs as an important determinant of physical activity levels in elementary schoolchildren. Introducing nutritional education and recreational football in elementary schools could be a great and effective strategy to improve physical activity, physical fitness, body composition, nutritional habits, nutritional knowledge and to prevent noncommunicable diseases in boys and girls, constituting an effective tool in health education and promotion. The outcomes of this study hold considerable importance and interest for a diverse audience, encompassing parents, educators, teachers, school administrators, and policymakers. These results strongly advocate for the inclusion of active school programs within curricula, thereby fostering the promotion of children's health. These data reinforce and justify that priority should be given to the development of national action programs that encourage the adoption of healthier lifestyles and to the creation of structural and environmental conditions favourable to child health. Further studies are needed to assess whether this intervention can form part of a more complex behaviour change intervention to prevent childhood obesity.

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.

Ethics statement

The studies involving humans were approved by Ethical Committee of the Faculty of Sport of the University of Porto (nr. CEFADE 05 2019). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

MM, AS and MS conceptualized and developed the methodology. MM and AC collected the data. MM and SV analysed the physical activity data. MM, AS and AC visualized and analysed the data (nutrition, body composition, physical fitness and psychological status). MM reviewed the literature and wrote the manuscript with AS and MS. MM, AS, MS, AC, SV and JC reviewed and modified 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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An empirical study on the effect of outdoor illumination and exercise intervention on Children's vision

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Objective: To explore the relationship between outdoor lighting and sports and the development of myopia, and to analyze the effects of outdoor lighting and exercise on the diopter of children with normal vision and myopia, so as to provide guidance for the prevention and treatment of myopia in children and adolescents in the future.

Methods: A total of 201 children were divided into two groups according to myopia or not. Each group was randomly divided into 4 groups: outdoor exercise group, outdoor control group, indoor exercise group and indoor control group. Among them, the outdoor exercise group and indoor exercise group received moderate and high intensity aerobic exercise 3 times a week for 60 min each time for 12 months, while the outdoor control group and indoor control group had normal study and life during the corresponding period of time. No additional exercise intervention. At the end of the experiment, the diopter of each group was compared.

Results: The diopter of all groups with normal vision and myopia decreased significantly after the experiment ($p < 0.01$). There were significant differences in diopter between outdoor exercise group and indoor control group ($p < 0.01$), between outdoor exercise group and indoor control group ($p < 0.05$), and between indoor exercise group and indoor control group ($p < 0.01$). There were significant differences in diopter between indoor exercise group and indoor control group ($p < 0.01$). The differences among myopic children after the experiment showed that there was significant difference in diopter between outdoor exercise group and indoor exercise group ($p < 0.05$), between outdoor exercise group and indoor control group ($p < 0.01$), and between outdoor control group and indoor control group ($p < 0.05$). There were significant differences in the changes of diopter between the outdoor control group and the indoor exercise group with normal vision and myopia before and after the experiment ($p < 0.05$).

Conclusion: Outdoor light and exercise intervention can have a beneficial effect on children's vision, but because of whether children are myopic or not, the effect is different, outdoor light and exercise have a better effect on reducing the diopter of children with normal vision.

KEYWORDS

exercise, retina, children, myopia, outdoor lighting, school

1 Introduction

Myopia is one of the most common eye diseases among children and adolescents. in 2020, the overall myopia rate of Chinese children and adolescents was 52.7%, an increase of 2.5 percentage points over 2019, including 14.3% for 6-year-old children, 35.6% for primary school students, 71.1% for junior high school students and 80.5% for high school students. Projections by Holden et al. on the global prevalence of myopia show that by 2050, there will be 4.758 billion people with myopia (49.8% of the world population) and 938 million people with high myopia (9.8% of the world population) (1). The increasing incidence of myopia year by year will further increase the risk of myopic complications such as retinal detachment, cataract, glaucoma and blindness, which will have a great impact on national security, socio-economic production activities and personal health. According to the National Visual Health report, as far as China is concerned, the socio-economic cost caused by various visual defects in 2012 alone reached more than 560 billion yuan (2). To sum up, the myopia of children and adolescents has become a major public health problem at home and abroad, so it is urgent to explore effective means and methods to prevent and cure adolescent myopia.

In recent years, researchers have made many attempts on how to effectively control the myopia of children and adolescents. Existing studies have shown that corneal plastic lens (3), surgical treatment (4) and drug therapy (5) all play a certain role in the prevention, relief and treatment of myopia, but there are also some drawbacks. For example, atropine in drug therapy can make the body develop drug resistance, and it is easy to rebound after drug withdrawal; long-term wearing of keratoplasty lens will induce keratitis; surgical treatment will also face the risk of blindness after failure. Therefore, how to solve the problem of myopia safely and effectively is still a clinical bottleneck that needs to be broken through. The above troubles force us to explore more safe and effective means of prevention and treatment of myopia in children and adolescents. With the deepening of the study of the relationship between exercise and health, the role of exercise in vision protection has gradually become the focus of academic attention (6). Previous studies have shown that exercise can relieve eye fatigue by promoting human metabolism and accelerating eye blood circulation, and it can also enhance the contractile strength and adjustment ability of intraocular regulatory muscles and extraocular convergent muscles. Make the regulation and axis of the eye more coordinated (7–9). Based on the above findings, more and more scholars try to reduce the rate of myopia in children and adolescents through exercise.

In addition to exercise, studies have found that outdoor light can also have a good effect on vision. It is reported that outdoor light can effectively prevent myopia by stimulating the release of dopamine in the retina, inhibiting the elongation of the eye axis and effectively preventing myopia (10, 11). On the other hand, it can also increase the level of vitamin D in the blood, resulting in differences in individual vitamin D levels, thus achieving the regulation of myopia (12). Both exercise and outdoor lighting have beneficial effects on myopia, but who plays a key role has always been controversial. At present, the latest foreign reports show that compared with exercise, outdoor lighting may be the most important factor in the prevention and treatment of myopia, but the relevant conclusions still need to be further confirmed by research (13).

To sum up, the situation of myopia among students is becoming more and more serious, how to effectively prevent and cure myopia has become an urgent problem to be solved. At present, there is a dispute about the prevention and treatment mechanism of myopia caused by outdoor sports, and the focus of the debate is whether exercise itself or outdoor light plays a major role in the prevention and treatment of myopia. Therefore, whether simple exercise or outdoor lighting or the superposition of outdoor lighting and exercise is the key to the prevention and treatment of myopia, which needs further study. In addition, for different groups of people, such as myopia or normal vision, there are few studies on whether outdoor light and exercise have different effects on the prevention and treatment of myopia. Based on this, this subject intends to take primary school students in Chengdu as the research object to explore the correlation between sports and outdoor lighting and the occurrence and development of myopia, and to further explore the effects of outdoor and sports on people with different eyesight. to provide reference for the prevention and treatment of myopia in children and adolescents.

2 Methods

2.1 Study design and participants

We conducted a randomized controlled trial on the effects of outdoor light and exercise intervention on children's vision in a primary school in Chengdu from March 2022 to March 2023. This research procedure is in line with the principles of the Helsinki Declaration, and has been approved by the Medical Ethics Committee of Chongqing Southwest University Hospital (approval number: 202215), and the study has been completed in accordance with the ethical requirements of clinical trials. an informed consent form was signed with each subject and his guardian before the start of the experiment. According to the pre-established inclusion criteria, 201 students were recruited, including 100 students with normal vision and 101 students with mild myopia ($-3.0D <$ binocular diopter $< -0.5D$). The students with normal vision and myopia were randomly divided into four groups: outdoor exercise group (T1 group), outdoor control group (T3 group), indoor exercise group (T5 group) and indoor control group (T7 group). Myopic subjects were randomly divided into outdoor exercise group (T2 group), outdoor control group (T4 group), indoor exercise group (T6 group) and indoor control group (T8 group). The specific grouping process is shown in Figure 1. The random packet sequence is generated by the random number generation algorithm on the computer to ensure the scientific distribution.

2.2 Intervention

The purpose of this study is to make use of the students' delayed service time after class to carry out the experiment, which requires students to carry out corresponding sports and outdoor light exposure according to the prior grouping arrangement. In the outdoor exercise group (T1, T2), the participants were required to do moderate and high intensity aerobic exercise in the outdoor playground for 12 weeks, three times a week for 60 min each time, while in the outdoor control group (T3, T4), the participants were asked to stay outdoors during the experiment without exercise intervention. In the indoor exercise

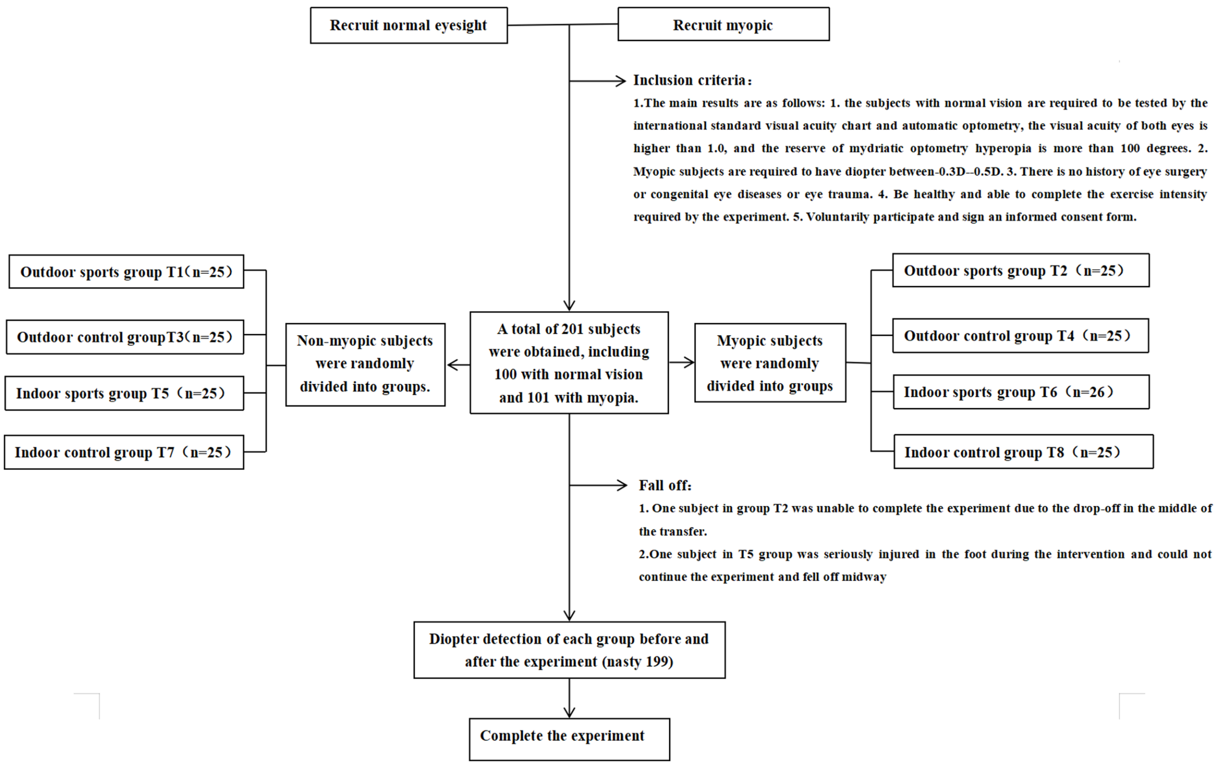

FIGURE 1
Experimental flow.

group (T5, T6), participants were required to do moderate and high intensity aerobic exercise indoors 3 times a week for 60 min each time for 12 weeks. In the indoor control group (T7, T8), the participants were asked to stay indoors during the experiment without exercise intervention. The specific intervention methods of each group are shown in Table 1. The subjects and data collectors were not informed of the purpose of this study throughout the experiment.

2.3 Data collection

In this study, two full-time ophthalmologists used the method of mydriatic refractive test to detect the diopter of the subjects before and after the experiment, specifically choosing compound tropicamide eye drops as a drug for ciliary paralysis, once per 5 min for a total of 3 times. After 20 min, doctors judged the condition of ciliary paralysis according to the pupil light reflex, with no pupil light reflex and pupil diameter greater than 6 mm as the judgment standard. Half an hour later, the diopter (SEQ) was examined by a full-time ophthalmologist. Each subject was tested for 3 times in the left and right eyes, and the average value of the effective measurement was taken for 3 times. The whole testing process is carried out in the hospital, and the measured data are collected by doctors.

2.4 Statistical analysis

SPSS25.0 was used to analyze the experimental data, variance homogeneity test was used to screen the data, and the average ± standard deviation (M ± SD) was used to express the continuous variables in accordance with normal distribution, and the data were accurate to two decimal places. The data processing of each group before and after the experiment, before and after the experiment, using paired sample T test; comparison between groups, using single-factor ANOVA analysis of variance, the process of normal distribution and variance homogeneity Bartlett test, and then single-factor analysis of variance, through LSD or Dunnett T3 for post-test, and using Bonferroni to correct p value. Independent sample T test was used to compare the difference of dioptre between normal vision and myopic subjects before and after the experiment. In the process, the normal distribution and homogeneity of variance of the data were tested, and then LSD or Dunnett T3 was used for post-test. Finally, Bonferroni was used to correct the p value. $p < 0.05$ means there is significant difference, $p < 0.01$ means that there is a very significant difference.

3 Results

3.1 Baseline characteristics of experimental subjects

As shown in Table 2, there were no significant differences in age ($p > 0.05$), sex composition ($p > 0.05$) and dioptre ($p > 0.05$) among T1, T3, T5, and T7 groups with normal visual acuity before intervention. There were no significant differences in age ($p > 0.05$), sex composition ($p > 0.05$) and dioptre ($p > 0.05$) among myopic subjects, that is, T2, T4, T6, and T8 groups (Table 2).

TABLE 1 Experimental intervention in different groups.

Group		Experimental intervention
Outdoor exercise group (T1、T2)	Frequency Intensity Content	3 times a week, 60 min each time, a total of 12 months. HRmax60% ~ 70% moderate intensity aerobic exercise was performed in the adaptation stage (1–2 months), High-intensity aerobic exercise in HRmax80% ~ 85% during the experimental stage (2–12 months). Exercise in the outdoor playground, the specific sports intervention is as follows: Monday is mainly endurance training, training content includes 4 × 25 m back and forth running, 400 m running, rope skipping, each project continues 15 min, inter-group rest 2 min. Wednesday is mainly strength training, including sit-ups, frog jump, bow and arrow steps, kneeling push-ups, head-hugging squats and so on. Each project continues to 8 min, and there is a 1 min break between groups. Friday is mainly agile and coordinated training, including rope ladder training, obstacle running, balance beam walking, small hurdle training, etc., each project continues 8 min, inter-group rest 1 min
Outdoor control group (T3、T4)	Frequency Intensity Content	3 times a week, 60 min each time, a total of 12 months. Carry out very low intensity (exercise intensity < HRmax50%) free leisure activities outdoors Take a walk, play chess, chat, etc
Indoor exercise group (T5、T6)	Frequency Intensity Content	3 times a week, 60 min each time, a total of 12 months. HRmax60% ~ 70% moderate intensity aerobic exercise was performed in the adaptation stage (1–2 months), High-intensity aerobic exercise in HRmax80% ~ 85% during the experimental stage (2–12 months). Exercise in the indoor training hall, the specific sports intervention is as follows: Monday is mainly endurance training, training content includes 4 × 25 m round-trip running, 400 m running, rope skipping, each project continues 15 min, inter-group rest 2 min. Wednesday is mainly strength training, including sit-ups, frog jump, bow and arrow steps, kneeling push-ups, head-hugging squats and so on. Each project continues to 8 min, and there is a 1 min break between groups. Friday is mainly agile and coordinated training, including rope ladder training, obstacle running, balance beam walking, small hurdle training, etc., each project continues 8 min, inter-group rest 1 min
Indoor control group (T7、T8)	Frequency Intensity Content	3 times a week, 60 min each time, a total of 12 months. Carry out very low intensity (exercise intensity < HRmax50%) free leisure activities indoors Listen to music, play chess, chat, etc.

3.2 Comparison of dioptre of subjects with normal vision before and after the experiment

At the end of the experiment, the differences among different groups with normal vision showed that the dioptre after the experiment was significantly lower than that before the experiment ($p < 0.01$). The results showed that there were significant differences in dioptre between outdoor exercise group and indoor control group ($p < 0.01$), between outdoor control group and indoor control group ($p < 0.05$), and between indoor exercise group and indoor control group ($p < 0.01$). There was no significant difference in dioptre between outdoor exercise group and outdoor control group, outdoor exercise group and indoor exercise group, and between outdoor control group and indoor exercise group ($p > 0.05$) (Table 3).

3.3 Comparison of dioptre of myopic subjects before and after the experiment

At the end of the experiment, the differences among different groups of myopic subjects showed that the dioptre after the experiment was significantly lower than that before the experiment ($p < 0.01$). The results showed that there was significant difference in dioptre between outdoor exercise group and indoor exercise group ($p < 0.05$), between outdoor exercise group and indoor control group ($p < 0.006$), and between outdoor control group and indoor control group ($p < 0.05$). There was no significant difference in dioptre between outdoor exercise group and outdoor control group, outdoor exercise group and indoor exercise group, and between indoor exercise group and indoor control group ($p > 0.05$) (Table 4).

3.4 Comparison of dioptre difference between normal vision and myopic subjects before and after the experiment

The study showed that after 12 months of experimental intervention, there was a significant difference in the change of dioptre before and after the experiment between the outdoor control group with normal vision and the myopic outdoor control group ($p < 0.05$). There was a significant difference in the change of dioptre before and after the experiment between the indoor exercise group with normal vision and the myopic indoor exercise group ($p < 0.05$). It is inferred that the effect of outdoor environment or sports training on myopia prevention and treatment of people with normal vision is better than that of myopia people (Table 5).

4 Discussion

Myopia is a common eye disease, its development will cause irreversible damage to individual eyes, and in severe cases, it will also lead to blindness. Therefore, how to effectively prevent myopia is the focus of attention from all walks of life at this stage. Many studies have shown that outdoor sports can have a good effect on the prevention

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TABLE 2 Baseline of subjects before experiment.

	Normal eyesight				Myopia				P_1/P_2
	T1	T3	T5	T7	T2	T4	T6	T8	
Age (Years)	6.40 ± 0.50	6.44 ± 0.51	6.46 ± 0.51	6.48 ± 0.51	6.50 ± 0.50	6.56 ± 0.51	6.46 ± 0.50	6.48 ± 0.50	0.95/0.91
Gender (M/W)	13/12	13/12	14/10	13/12	11/13	14/11	13/13	16/9	0.96/0.60
Dioptre (D)	1.56 ± 0.25	1.52 ± 0.20	1.62 ± 0.23	1.49 ± 0.23	−1.44 ± 0.48	−1.39 ± 0.53	−1.56 ± 0.57	−1.60 ± 0.58	0.23/0.49

T1 and T2 represent outdoor exercise group, T3 and T4 represent outdoor control group, T5 and T6 represent indoor exercise group, T7 and T8 represent indoor control group, P1 is significant difference between normal vision groups, P2 is significant difference between myopia groups, *means $p < 0.05$, *means $p < 0.01$.

TABLE 3 Changes of dioptre of subjects with normal visual acuity before and after experiment.

Group	Dioptre before experiment (D)	Post-experimental dioptre (D)	$P_{\#}$	$P_{\&}$	$P_{\oint}$	$P_{£}$	$P_{\S}$
Outdoor exercise group	1.56 ± 0.25	1.26 ± 0.28	0.000**	—	0.148	0.997	0.001**
Outdoor control group	1.51 ± 0.20	1.12 ± 0.14	0.000**	—	—	0.215	0.031*
Indoor exercise group	1.64 ± 0.24	1.23 ± 0.21	0.000**	—	—	—	0.001**
Indoor control group	1.52 ± 0.22	0.95 ± 0.24	0.000**	—	—	—	—

means comparison of differences within the group, & means comparison with outdoor sports group, ∮means comparison with outdoor control group, £ means comparison with indoor sports group, § means comparison with indoor control group, *means $p < 0.05$, **means $p < 0.01$.

TABLE 4 Changes of dioptre of myopic subjects before and after experiment.

Group	Dioptre before experiment (D)	Post-experimental dioptre (D)	$P_{\#}$	$P_{\&}$	$P_{\oint}$	$P_{£}$	$P_{\S}$
Outdoor exercise group	−1.44 ± 0.48	−1.79 ± 0.63	0.000**	—	0.483	0.045*	0.006**
Outdoor control group	−1.39 ± 0.53	−1.91 ± 0.54	0.000**	—	—	0.187	0.036*
Indoor exercise group	−1.57 ± 0.56	−2.13 ± 0.59	0.000**	—	—	—	0.414
Indoor control group	−1.59 ± 0.57	−2.26 ± 0.59	0.000**	—	—	—	—

means comparison of differences within the group, & means comparison with outdoor sports group, ∮means comparison with outdoor control group, £ means comparison with indoor sports group, § means comparison with indoor control group, *means $P < 0.05$, **means $P < 0.01$.

TABLE 5 Comparison of dioptre difference between normal visual acuity and myopic subjects before and after the experiment.

Group	Dioptre difference before and after experiment in normal vision group (D)	Dioptre difference before and after experiment in myopia group (D)	F	P
Outdoor exercise (normal vision vs. myopia)	−0.29 ± 0.09	−0.35 ± 0.21	11.74	0.266
Outdoor control (normal vision vs. myopia)	−0.39 ± 0.19	−0.51 ± 0.15	2.26	0.017*
Indoor exercise (normal vision vs. myopia)	−0.41 ± 0.16	−0.56 ± 0.27	6.93	0.022*
Indoor control (normal vision vs. myopia)	−0.56 ± 0.16	−0.67 ± 0.30	7.39	0.145

*means $P < 0.05$, **means $P < 0.01$.

and control of myopia, such as inhibiting the growth of eye axis, promoting eye blood circulation and relieving eye fatigue, and some studies are devoted to in-depth analysis. to explore the separate benefits of outdoor and exercise for the prevention and treatment of myopia, the related research results are controversial. For this reason, this study conducted a randomized controlled trial in a primary school in Chengdu, China, to explore the effects of outdoor environment and physical exercise on the eyesight of school-age children, and to further clarify the relationship between outdoor and exercise and myopia.

Our study found that with the increase of children's age, whether they have normal vision or myopia, their eyeball dioptre shows a downward trend. Sports and outdoor environment can not completely stop the decline of children's dioptre, but it can effectively slow down the rate of decline and delay the occurrence of myopia in children. This is similar to the results of Guggenheim et al. (14) which pointed out in a prospective cohort study on the incidence of myopia in school-age children that physical activity and the length of time spent outdoors were significantly associated with the decline in the incidence of myopia in children. Studies have shown that the benefits of sports in the prevention and treatment of myopia are mainly attributed to the improvement of eye-related muscle function and blood circulation during exercise, the decrease of intraocular pressure and the increase of choroidal blood flow velocity after exercise, which makes the retinal blood supply sufficient. A higher level of retinal blood supply can effectively promote the development of children's eye nerves and muscles (15, 16). As early as

2002, Mutti et al. (17) found in a 5-year cohort study that higher frequency and intensity of physical exercise is a protective factor for the eyesight of children and adolescents. Follow-up studies also confirmed that there is an intensity-time dose relationship between physical exercise and myopia prevention and control. Chinese scholar Chen Dingyan (18) found that medium-intensity physical exercise is the best in protecting the eyesight of children and adolescents. Xu Shaojun et al. (19)pointed out that only the duration of physical exercise is more than 1 h can play a role in the prevention and control of myopia. In this study, the exercise intensity was medium and high intensity (HRmax80% ~ 85%), and the exercise duration was 1 h. The results showed that exercise had a significant effect on alleviating children's myopia. The exercise stimulation with high intensity can mobilize the blood stored under the skin or viscera to a greater extent, which increases the circulating blood volume of the body per unit time, which promotes the improvement of the blood supply of eye-related muscles to a certain extent. and then play the effect of alleviating children's myopia. However, it should be pointed out that the improvement effect of exercise on myopia observed in our study is limited to non-myopic children, and we have not found that exercise has a significant effect on myopia relief in myopic children. This may be related to the good development of eye-related nerves and muscles that can not reverse the increased axial length of the eye. Similar to our observation in myopic children, Lundberg et al. (20) used ActiGraph accelerometer to monitor the amount and intensity of physical activity in a prospective study of the relationship between physical activity and myopia in 307 Danish children. After excluding confounding factors such as age and sex, linear regression did not find the correlation between physical exercise and the increase of children's eyeball diopter and average axial length. Although in this experiment, Lundberg and other ActiGraph accelerometers used to measure sports have limitations, they can not effectively monitor children's swimming, cycling and other weight-bearing exercise, which leads to the underestimation of the amount of exercise. The internal relationship between sports and myopia and the effects of sports on different eyesight groups need to be further studied.

In the study of outdoor sports and myopia, a large number of studies have pointed out that outdoor environment is the most important factor independent of sports affecting children's myopia. A systematic study conducted by the University of Cambridge in the United Kingdom shows that children who spend an extra hour a week outdoors reduce their risk of myopia by 2%, and if they spend an extra hour a day outdoors, the risk of myopia is reduced by 13% (21). Our study also observed that no matter the subjects with normal vision or myopia, there was a significant difference in the refractive value between the outdoor control group and the indoor control group after the experiment, which suggests that outdoor factors can effectively prevent the development of myopia in children. Some studies have pointed out that the improvement of myopia in the outdoor environment may be related to the peripheral defocus of the retina induced by the environment. In the outdoor environment, the object is usually far away from the eyeball, and the refractive environment of the object tends to be consistent. Therefore, when outdoors, peripheral objects are defocused to a minimum (22). On the contrary, when indoors, the object is usually closer to the eyeball, resulting in a greater distance of refractive changes in the eyeball. In this refractive environment, the object may produce greater hyperopia defocus. It is this kind of hyperopic defocus around the retina that leads to the growth of the eye axis and the deepening of myopia in children.

Other studies have pointed out that the improvement of myopia by outdoor environment mainly lies in the lighting factors in outdoor environment, and is directly related to the duration and intensity of outdoor light. Read et al. (23) found that there was a significant difference in the prevalence of myopia between Australia and Singapore. The overall myopia prevalence rate of Australian children was significantly lower than that of Singaporean children. Further studies showed that this difference was due to the difference in daily outdoor light patterns between Australian children and Singaporean children. The former was 105 ± 6.42 min/ days, and the latter was 61 ± 6.40 min/ days. Morgan et al. (24) conducted a randomized controlled trial in Taiwan to explore the relationship between myopia prevention and outdoor light intensity. A total of 693 first-year students from 16 primary schools were enrolled in the randomized controlled trial to strictly monitor the outdoor light intensity of the students during their one-year stay in school. It was found that the change of eye axis length after 1 year was related to the intensity and duration of outdoor light. Specifically, students spending enough time outdoors under medium to high intensity light can effectively slow down the development of myopia. And compared with medium intensity light (1,000 lux-3000 lux) under high intensity light (>10,000 lux), the inhibitory effect of myopia can be obtained for a shorter time. The prevention and treatment mechanism of light on myopia is mainly attributed to the "light-dopamine" hypothesis. Dopamine, as an important neurotransmitter, can effectively inhibit the increase of eye axis length. In animal experiments, it was observed that the rate of dopamine release from chicken retina increased logarithmically with the increase of light intensity (25). Increasing outdoor light can prevent myopia by regulating the secretion of dopamine in the retina and then affecting the length of the eye axis (26).

In addition to observing the significant inhibitory effect of outdoor light and exercise on the development of myopia in school-age children, the study also found that there were differences in the reducing effect of outdoor light or exercise on the diopter of children with different vision (normal vision vs. myopia). Specifically, we compared the difference of diopter between normal vision subjects and myopic subjects who took the same intervention. The study found that compared with myopic subjects, outdoor light or exercise intervention had a better effect on reducing diopter in subjects with normal vision. Our results are similar to the results of a meta-analysis by Xiong et al. (27) which included 25 experiments related to outdoor lighting and myopia. It is concluded that outdoor factors are more effective in the prevention and treatment of myopia in non-myopic individuals. Also on the meta-analysis of the relationship between outdoor lighting and myopia, Ho et al. (28) also found that outdoor lighting factors significantly inhibit the growth of eye axis length in both myopic and non-myopic individuals, but different from our results, Ho and other studies pointed out that outdoor lighting factors are more effective in slowing down the development of myopia than non-myopic individuals. Among the 13 studies included in the analysis by Ho et al., there are some studies in which the daily outdoor time of children is evaluated by sending questionnaires to their parents. The subjective recall of parents can not accurately measure the level of outdoor light exposure of children during the study, resulting in underestimation or overestimation, resulting in the deviation of the research data, and then affect the results of meta-analysis. This may be the reason why the results of Ho and other studies are different from ours.

In short, our study objectively explored the effects of outdoor and exercise on eyeball diopter in children with non-myopia and myopia through randomized controlled trials. The study suggests that more outdoor sports before children are myopic can prevent the occurrence of myopia to the greatest extent; for myopic children, staying outdoors or in an environment with sufficient light is more effective in slowing down the further development of myopia. This study also has some limitations, the study does not use the relevant instruments to accurately monitor the environmental light level and the amount of physical activity of the subjects, and children's exercise participation and outdoor light exposure duration can not be controlled during weekends and holidays, which may to some extent lead to the overestimation of outdoor light intensity in overcast and rainy days and the underestimation of the amount of exercise in the exercise control group. In addition, we also failed to evaluate the length of close eye use during the experiment, which may lead to overestimation of the impact of outdoor and sports factors on the growth of myopia in the indoor control group.

Future research should design more scientific and rigorous large-scale animal or human experiments, through the strict detection and regulation of outdoor light variables and movement variables to verify the applicability of the current research conclusions. In addition, whether there is the most suitable light intensity and exercise intensity to improve myopia, and under the most suitable conditions, which of the above two factors have a better effect on myopia needs to be studied and discussed. In addition, gender, race and genetic factors should also be taken into account, and the impact of the differences in these factors on the results needs to be further confirmed.

5 Conclusion

Outdoor light and exercise intervention lasting for 12 months can significantly inhibit the decrease of children's eyeball dioptre and improve myopia. In terms of individual benefits, outdoor lighting factors have a significant effect on the reduction of eyeball dioptre in both myopic and non-myopic children, while exercise intervention factors are only effective in reducing dioptre in non-myopic children. Outdoor light and exercise intervention have different effects on dioptre of children with different visual acuity. Compared with myopic children, the effect of outdoor light and exercise intervention on dioptre of children with normal vision is better.

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 humans were approved by the Medical Ethics Committee of Southwest University Hospital of Chongqing. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/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

SL: Writing – original draft, Writing – review & editing. XL: Writing – review & editing. NB: Conceptualization, Writing – original draft. DW: Investigation, Writing – review & editing. WY: Conceptualization, Writing – original draft. FW: Writing – review & editing. HJ: Investigation, Writing – original draft.

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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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Development and feasibility of a virtual reality-based exergaming program to enhance cardiopulmonary fitness in children with developmental coordination disorder

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Introduction: Developmental coordination disorder (DCD) is a neurodevelopmental disorder characterized by motor skill deficits. Such deficits often limit children's participation in physical activities, further affecting their overall health, including through reduced cardiopulmonary fitness. Because virtual reality (VR) devices offer interactive games and activities that require various movements and coordination, they can serve as motivating and enjoyable means for children to perform physical exercise. In this study, we developed a VR-based exergaming system and tested its ability to enhance the cardiopulmonary fitness of children with DCD.
Materials and methods: A total of 13 children with DCD and 10 young adults were recruited in phase I to examine the test–retest reliability and concurrent validity of our system (including a custom-made heart rate monitor) with a commercial heart rate device. In phase II, we included an additional 13 children with DCD to test the feasibility of the system. We tested the outcomes using the enjoyment rating scale, intrinsic motivation inventory (IMI), and 20-m shuttle run test (20mSRT).
Results: In phase I, test–retest reliability was good to excellent in the static task and moderate to good in the dynamic task. Concurrent validity was excellent in both tasks. In phase II, more than half of the children (18 out of 26) assigned the maximum rating for their enjoyment of the game; they also had high average scores on the IMI. Furthermore, after the 8-week training using the VR program, the average running distance of the 26 children in the 20mSRT had increased significantly from 129.23 m to 176.92 m ($p < 0.001$).
Conclusion: Our VR-based exergaming program can serve as an alternative intervention for enhancing cardiopulmonary fitness in children with DCD.

KEYWORDS

developmental coordination disorder, cardiopulmonary fitness, exergame, virtual reality, motor skill deficit

1. Introduction

Developmental coordination disorder (DCD) is a neurodevelopmental disorder characterized by motor skill deficits. These deficits experienced by individuals with DCD often limit their performance of and participation in physical activities, further harming their overall health through, for example, reduced cardiopulmonary fitness. A systematic review indicated that the oxygen consumption at peak physical exertion ($\dot{V}O_{2max}$) of typical children and adolescents aged 8–19 years is 35–47 ml/kg/min during cardiopulmonary endurance exercise (1). However, the $\dot{V}O_{2max}$ in children with DCD is much lower, only 33.5–34.4 ml/kg/min on average (2). In addition, a longitudinal study revealed that the difference in cardiopulmonary endurance between children with DCD and typical children increased with age (3).

The American College of Sports Medicine indicates that cardiopulmonary fitness is promoted by aerobic exercise, especially exercise that increases the heart rate to 65%–75% of its maximum. Aerobic exercise can improve cardiopulmonary fitness, muscle power, body composition, cognition, and inhibitory control (4–8). Lau et al. also demonstrated that aerobic exercise and moderate-to-vigorous physical activity from 19.2 to 29.33 ml/kg/min could improve cardiopulmonary fitness through increased $\dot{V}O_{2max}$ (9). Although studies have demonstrated the benefits of traditional aerobic exercise, children often regard this exercise as boring or difficult.

In virtual reality (VR), multimedia technology and an interface between the human body and a computer enable people to experience a virtual environment and the objects in it as they do in the real world. Because VR offers interactive games and activities requiring various movements and coordination, it represents a motivating and enjoyable approach to physical exercise. VR technology is thus highly suitable for combining exercise with gaming (exergaming). Studies have indicated that individuals using VR training outperformed those using traditional training programs in the Fugl–Meyer assessment, Berg balance scale, timed up-and-go test, functional reach test, and 10-m walking test (10–12). Moreover, individuals with cerebral palsy or Down syndrome exhibited marked improvements in their motor coordination, balance, and ambulatory function after undergoing weekly 1-h VR training sessions, highlighting the efficacy of this training for improving physical capabilities (13, 14). Many scholars have reported improved motor control in patients undergoing VR training, but the results have been inconsistent. Moreover, studies have yet to examine the effect of VR training in children with DCD.

2. Method

2.1. Participants

A total of 10 young adults (age: 25.9 ± 4.3 years; 3 men and 7 women) and 13 school-age children with DCD (average age: 8.8 ± 0.9 years; 7 boys and 6 girls) participated in our phase I study to examine the test–retest reliability and concurrent validity of the system and program that we developed with a customer. In our phase II feasibility study, a further 13 children with DCD joined the original 13 children with DCD, leading to a total of 26 participants (age: 8.3 ± 1.0 years, 16 boys and 10 girls). These children completed an 8-week program with our VR device. The young adults were recruited from a university for convenience. Individuals with a neurological, musculoskeletal, or cardiopulmonary condition were excluded. Children with DCD were screened and referred by teachers from local primary schools. DCD diagnosis was based on the criteria of the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition*. We used the Movement Assessment Battery for Children, Second Edition (MABC-2) to confirm the children's motor skill deficits. Motor difficulty was indicated by a total score at or below the 16th percentile of the age norm. This study was approved by the ethics committee of our university, and the participants provided informed consent prior to their participation, in accordance with the Declaration of Helsinki.

Table 1 presents the demographic characteristics of the participants. All of the children with DCD in the phase I and II studies had total MABC-2 scores that were below the 16th percentile. Their subtest scores also revealed motor difficulties in aiming, catching, and balance.

2.2. Equipment and apparatus

2.2.1. Hardware

ProComp5 Infiniti encoder (SA7525, Thought Technology Ltd., 2007, Canada.)

The ProComp5 Infiniti™ (SA7525, Thought Technology Ltd., 2007, Canada.) is encased in an ergonomically designed housing, requiring only a USB port for seamless connectivity to the computer. With two sensor channels, it ensures optimal signal fidelity, providing a high sampling rate of 2,048 samples per second for observing raw heart rate signals.

2.2.1.1. VIVE pro (HTC Corporation, Taiwan)

To develop our VR-based exergaming program, we used the VIVE pro (HTC Corporation, Taiwan) as our application programming interface. The VIVE pro is a portable and convenient VR system that includes a head monitor and four sensors, two each for the hands and feet. The head monitor has a 110° field of view, a

TABLE 1 The demographic characteristics of phase I and II participants.

	pDCD children	pDCD children	Adult
Number	26	13	10
Gender (Male/Female)	16/10	7/6	3/7
Age (Years)	8.3 ± 0.99	8.8 ± 0.89	25.9 ± 4.28
Height (cm)	128.67 ± 8.9	131.71 ± 8.62	166.3 ± 6.38
Weight (kg)	31.83 ± 8.61	34.07 ± 9.86	57.5 ± 10.07
Total score of C-PPVT-R (%)	82.62 ± 15.92	88.3 ± 7.88	
Total score of MABC-2 (%)	6.69 ± 3.3	7.54 ± 3.73	
Manual Dexterity (%)	28.96 ± 16.87	28.31 ± 16.03	
Aiming and Catching (%)	13.35 ± 14.88	16.24 ± 13.74	
Balance (%)	9.46 ± 8.41	9.69 ± 7.73	

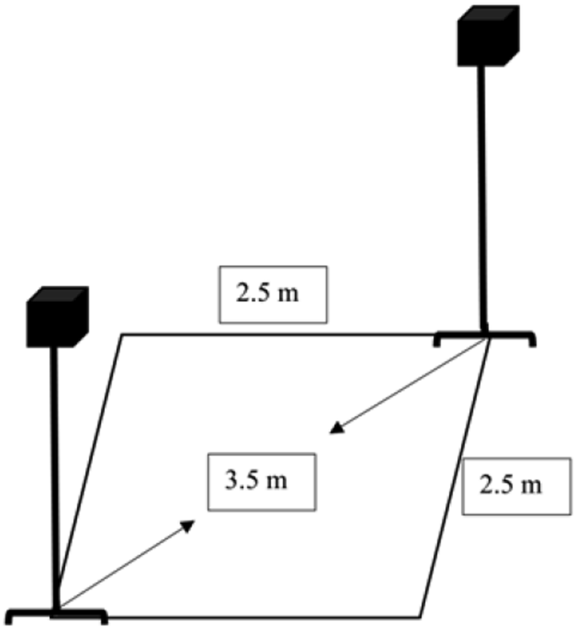

FIGURE 1
The experiment setting. In the virtual reality environment setup, cameras are placed at diagonal corners with a spacing of 3.5 m, forming a rectangular frame measuring 2.5 m in length and width. Children will perform action training within this area.

resolution of 1,080 × 1,200 pixels per eye, and a refresh rate of 90 Hz. We added a custom-made heart rate monitor to this system. The sensor was attached to the pulp of the index finger of the non-dominant hand and fixed at the wrist by a wire. **Figure 1** demonstrates the experimental setting.

2.2.2. Software

We designed an exergaming program named "Animal Escape" by using Unity software (Unity 5.0, Unity-Technologies, 2004, San Francisco, California, USA; **Figure 2**). The game content was task oriented, with a focus on repetitive practice of real-life functional tasks.

Consistent with the principles of aerobic exercise training, the game is structured as follows: first, a 5-min warm-up stretching activity, then 20 min of training activities, and finally, a 5-min cool-down activity (15). The game involves returning escaped animals to their farm. Different animals appear one after another and hide in random locations. As soon as one appears, the player must catch it. The interval between the appearance of animals is 1 s during the warm-up and cool-down stages but 0.5 s or 0.25 s during the training stage. Players receive a coin reward after having caught 100 animals.

2.2.3. Movement assessment battery for children-second edition (MABC-2)

The MABC-2 is a norm-referenced motor test for children aged 3–16 years (16).

The test is divided into three age bands (3–6, 7–10, and 11–16 years) and consists of three subtests (manual dexterity, aiming and catching, and balance). The total score on the three subtests is used to diagnose motor difficulties in children. A total score at or below the 5th percentile denotes a significant movement difficulty, whereas scores between the 5th and 15th percentiles indicate the child is at risk of having movement difficulties (16). The MABC-2 test has been widely used in hospitals and research because of its good-to-excellent test–retest reliability and validity (17). In this study, children with a total MABC-2 score lower than the 16th percentile were regarded as having DCD.

2.3. Outcome measurement

2.3.1. Enjoyment rating scale

After the whole training session, we used the enjoyment rating scale (**Table 2**) to measure how much the children enjoyed the exergaming program. We used a 5-point Likert scale (0: no fun at all, 1: boring, 2: a bit of fun, 3: fun, and 4: super fun) (18, 19).

FIGURE 2
The VR exergaming program. The virtual reality system creates a cardiorespiratory fitness exercise game with the background of small animals escaping from a farm. Children are required to help the farmer catch the small animals and bring them back to the farm.

TABLE 2 The results of the enjoyment scale.

Enjoyment Scale	pDCD children (*N* = 26)
0 (no fun at all)	0
1 (boring)	1
2 (a bit of fun)	2
3 (fun)	5
4 (super fun)	18

2.3.2. Intrinsic motivation inventory scale (IMI scale)

The intrinsic motivation inventory (IMI), a multidimensional measurement device that is grounded in self-determination theory, is intended to assess participants' subjective experiences related to a target activity. There are seven subscales of IMI. However, we only used the following three subscales of the IMI: interest/enjoyment (seven items), perceived competence (six items), and effort/importance (six items; **Table 3**). Each item is scored from 1 to 7 points, with more points indicating more favorable performance. The IMI has been applied in healthy adults, athletes, patients with schizophrenia, and patients with stroke (20–23). This scale has favorable test–retest reliability (intraclass correlation $r = 0.77$) (20).

TABLE 3 The results of the IMI score.

Part I. Interesting condition	Average ± SD
1. I enjoyed doing the game	6.42 ± 1.5
2. I liked the virtual reality game; it was better than the traditional exercise.	6.73 ± 0.72
3. The virtual reality game was fun to do.	6.46 ± 1.47
4. I thought the game was quite enjoyable	6.15 ± 1.71
5. While I was doing the game, I was thinking about how much I enjoyed it.	6.11 ± 1.7
6. I thought the game was a boring activity.	1.26 ± 1.18
7. The game did not hold my attention at all.	1.96 ± 2.04
Scale of Interesting condition (Average ± SD)	6.37 ± 1.42
Part II. Performance condition	
Perceived competence	
1. I think I am pretty good at the game.	6 ± 1.9
2. I think I did pretty well at the game compared to other children.	5.04 ± 2.4
3. After working at the game for a while, I felt I could do it.	5.8 ± 2
4. I am satisfied with my performance in the game.	6.24 ± 1.23
5. I am good at the game.	5.75 ± 1.89
6. I think I am not good at the game.	1.48 ± 1.29
Average ± SD of the clockwise items	5.76 ± 0.44
Effort/importance	
1. I put a lot of my attention into the game.	6.28 ± 1.17
2. I tried very hard in the game.	6.4 ± 1.22
3. It was important to me to do the game.	4.76 ± 2.5
4. I could not do the game very well.	1.48 ± 1.29
5. I did not try very hard in the game.	1.52 ± 1.44
6. I did not put a lot of my attention into the game.	1.83 ± 1.88
Average ± SD of the clockwise items	5.81 ± 0.91
Scale of performance condition of the clockwise items (average ± SD)	5.78 ± 0.32
Total of score (average ± SD)	6.07 ± 0.87

2.3.3. Twenty-meter shuttle run test

The 20-m shuttle run test (20mSRT) is a common field test for measuring cardiorespiratory fitness and has favorable test–retest reliability ($r = 0.89$) (24, 25). In the test, a participant must run back and forth between two lines before a beep sounds. The test ends when the child fails to reach the line before the designated time. The total distance ran represents the test performance.

2.4. Procedure

A total of 10 young adults and 13 children with DCD participated in phase I of our study, in which we examined the test–retest and concurrent validity of our custom-designed heart rate device. We measured the participants' heart rate under static and dynamic conditions. In the static condition, a participant was asked to sit quietly and relax on a chair with its height adjusted to their leg length to ensure hip and knee flexion of 90° and that their feet were flat on the floor. The participant's hands were naturally placed on their thighs. The examiner twice recorded the participant's heart rate for 1 min, with the interval between measurements being 30 min. Subsequently, for the dynamic task, the participant performed a modified stepping test; the adults and children used 35 cm and 20 cm steps, respectively. The task involved 24 up-and-down cycles per minute for 2 min, yielding 96 steps. Immediately after the test, the participant sat on a chair in the same manner as previously described, and their heart rate was measured for 1 min; the measurement was repeated after 30 min. In our phase II study for measuring the feasibility of the system, another 13 children with DCD joined the original 13 children for an 8-week exergaming program using our VR device. After the 8-week program, all participants completed the enjoyment rating scale, IMI, and 20mSRT (26). All participants completed the enjoyment rating scale and IMI after the physical fitness game.

2.5. Statistical analysis

The participants' demographic data and their scores on the enjoyment rating scale and IMI are presented as means and standard deviations. We examined the test–retest reliability and concurrent validity of our device by using Pearson correlation analysis (i.e., calculating the intraclass correlation coefficient, ICC; SPSS version 20; Chicago, IL, USA). Pearson correlation coefficients of <0.5, 0.5–0.75, and >0.75 indicate no correlation, moderate-to-good correlation, and excellent correlation, respectively.

3. Results

3.1. The test−retest reliability and concurrent validity with self-developed heart rate monitor device

In the static task, the device exhibited good-to-excellent test–retest reliability (adult group ICC = 0.946, $p = 0.000$; children group ICC = 0.768, $p = 0.001$) and concurrent validity (adult group $r = 0.992$, $p = .000$; children group $r = 0.943$, $p = .000$). In the dynamic task, the device exhibited moderate-to-good test–retest reliability (adult group ICC = 0.93, $p = 0.000$; children group ICC = 0.913, $p = 0.000$) and excellent concurrent validity (adult group $r = 0.98$, $p = .000$; children group $r = 0.967$, $p = .000$).

3.2. Feasibility of the VR-based training system

The average rating on the enjoyment rating scale was 3.6 ± 0.8 points (maximum = 4; **Table 2**). In terms of the IMI, the average scores were 6.4 ± 1.4 and 5.8 ± 0.3 points for the interest and performance subdimensions, respectively (**Table 3**). After 8 weeks of training with the VR-based exergame, the children with DCD exhibited a significant improvement in the distance they ran in the 20mSRT from 129.23 m to 176.92 m ($p < 0.001$). However, their $\dot{V}O_{2max}$ was not significantly better after the training program.

4. Discussion

In this study, we examined the test–retest reliability, concurrent validity, and feasibility of an exergame system aimed at improving cardiopulmonary fitness. In the feasibility test, we considered the participants' enjoyment, intrinsic motivation, and performance on the 20mSRT after 8 weeks of training. Our results indicated that the concurrent validity of the heart rate device was good to excellent and that the participants enjoyed using the system. They also had high scores for the interest and performance subdimensions of the IMI.

4.1. High reliability and validity of the heart rate device

Our heart rate device exhibited good-to-excellent test–retest reliability and concurrent validity. Individuals with gross motor deficits have consistently been found to have lower cardiopulmonary fitness and reduced anaerobic exercise capacity (27, 28). Cardiopulmonary fitness is commonly assessed using heart rate and $\dot{V}O_{2max}$. In our study, the average resting heart rate in the healthy adults was 80–83 beats per min, consistent with findings from previous studies (29, 30). In addition, the children with DCD in our sample had higher resting heart rates than typically developing children, ranging from 90 to 97 beats per min. This can be attributed to their engagement in static activities for prolonged periods and limited participation in moderate-to-vigorous-intensity exercise (31). We employed static and dynamic tasks to observe changes in heart rate. During the dynamic task, our heart rate device exhibited slightly lower test–retest reliability than a commercial heart rate device with cable transmission. However, our heart rate device remains viable because of its portability and wireless transmission capability (contingent on a stable wireless connection).

4.2. Change in fitness level after VR training

4.2.1. Objective change

The 20mSRT is a widely recognized measurement tool for assessing $\dot{V}O_{2max}$ in children and adults. Numerous studies have reported that children with DCD tend to cover a shorter distance during the 20mSRT than do typically developing children, indicating lower cardiorespiratory fitness in children with DCD (28). Furthermore, the 20mSRT has been proven effective in detecting changes in fitness following training interventions. After our participants used our VR fitness program, the distance they covered in the 20mSRT was significantly higher than that before. However, we discovered no significant change in their $\dot{V}O_{2max}$. The VR game helped improve the participants' cardiopulmonary fitness because they could run longer distances than before playing the game. Other research has also demonstrated that physical fitness programs can improve muscle power and endurance (32). Leger et al. reported that for estimating the $\dot{V}O_{2max}$ of children aged 6–18 years, data from the multistage 20mSRT had good reliability. Additionally, relative to a treadmill test, the 20mSRT was discovered to have moderate reliability for estimating $\dot{V}O_{2max}$ in children aged 6–10 years (33). Although the estimated $\dot{V}O_{2max}$ derived from the multistage 20mSRT is a useful option for estimating cardiorespiratory fitness, it may yield more accurate results in adults than in children (34). Notably, discrepancies may have arisen between the distance covered during the 20mSRT and the estimated $\dot{V}O_{2max}$, potentially leading to inconsistent performance rankings in our study. We conducted the test outdoors to provide a natural environment for the children. Additionally, some of the children may have felt hot and tired during the outdoor testing, and these factors may have affected their motivation and performance.

4.2.2. Perceived change

We used the enjoyment rating scale, which has favorable reliability (35, 36), to measure the children's motivation. The children in our study comprehended the scale's meaning and provided responses accordingly. Most of the children reported having fun while playing our game. However, three children expressed boredom or less enjoyment and perceived the game as too easy, leading to low motivation. To assess our participants' abilities, performance, and mental engagement, we used the IMI (37). The children understood the scale items and could thus accurately answer them. The children's answers on the IMI prior to playing the game indicated that most of them had high expectations. Moreover, we observed that the children concentrated and exerted considerable effort during the game because they believed that maintaining their motivation was crucial given the perceived difficulty level. After playing the game, most of the children reported liking it and had increased confidence because their abilities and physical fitness had improved. Additionally, the VR game fostered closer relationships between the children and their classmates.

4.3. Study limitation

Because of the unstable wireless connection of the heart rate device during the dynamic task, only moderate test–retest reliability was discovered for this task. Moreover, the estimated $\dot{V}O_{2max}$ of our 26 participants, measured using the multistage 20mSRT, was not improved after our VR training program. We recognize that this test may not be the most accurate for measuring $\dot{V}O_{2max}$ changes, but it was the only one we employed. Three children provided low enjoyment scores, suggesting room for improvement in the game's content to make it more challenging and interesting. In addition, the small sample size affects the study's generalizability and application.

4.4. Future study

We aim to adopt a higher-quality wireless transmission module to improve our heart rate device performance. To enhance the children's enjoyment of the game, we plan to introduce different game levels to challenge the children appropriately in accordance with their abilities.

5. Conclusion

Our device has good reliability and validity. Additionally, we obtained preliminary evidence that our VR game can improve physical fitness, but further research with a larger sample size is necessary. The VR game and heart rate device that we have designed may be useful for physical fitness interventions 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.

Ethics statement

The studies involving humans were approved by National Cheng Kung University Governance Framework for Human Research Ethics. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

Totally, five researchers completed the study together, such as R-JC and students, Y-JJ and P-SH, designed the game program and performed this study project. Y-CD and his student, H-CH, wrote the programming of heart rate device and virtual reality system. All authors contributed to the article and approved the submitted version.

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Conflict of interest

H-CH was employed by the company Voltafield Technology Corporation.

The remaining 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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Relationship between perceived enjoyment, exercise commitment and behavioral intention among adolescents participating in "School Sport Club"

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This study aimed to examine ways to improve the quality of physical activity (PA) to address social problems related to obesity and being overweight among adolescents, through an educational approach. In this regard, the current study identified associations between factors that lead to sustained PA participation among middle school students participating in school sports club activities, and derived academic implications that can be incorporated into future school education programs. The researchers explored the relationship between perceived enjoyment, exercise commitment, and behavioral intention in middle school sports club participants. The subjects of the study were selected as middle school students who had participated in school sports clubs for more than 6 months. Using convenience sampling, 350 datasets were collected from middle school students living in metropolitan cities in South Korea. Finally, 336 datasets were used for the final analysis after eliminating 14 questionnaires that were judged to be incorrectly indicated or incomplete. Frequency analysis, exploratory factor analysis, and reliability verification (Cronbach's α) were conducted. The findings were as follows: first, among the sub-factors of perceived enjoyment, the following were found to have a positive relationship with cognitive commitment: daily escape ($\beta = 0.259$), competitive victory ($\beta = 0.228$), interpersonal relationships ($\beta = 0.204$), and physical fitness ($\beta = 0.119$). Furthermore, among the sub-factors of perceived fun, physical health ($\beta = 0.330$), daily escape ($\beta = 0.205$), interpersonal relationships ($\beta = 0.307$), and competitive victory ($\beta = 0.228$) had positive relationships with behavioral commitment. Second, among the sub-factors of perceived enjoyment, physical health ($\beta = 0.423$), interpersonal relations ($\beta = 0.139$), and daily escape ($\beta = 0.138$) were found to have a positive association with behavioral intention. On the other hand, there was no significant relationship between competitive winning ($\beta = 0.071$) and behavioral intention. Third, behavioral commitment ($\beta = 0.237$) and cognitive commitment ($\beta = 0.183$) were confirmed to have a significant positive relationship with behavioral intention. These findings highlight that middle school students' perceived enjoyment from participating in school sports clubs is a positive factor leading to increased immersion in sports activities and a sufficient basis for continuing sports activities. Furthermore, class organization, environmental factors, and appropriate instructional content for school sports club activities are essential for exercise commitment.

KEYWORDS

school sports club, perceived enjoyment, exercise commitment, behavioral intention, physical education, physical activity

1 Introduction

Adolescence is the middle stage of growth that continues until adulthood. It is a period in which individuals focus on personality development and learn to adapt to society (1, 2). As such, physical activities performed in adolescence have been found to be effective in improving mental and physical health, and social, academic, and lifestyle skills (3, 4). However, according to various domestic and foreign studies (5–7) that analyzed the current status of physical activity in South Korean youth by age group, the recommended PA (60 min of high-intensity PA per day) achievement rate of male and female remained significantly low at 53 and 38.1%, respectively. In addition, the greater the intensity of exercise, the larger the difference in PA, and a lack of PA among adolescents leads to poor health (7). Essentially, adolescents' energy intake exceeds their energy consumption; consequently, the probability of youths developing adult diseases is increasing (8), and the age of onset of adult diseases in adolescents is decreasing (9).

School physical education (PE) has attracted attention as youth health problems worsen in South Korea. This is because most teenagers spend a considerable amount of time in school and school PE targets health problems as its major educational goal (7). Most schools have professional manpower (e.g., P.E. teachers) and an efficient curriculum operation system that can help manage youth health problems (10). Nevertheless, this is not the case in South Korea. As mentioned above, most of South Korean adolescents spend most of their time at school, but the amount of PA time suitable for adolescence is far from sufficient. For example, as most schools focus on university entrance education, free PA time is not guaranteed except for regular PE classes (2 to 3 times a week, 45 to 50 min) (11). In particular, in South Korea, community PA facilities and programs for teenagers are scarce. Therefore, active efforts by school P.E programs are required to solve youth health problems (12).

PE systems in school are majorly responsible for physical activities in adolescence. However, there has been a growing perception that health promotion cannot be achieved by regular sports activities (P.E. classes) alone (9). The reason for this is that the number of P.E. classes in Korean schools is extremely insufficient compared with a majority of advanced countries (7). The United States Department of Health and Human Services raised the need for comprehensive school sports operations to promote PA throughout school life based on a daily exercise system (13). In fact, many countries have focused on providing sufficient PA for adolescents through programs such as the Comprehensive School-based PA Program (USA), Active School Flag (Ireland), Schools on the Move (Finland), and Moving Schools (Germany) (9). In South Korea, school sports club activities (operating as regular class activities once or twice a week) and after-school sports activities (operating as autonomous sports activities once or twice a week) have been operating under the school sports reinforcement policy since 2012 (14). Recently, the school sports club system policy has been implemented to achieve the effect of daily sports (sports activities five days a week) (15). Middle school students perceive school sports club activities as a time to act apart from their daily lives, to escape academic pressure, and to spend time with friends (16). For this reason, the Korean Ministry of Education has actively extended support for middle school students' school sports club activities (17).

However, regardless of the educational value of continuous school sports club activities, these activities cannot last long unless enjoyment is guaranteed (18). From this perspective, the importance of enjoyment in participation and continuation of an activity is emphasized (19). In recent years, social problems such as bullying, school violence, obesity, being overweight, and sedentary school lifestyles among teenagers have become serious in South Korea (7). The Ministry of Education has implemented various educational initiatives to solve these problems; school sports club activities are at the center of these efforts (17). Continuous efforts and attention are needed to actively promote and encourage sports activities through school sports clubs in all schools. In particular, the focus should be on the fact that middle school students experience psychological aspects of fun and pleasure in most aspects of their daily lives. Enjoyment in sports activities is a positive emotional experience, involving passion, pleasure, and fun, obtained through physical activities (20). Perceived enjoyment affects factors such as challenges, overcoming challenges, and gaining confidence (21). These factors include the perception of competence and confidence through the improvement of sports skills, tension or excitement experienced in competitive situations, and formation of fraternity with peer groups (22–24). Based on these findings, it is necessary to develop a more focused program on enjoyment factors to further maximize the effectiveness of middle school students' sports club activities (25).

The enjoyment of participating in sports leads to commitment to exercise or PA, which increases participation persistence (26). Exercise commitment can be defined as a physical and psychological state of desire or willingness to continue exercising and increase the desire to participate through positive thinking about exercise (27). Exercise commitment is used as an indicator of the degree of internal motivation, and refers to the state of immersion in a specific activity (28). Exercise commitment not only leads to positive results but can also be strengthened through satisfaction with the results (29). Moreover, exercise commitment is presented as a major factor in explaining outcome expectations (the more value and importance the outcome is recognized as having, the more likely it is to be acted upon) (30). That is, exercise commitment may be an important factor in sustaining sports participation, and is related to the exercise outcome expectation that induces more active participation in sports (31). Eventually, enjoyment increases exercise commitment, which may be a significant factor mediating continuous participation in exercise and sports (32).

Behavioral intention refers to future planned behavior as a direct factor in determining behavior in a decision-making model (33). It is defined as an individual's will or belief that manifests as satisfaction or dissatisfaction with a particular activity (34). Since the Behavioral Intention Model was proposed, behavioral intent has been used in many studies as a decision variable. Fishbein and Ajzen (35) explained that individual behavior is directly affected by the degree of intention to perform. In general, because people behave according to certain intentions, behavioral intention is a vital indicator of an individual's behavior (36). Furthermore, when an attitude toward a specific object is formed, an individual has the will and belief to perform a specific future behavior; therefore, behavioral intention can be utilized as an important predictor of behavior to achieve an individual's goals (37, 38).

In previous studies, a positive influence of perceived enjoyment on exercise commitment was reported for water leisure activity participants, college students participating in windsurfing classes, and middle school P.E. class participants (32, 39, 40). An influential relationship was also found between perceived enjoyment and behavioral intention in college winter-class participants and middle school dance-class participants (41, 42). Furthermore, perceived enjoyment had a significant relationship on exercise commitment and behavioral intention in baseball club members and bowling participants (43, 44). Given that perceived enjoyment of PA participation is strongly related to exercise commitment and has a positive association on persistent behavioral intention, it is necessary to prove the association between these three factors in the context of school sports clubs involving middle school students. In particular, this study highlights perceived enjoyment as an important factor in maintaining PA among adolescents and may have useful implications for future program organization and management of school sports club class. To achieve the research purpose, a conceptual model of the hypotheses was developed (Figure 1).

The hypotheses corresponding to each path in the conceptual model are:

> *H1*: Perceived enjoyment of school sports club activities will have a positive association with exercise commitment.

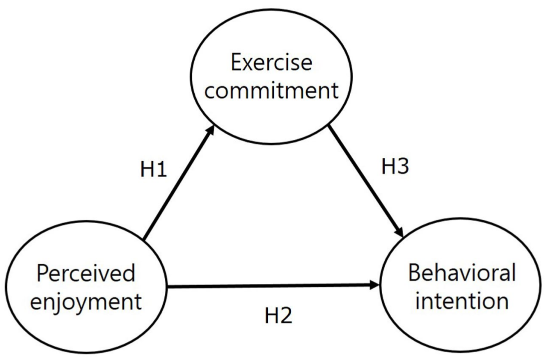

FIGURE 1
Research model.

> *H2*: Perceived enjoyment of school sports club activities will have a positive association with behavioral intention.

> *H3*: Exercise commitment in school sports club activities will have a positive association with behavioral intentions.

2 Methods

Based on previous studies, we found that perceived enjoyment of PA participation is closely related to exercise commitment and positively associated with continued behavioral intention. Furthermore, this study aims to investigate the relationship between perceived enjoyment, exercise commitment, and behavioral intention in order to promote voluntary and continuous participation in school sports clubs among middle school students. The detailed research model is as follows (Figure 1).

2.1 Participants

Middle schools in Seoul and Gyeonggi-do, South Korea, were selected as the target population. For sampling, 350 participants who had participated in school sports clubs for more than six months were selected using convenience sampling. The researchers visited middle schools in person to place advertisements for research participation and conducted a survey only with students who expressed their intention to voluntarily respond.

2.2 Measurements of key variables

A structured questionnaire based on previous studies and theories was used for assessment. It comprised 30 questions, including 2 items on demographic characteristics, 12 on perceived enjoyment, 12 on exercise commitment, and 4 on behavioral intention. Specifically, perceived enjoyment was measured by modifying the items used by Kim and Seong (45) and Yoon et al. (46). The perceived enjoyment scale consisted of 12 questions with four sub-factors: daily escape (3 questions), physical health (3 questions), interpersonal relations (3 questions), and competitive victory (3 questions). The exercise commitment scale, developed by Scanlan et al. (27) and translated into Korean by Jeong (28), was modified and measured according to the study purpose. It consisted of two factors: cognitive commitment (8 questions) and behavioral commitment (4 questions). Behavioral intention was assessed by adapting the questions in Zeithaml et al. (37). There were four questions (willingness to rejoin, talk positively, recommendations for activities and personal time and expense investment).

2.3 Procedure and statistical analysis

The researchers visited the schools and asked P.E. teachers for their cooperation in the survey. Furthermore, consent forms for study participation were distributed to the students to obtain their parents' consent. After explaining the purpose and method for completing the questionnaire, the survey was conducted using the self-evaluation technique. If a face-to-face survey was not possible because of COVID-19, the purpose of the study and the survey method were delivered through the ZOOM program, and the questionnaire was sent and collected via e-mail (electronic signature). The survey was conducted once and took approximately 10–15 min to complete. Finally, before the survey was conducted, voluntary participation in the research was announced, and students who were unwilling to participate were excluded from the survey. Among the sampled survey data, 336 datasets were used for the final analysis after eliminating 14 questionnaires that were judged to be incorrectly indicated or incomplete. The questionnaires were removed by experts (statistical analysis experts and two doctors in the sociology of sports) other than the researchers.

Responses to the measurement tools were recorded on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). To examine the validity of the structured questionnaire, content validity was verified based on the advice of two professors majoring in sports sociology and two doctors. Exploratory factor analysis (EFA) using the maximum likelihood method and reliability analysis using Cronbach's α coefficient were conducted to confirm the validity and reliability, respectively, of the measurement tools. The outcomes of the EFA are presented in Table 1. In particular, behavioral intention was a single factor, and the Cronbach's α value was 0.887.

2.4 Statistical analysis

The collected data were processed as follows: first, a frequency analysis was conducted. Second, confirmatory factor analysis and reliability verification (Cronbach's α) were conducted to verify the validity of the survey tool. Third, correlation and standard multiple regression analyses were performed. All analyses were conducted using the SPSS 21.0 program. The probability of statistical significance was set at 0.05.

3 Results

3.1 Characteristics of participants

The specific characteristics of the participants in this study were as follows. Of the 336 participants, 192 were male (57.1%) and 144 were female (42.9%). In terms of grade, 97 students were in first grade (28.9%), 113 students were in second grade (33.6%) and 126 students were in third grade (37.5%).

3.2 Correlation analysis among study variables

As shown in Table 2, the correlation between each factor determined the satisfaction of discriminant validity between each factor for those with a single dimensionality. There was a partially significant correlation (r) between the relevant variables (Table 2). Because the values of all correlation coefficients did not exceed 0.80, discrimination was obtained based on the criteria of Kline (47). Additionally, all variables were lower than 0.80, which is the criterion for multicollinearity between independent variables, indicating that there was no multicollinearity problem (48).

3.3 Effect of perceived enjoyment on exercise commitment

Table 3 shows the results of multiple regression analysis to verify the influence of perceived enjoyment on exercise commitment. Perceived enjoyment had a significant association on cognitive commitment ($p < 0.001$), and the explanatory power of the regression model was approximately 26.7% ($R^2_{adj} = 25.7\%$). The Durbin–Watson (DW) statistic was 2.090, showing a value close to 2, which was evaluated as no problem in the independence assumption of the residuals. The Variance Inflation Factor (VIF) was also found to be less than 10, indicating that there was no multicollinearity problem. After verifying the significance of the regression coefficients, daily escape ($\beta = 0.259$, $p < 0.001$), competitive victory ($\beta = 0.228$, $p < 0.001$), interpersonal relationships ($\beta = 0.204$, $p < 0.001$), and physical fitness ($\beta = 0.119$, $p < 0.05$) were confirmed to have significant positive relationships with cognitive commitment. In other words, the higher the daily escape, competitive victory, interpersonal relationships, and physical health, the higher the cognitive commitment.

The regression model for the relationship of perceived enjoyment on behavioral commitment was statistically significant ($p < 0.001$), and the explanatory power of the model was approximately 14.7% ($R^2_{adj} = 13.7\%$). The DW statistic was 2.151, showing a value close to 2, which was evaluated as no problem in the independence of the residuals. On verifying the significance of the regression coefficients, physical health ($\beta = 0.330$, $p < 0.001$), daily escape ($\beta = 0.205$, $p < 0.001$), interpersonal relationships ($\beta = 0.307$, $p < 0.05$), and competitive victory ($\beta = 0.228$, $p < 0.05$) were confirmed to have significant positive associations with behavioral commitment.

3.4 Effect of perceived enjoyment on behavioral intention

Table 4 presents the results of the multiple regression analysis to verify the influence of perceived enjoyment on behavioral intention. Perceived enjoyment showed a statistically significant relationship on behavioral intention ($p < 0.001$), and the explanatory power of the regression model was approximately 22.1% ($R^2_{adj} = 21.2\%$). The DW statistic was 1.926, which was approximately 2 and evaluated as no problem in the independence assumption of the residuals. The VIF was less than 10, indicating that there was no multicollinearity. On verifying the significance of the regression coefficients, physical health ($\beta = 0.423$, $p < 0.001$), interpersonal relations ($\beta = 0.139$, $p < 0.01$), and daily escape ($\beta = 0.138$, $p < 0.01$) were confirmed to have significant positive relationships with behavioral intention. However, there was no significant relationship between competitive victory ($\beta = 0.071$) and behavioral intention.

3.5 Effect of exercise commitment on behavioral intention

Table 5 shows the results of the multiple regression analysis between exercise commitment and behavioral intention. Exercise commitment had a statistically predictive association on behavioral intention ($p < 0.001$), and the explanatory power of the regression model was 14.52% ($R^2_{adj} = 13.9\%$). The DW statistic was 2.014, which

TABLE 1 Exploratory factor analysis (EFA) and reliability of latent variables.

	Classification	Daily escape	Physical health	Interpersonal relations	Competitive victory
Perceived enjoyment	Stress	**0.884**	0.022	0.034	0.032
	Freedom	**0.868**	0.062	0.007	0.045
	Pleasure	**0.863**	0.018	0.011	0.052
	Physical health	0.015	**0.912**	0.033	0.030
	Mental health	0.139	**0.889**	0.046	0.060
	Physical strength	0.120	**0.828**	0.040	0.018
	Making friends	0.014	0.032	**0.916**	0.040
	Getting close to friends	0.031	0.032	**0.877**	0.062
	Getting along well with friends	0.050	0.032	**0.825**	0.017
	Fun of competition	0.053	0.058	0.046	**0.894**
	Improvement of athletic ability	0.135	0.030	0.1137	**0.863**
	Fun of winning or losing	0.243	0.019	0.035	**0.717**
	Eigen value	2.398	2.320	2.312	2.074
	Common variance (%)	19.986	19.336	19.266	17.282
	Total variance (%)	19.986	39.322	58.588	75.870
	Reliability	0.850	0.846	0.847	0.774

	Classification	Cognitive commitment	Behavior commitment
Exercise commitment	Fun to think about	0.822	0.135
	Wait for participation	0.789	0.246
	Precious in life	0.764	0.137
	Continue to participate	0.755	0.247
	Feeling happy about participating	0.752	0.164
	Do more if I have time	0.694	0.222
	Gather information about skill	0.143	0.816
	I think I'm into exercise	0.228	0.745
	Imagining a great exercise performance	0.231	0.716
	View exercise media in priority	0.142	0.714
	Eigen value	3.646	2.479
	Common variance (%)	36.463	24.787
	Total variance (%)	36.463	61.249
	Reliability	0.877	0.770

1. K.M.O = 0.789, Bartlett's, $p < 0.001$. 2. K.M.O = 0.868, Bartlett's, $p < 0.001$. Exploratory factor analysis shows the results of grouping factors together.

was close to 2, determining that there was no problem in the independence of the residuals. The VIF was less than 10, indicating that there was no multicollinearity. As a result of verifying the significance of the regression coefficients, behavioral commitment ($\beta = 0.237$, $p < 0.001$) and cognitive commitment ($\beta = 0.183$, $p < 0.05$) were confirmed to have a significant positive relationship with behavioral intention.

4 Discussion

According to Trost (49), PA during adolescence has been shown to have positive effects on health development and future health maintenance in adulthood, so adolescent health policies and education should focus on PA. Specifically, sports club activities in which adolescents can freely participate at school are among the most important educational activities promoting PA (16). Hence, it is crucial to establish a theoretical basis for increasing adolescent participation in sports club activities and maximizing PA. Based on this theoretical perspective, this study attempted to investigate the relationship between perceived enjoyment, exercise commitment, and behavioral intention to induce voluntary and continuous participation of middle school students in school sports clubs. Participating in various sports activities in school plays an important role in satisfying the desire for PA, decreasing obesity, improving physical strength, preventing school violence, and developing personality (15–17).

First, considering the present results, students participating in middle school sports clubs experienced enjoyment through physical

TABLE 2 Correlation analysis among variables.

Variables	1	2	3	4	5	6	7
Daily Escape	1						
Physical Health	0.026	1					
Interpersonal Relations	0.160**	0.123*	1				
Competitive Victory	0.174**	0.104	0.124*	1			
Cognitive Commitment	0.122*	0.172**	0.258***	0.220***	1		
Behavior Commitment	0.324***	0.302***	0.193***	0.111*	0.668***	1	
Behavioral Intention	0.418***	0.138**	0.149**	0.065	0.128*	0.198***	1

*$p<0.05$, **$p<0.01$, ***$p<0.001$. 1. Daily escape, 2. Physical health, 3. Interpersonal relations, 4. Competitive victory, 5. Cognitive commitment, 6. Behavior commitment, 7. Behavioral intention.

TABLE 3 Effect of perceived enjoyment on exercise commitment.

	Section	β	t		Section	β	t	VIF
Cognitive commitment	Daily escape	0.259	5.156***	Behavior commitment	Daily escape	0.200	3.9281***	1.001
	Physical health	0.119	2.358*		Physical health	0.330	6.494***	1.004
	Interpersonal relations	0.204	4.043***		Interpersonal relations	0.142	2.470*	1.011
	Competitive victory	0.228	4.513***		Competitive victory	0.130	2.201*	1.014
$F=16.545$ ($p<0.001$), $R^2=0.267$, $R^2_{adj}=0.257$, DW = 2.090				$F=14.291$ ($p<0.001$), $R^2=0.147$, $R^2_{adj}=0.137$, DW = 2.151				

*$p<0.05$, **$p<0.01$, ***$p<0.001$.

TABLE 4 Effect of perceived enjoyment on behavioral intention.

	Section	β	t	VIF
Behavioral intention	Daily escape	0.138	2.844**	1.001
	Physical health	0.423	8.712***	1.004
	Interpersonal relations	0.139	2.849**	1.011
	Competitive victory	0.071	1.460	1.014

$R^2=0.221$, $R^2_{adj}=0.212$, DW = 1.926. *$p<0.05$, **$p<0.01$, ***$p<0.001$.

TABLE 5 Effect of exercise commitment on behavioral intention.

	Section	β	t	VIF
Behavioral intention	Cognitive commitment	1.83	1.376*	1.281
	Behavior commitment	2.37	3.912***	1.281

$R^2=0.145$, $R^2_{adj}=0.139$, DW = 2.014. *$p<0.05$, **$p<0.01$, ***$p<0.001$.

health, daily escape, interpersonal relations, and competitive victory. Perceived enjoyment had a significant association on cognitive and behavioral commitment. To be more specific, among the sub-factors of perceived enjoyment, the following were found to have a positive relationship with cognitive commitment: daily escape ($\beta=0.259$), competitive victory ($\beta=0.228$), interpersonal relationships ($\beta=0.204$), and physical fitness ($\beta=0.119$). Furthermore, among the sub-factors of perceived fun, physical health ($\beta=0.330$), daily escape ($\beta=0.205$), interpersonal relationships ($\beta=0.307$), and competitive victory ($\beta=0.228$) had positive relationships with behavioral commitment. Ultimately, middle school students' participation in school sports clubs means that they are engaged in healthy physical activities that can protect their physical and mental health. In addition, students can relieve stress and experience escape and freedom from daily life chores by voluntarily participating in sports, forming new interpersonal relations, and experiencing a variety of emotions in competitive victory and defeat (40). This perceived enjoyment may be a significant means of experiencing happiness in life by positively influencing cognitive and behavioral commitment to exercise and sports (39), and continuous sports participation in the future (50). The competitive element and positive perception of the physical aspect acquired through school sports club activities may serve as driving forces for further engagement in sports activities. In addition, positive interpersonal relationships formed through sports activities and special experiences in daily life or school are important factors that lead to a greater focus on sports activities (51). Thus, it can be inferred that, among the current study participants, school sports club activities significantly influenced exercise commitment, physical and psychological health, social cultivation, and a sense of achievement. If middle school students actively participate in school sports club activities and experience enjoyment during the process, exercise commitment is promoted (52). Thus, it is possible to confirm a scientific basis for the effect of perceived enjoyment on exercise commitment in school sports clubs activities in which the students in this study participated.

Second, in terms of analyzing the relationship between perceived enjoyment and behavioral intention of participants in middle school sports clubs, the factors of daily escape, interpersonal relations, and physical health significantly influenced behavioral intention. Among the sub-factors of perceived enjoyment, physical health ($\beta=0.423$), interpersonal relations ($\beta=0.139$), and daily escape ($\beta=0.138$) were found to have a positive association with behavioral intention. On the other hand, there was no significant relationship between competitive winning ($\beta=0.071$) and behavioral intention. More specifically, middle school students' participation in sports clubs was one of the most important ways to feel free from daily routines and relieve stress. In addition, the other factors in the perceived enjoyment, which is associated with the development of physical and mental health and the formation of peer relationships, is an important variable that positively affects behavioral intention. Previous studies have found a significant relationship between perceived enjoyment and behavioral intention obtained from marine leisure experiences. The academic implication is that enjoyment from participation in scuba diving, a marine recreational activity, can lead to positive behavioral intentions (53). Yoon et al. (41) noted that the enjoyment factors involved in college students' participation in skipping and snowboarding classes had a positive association on their intention to continue exercising, and the higher the level of enjoyment, the higher their behavioral intention. Furthermore, Park et al. (54) emphasized that university students' perceived enjoyment from participation in liberal arts golf classes had a positive influence on their exercise adherence intention. Hence, perceived enjoyment obtained from participating in various sports activities positively affects behavioral intention. In fact, if one does not experience enjoyment when participating in a sports activity, one is very likely to drop out of it; the need for perceived enjoyment is an important factor in increasing behavioral intention (26). Consequently, the positive relationship between perceived enjoyment and behavioral intention found in this study provides an important basis for sustained participation in school sports clubs among middle school students (42). However, the factors of competition and victory experienced by the participants had no effect on behavioral intention. According to Scanlan & Simons (55), sports enjoyment refers to intrinsic rather than extrinsic feelings such as fun, liking, and enjoyment, and these positive emotional responses influence continued sports participation. In addition, Wankel et al. (24) stated that intrinsic rewards such as enjoyment, fun, and having a good time are the most important factors in sports participation. Therefore, administrators of school sports clubs (e.g., P.E. teachers) need to pay more attention to enjoyment factors in planning sports activities (56).

Third, as a result of verifying the significance of the regression coefficients, behavioral commitment ($\beta = 0.237$) and cognitive commitment ($\beta = 0.183$) were confirmed to have a significant positive relationship with behavioral intention. In other words, exercise commitment gained through school sports club activities may be an important factor influencing students' behavioral intentions. Various studies have examined this relationship. Min et al. (57) stressed that exercise commitment perceived by triathlon club members had a positive effect on exercise continuity behavior. Moreover, exercise commitment in social baseball had a positive relationship on exercise satisfaction and exercise continuity behavioral intention (43). Yoon and Lee (41) showed that exercise commitment perceived by college students participating in skiing and snowboarding classes had a significant effect on continuous exercise behavior. These results suggest that increasing exercise commitment is important in school sports club activities. In particular, the findings regarding a positive association of exercise commitment on behavioral intention of students participating in after-school physical education classes (58) support the results of this study. As exercise commitment is an important factor in the continued intention to participate in sports activities (59), the exercise commitment experienced by students in school sports clubs may be one of the most important factors. Therefore, reasonable activity operation management that can increase students' desire and willingness to continue participating in school sports clubs is essential. Additionally, environmental factors that can induce students to exercise should be considered. For example, facility conditions and class atmosphere are important. Most importantly, the club operator, for example, P.E. teachers, should consider which sports event to choose. In other words, sports club activities should be designed primarily for sports that induce students' commitment to exercising. This increases the chances of creating an educational environment that encourages students to participate in sports clubs, from a long-term perspective.

To promote student engagement in PA, Mohammadi et al. (60) suggested that schools increase the frequency and duration of P.E. classes. Furthermore, in order to expand the physical activity program of adolescents, the concept of physical literacy (PL) needs to be dealt with in school physical education (61). In particular, PL can expand physical activity in relation to adolescents' holistic development (62). Therefore, it will be necessary to develop specific programs and manuals that can teach PL through sports club activities. In addition, PE teacher education for physical activity education based on PL should be accompanied. In South Korea's physical education curriculum, the number of hours of P.E. classes per week is set by law. Therefore, institutional changes are needed to allow students to participate in sports club activities in their spare time. In other words, there is a need to find ways to increase the frequency and duration of PA in schools. Moreover, the results suggest that sports club activity programs should focus more on students' perceived enjoyment. Based on the results of this study, sports club activities that can increase adolescents' exercise commitment need to be further encouraged, and it is considered necessary to develop programs that can include PL. Eventually, through these programs, it will be possible to increase the behavioral intention of adolescents' sports club activities, and further lead to long-term participation.

On the other hand, this study has the following limitations. First, this study focused on continuous PA, which limits its ability to address a range of youth social problems, including overweight and obesity. Second, as a limitation of this study, Korean school sports club events are operated in various sports by schools in each region, so it was difficult to present specific programs for each sport event in this study. Therefore, future research should be conducted on the development of specific sports club events and detailed programs to be introduced by individual physical education teachers according to students' voluntary participation and needs.

5 Conclusion

The current study attempted to derive the academic implications of middle school students' continuous participation in school sports club activities. The researchers explored the relationship between perceived enjoyment, exercise commitment, and behavioral intention of middle school sports club participants in a metropolitan city in South Korea.

First, it was found that competitive factors and the positive perception of fitness aspects acquired by students in school sports club activities can be positive factors for further immersion in sports activities. In particular, the positive experience of interpersonal relationships formed in sports activities can be an opportunity to focus more on physical activities. Thus, the hypothesis that perceived enjoyment from active participation in school sports club activities promotes exercise commitment was supported. Second, perceived enjoyment gained from participating in school sports clubs became a sufficient basis for the continuity of physical activity. Accordingly, it is suggested that school sports club activities be planned and conducted with more emphasis on the enjoyment that comes from the activity itself, rather than the importance of transferring classroom knowledge. Third, exercise commitment had a positive predictive association on behavioral intention. Previous studies have shown that class organization, environmental factors, and appropriate instructional content are essential for increasing exercise engagement in school sports club activities (15, 16, 25). Therefore, it is necessary to create an educational environment in which students can become immersed in physical activities to induce behavioral intentions.

Based on the above findings and discussion, suggestions for follow-up research are outlined. First, there is a need for research on factors other than enjoyment that can attract students' interest and increase their participation rate in the planning and operation of middle school sports clubs. Second, additional qualitative research should be conducted to understand the students' specific perceptions of participating in middle school sports clubs. Third, based on the findings of this study, it is necessary to apply the Delphi technique with a group of experts to develop specific PA programs that can be implemented in schools 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 authors.

Ethics statement

The studies involving humans were approved by Kangnam University Institutional Review Board (NO. KNU-HR2109001). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the minor(s)' legal guardian/next of kin for the publication of any potentially identifiable images or data included in this article.

Author contributions

KJ: Data curation, Formal analysis, Investigation, Supervision, Writing – original draft. WJ: Conceptualization, Data curation, Software, Supervision, Writing – original draft. GK: Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing.

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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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Effect of high-intensity interval training on cardiorespiratory in children and adolescents with overweight or obesity: a meta-analysis of randomized controlled trials

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Objective: This meta-analysis aimed to examine the effect of high-intensity interval training on cardiorespiratory fitness in children and adolescents with overweight or obesity, and to explore the optimal dose of high-intensity interval training to improve cardiorespiratory fitness in children and adolescents with overweight or obesity.

Methods: Randomized controlled trials on the effects of HIIT on cardiorespiratory fitness in children and adolescents with overweight or obesity were retrieved from six electronic databases, including PubMed, Web of Science, Cochrane Library, CNKI, Wanfang, and VIP. The quality assessment of the included studies was conducted following the revised quality evaluation method based on the PRISMA principles. Keywords for literature search mainly include high-intensity interval, cardiorespiratory fitness, overweight, obese, children, and adolescent, etc.

Results: (1) A total of 18 studies, comprising 581 participants (288 in the intervention group and 293 in the control group), were included and all of them were of moderate to high quality. (2) HIIT had a positive effect on the cardiorespiratory fitness levels of in children and adolescents with overweight or obesity (SMD = 0.91; 95% CI: 0.66, 1.15; $p < 0.00001$). (3) The improvement in cardiorespiratory fitness was more significant when the HIIT intervention lasted for more than 10 weeks (SMD = 1.04; 95% CI: 0.74, 1.34; $p < 0.00001$), was conducted 3 times per week, with 2 to 8 sets per session (SMD = 1.13; 95% CI: 0.71, 1.55; $p < 0.00001$), and maintained a ratio of approximately 1:1 between exercise and rest intervals (SMD = 1.11; 95% CI: 0.73, 1.50; $p < 0.00001$).

Conclusion and recommendations: (1) Long-term HIIT can improve cardiorespiratory fitness in children and adolescents with overweight or obesity. (2) To achieve significant improvements in cardiorespiratory fitness in a short period, children and adolescents with overweight or obesity can engage in HIIT programs lasting for more than 10 weeks, conducted 3 times per week, with 2 to 8 sets per session, and a ratio of approximately 1:1 between exercise and rest intervals.

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high-intensity interval training, obesity, children and adolescents, cardiorespiratory fitness, dose–response relationship

1 Introduction

Childhood and adolescent obesity and overweight have become a global public health concern. Severe obesity and overweight significantly reduce an individual's cardiorespiratory fitness (CRF). CRF, as one of the important indicators of physical health, is crucial for maintaining overall health and quality of life. Numerous studies have demonstrated a close association between low CRF levels and increased all-cause mortality rates and the incidence of various cancers (1, 2). Additionally, children and adolescents in their developmental stage who experience prolonged low levels of cardiorespiratory fitness are at a higher risk of cardiovascular and metabolic diseases in adulthood (3, 4). Over the years, Traditional long-duration aerobic exercise (similar to a marathon) has been regarded as a crucial means to reduce fat and promote cardiorespiratory health. Engaging in over 60 min of physical exercise daily can help maintain healthy cardiorespiratory function, and when combined with dietary control or medication, it produces a potent synergistic effect on improving cardiorespiratory fitness and physical health levels in children and adolescents. However, due to high academic pressure and increased entertainment distractions, modern children and adolescents find it challenging to allocate dedicated time for physical exercise beyond school physical education classes. This is where high-intensity interval training (HIIT) comes into play as a time-efficient, highly effective, and rapidly impactful exercise modality, gradually gaining popularity among the general population.

High-intensity interval training (HIIT) is a form of exercise training that involves brief periods of intense, maximal, and explosive movements followed by lower-intensity exercise or rest intervals for recovery (5–7). Previously, HIIT has been proven to have a significant effect on obesity intervention and cardiorespiratory fitness improvement in adults as an emerging, efficient, and time-saving exercise method (8, 9). Existing research suggests that the mechanisms by which HIIT influences body fat content and cardiorespiratory function may involve enhanced fat oxidation after high-intensity exercise and an increase in the secretion of certain hormones. For example, studies by Burgomaster (10) and Talanian (11) have demonstrated that HIIT can increase fatty acid oxidation capacity, thereby accelerating fat consumption to achieve weight control. Additionally, the substantial secretion of catecholamines during HIIT exercise is also a crucial factor in driving the reduction of visceral fat. Another significant mechanism is that HIIT may reduce energy intake by suppressing appetite, consequently decreasing fat accumulation (12). In recent years, related studies and systematic reviews have indicated that HIIT has a beneficial impact on improving cardiorespiratory fitness in obese or overweight children and adolescents (13–15). There is a strong correlation between high levels of childhood obesity, elevated blood pressure, decreased cardiorespiratory fitness, and a lack of physical activity (16). Compared with traditional sports programs, HIIT is short-term, interesting and acceptable. It is a method that can efficiently improve the physical fitness and cardiorespiratory fitness of children and adolescents. Therefore, it is particularly important to explore the effect of high-intensity interval training on cardiorespiratory fitness in children and adolescents with overweight or obesity, and the optimal dose of high-intensity interval training to improve cardiorespiratory fitness in children and adolescents with overweight or obesity.

Currently, although the positive impact of high-intensity interval training on cardiorespiratory health levels has been confirmed (17–19), and there have been controlled experiments and systematic reviews on children and adolescents with overweight or obesity (20–22), the results of the above studies have not reached a consensus. Specifically, there is significant variation in the intervention effects of high-intensity interval training on cardiorespiratory fitness in children and adolescents with overweight or obesity. For example, Abdessalem Koubaa and Brooke Starkoff found that the CRF of participants in the HIIT group was only 10 to 14% higher than that of the control group at the end of their experiments, while Wing Chung Patrick Lau's research showed that the HIIT group had a CRF value nearly 25% higher than the control group. We believe this discrepancy is closely related to differences in exercise protocols and intervention dosages in experimental designs. Additionally, with the evolution of high-intensity interval exercise, numerous recent studies have emerged on the impact of high-intensity interval training on cardiorespiratory fitness in children and adolescents with overweight or obesity. However, none of these studies have been included in a new systematic review or meta-analysis to expand our understanding of the effects of high-intensity interval training on cardiorespiratory fitness in this population. Furthermore, the existing research has not identified the optimal dose–response relationship of high-intensity interval training in improving cardiorespiratory health levels in children and adolescents with overweight or obesity.

Therefore, this study employs a Meta-analysis method, ensuring methodological quality, to quantitatively analyze randomized controlled trials involving high-intensity interval training for improving cardiorespiratory health levels in children and adolescents with overweight or obesity. The main objectives are to explore two key questions: (1) the overall impact of high-intensity interval training on improving cardiorespiratory fitness in children and adolescents with overweight or obesity, and (2) the optimal dose–response relationship of high-intensity interval training in enhancing cardiorespiratory health levels in children and adolescents with overweight or obesity. This study aims to provide objective evidence for future physical practice and health interventions aimed at improving cardiorespiratory health levels in children and adolescents with overweight or obesity.

2 Research methods

2.1 Literature search

Six electronic databases, including PubMed, Web of Science, Cochrane Library, CNKI, Wanfang, and VIP, were selected to search for randomized controlled trials (RCTs) on the effects of high-intensity interval training (HIIT) on cardiorespiratory fitness in overweight and obese children and adolescents. The search period ranged from the inception of the databases to March 31, 2023. A combination of subject terms and free-text terms was used to construct the search strategy. The English search strategy was as follows: ("high-intensity interval" OR "high-intensity interval" OR "high intensity intermittent" OR "high-intensity intermittent" OR HIIT) AND ("cardiorespiratory fitness" OR "maximal oxygen uptake" OR "peak oxygen uptake" OR CRF) AND ("children" OR "adolescent") AND ("obese" OR "overweight"). The Chinese search strategy was as follows: SU = ("High-intensity interval training "+ "HIIT") AND SU = "Children" + "adolescents" + "pediatric" AND SU = ("obesity" + "overweight") AND SU = ("cardiorespiratory fitness" + CRF). A total of 1,676 relevant articles were retrieved from the electronic databases. After removing 647 duplicate articles, 1,049 articles remained for further analysis.

2.2 Inclusion and exclusion criteria

Two researchers independently assessed the inclusion and exclusion of articles. In cases of disagreement, a third researcher was consulted to reach a consensus through group discussion. The following criteria were used to include studies:

Population: the participants were children and adolescents with overweight or obesity (aged 7–17 years) without prior professional training; The participants did not have acute or chronic diseases.

Intervention: the intervention in the experimental group was HIIT.

Comparison: the intervention in the control group was normal routine or traditional aerobic training.

Outcome: the primary outcome was VO2max. The outcome measures included VO2max or tests from which VO2max values could be indirectly calculated; Secondary outcomes are duration of intervention, intervention period, frequency of intervention, etc.

Study design: published randomized controlled trials (RCTs) were eligible for inclusion, and nonrandomized studies were excluded.

2.3 Literature screening

Based on the search and removal of duplicates, 1,049 articles were obtained. Two researchers screened the titles and abstracts and conducted a full-text review, following the inclusion and exclusion criteria. A total of 1,011 articles were excluded, and ultimately, 18 articles were included in the meta-analysis. The process of literature screening is shown in Figure 1.

2.4 Characteristics of included studies

The included 18 studies were coded for their characteristics using Excel software. The following features were extracted: author, publication year, sample size, participant age, intervention dose (load time, rest time, number of intervention sets, intervention frequency, intervention duration), and outcome measures (as shown in Table 1). All 18 included studies were RCTs published after 2013. The total sample size of the studies was 581, with 288 participants in the intervention group (ranging from 7 to 23 participants per group) and 293 participants in the control group (ranging from 6 to 26 participants per group). The number of intervention sets varied from 2 to 20, and the intervention duration ranged from 4 to 24 weeks. The intervention frequency was consistent across all studies, with interventions conducted 3 times per week. Regarding outcome measures, except for three studies (Lau, Bogataj, Cvetkovic) that used the YO-YO test to indirectly estimate VO2 max, the remaining 15 studies directly measured VO2 max. The unit of measurement for VO2 max in all included studies was ml/min/kg.

2.5 Quality assessment

The quality assessment of the included studies was conducted by two researchers independently, referring to the quality evaluation method revised based on the PRISMA principles by Buchheit (37). The included studies were categorized into three levels of risk: high risk (0–3 points), medium risk (4–6 points), and low risk (7–8 points) based on the cumulative evaluation score. The assessment included eight criteria: (1) clear inclusion criteria, (2) random allocation, (3) no significant baseline differences between groups, (4) blinding of outcome assessors, (5) all participants received the intended intervention or intention-to-treat analysis was performed, (6) dropout or lost to follow-up rate < 20% with detailed reasons, (7) sample size meeting the calculation requirements, and (8) reporting of effect size, precision, and results for each group (as shown in Table 2).

2.6 Data analysis

Review Manager 5.4 and Stata 17 software were used for the meta-analysis in this study. Since the included studies had continuous variables and inconsistent outcome measures, the statistical analysis was conducted using the standardized mean difference (SMD) and its 95% confidence interval (CI). A value of $p < 0.05$ was considered statistically significant. Additionally, Cochran's Q test and the I^2 statistic were employed to determine the magnitude of heterogeneity among studies: $I^2 < 25\%$ indicates low heterogeneity, $25\% < I^2 < 50\%$ indicates moderate heterogeneity, and $I^2 > 50\%$ indicates high heterogeneity. A significance level of $p < 0.05$ indicates significant heterogeneity. Only when $I^2 < 50\%$ and $P > 0.05$, a fixed-effects model can be used for analysis; otherwise, a random-effects model is applied. Egger's test and funnel plots were used to assess publication bias among the included studies. If publication bias was detected, the trim and fill method was employed to assess the stability of the combined results. Additionally, sensitivity analyses were conducted using two methods to ensure the reliability of the results: (1) switching between random-effects and fixed-effects models and reanalyzing all statistical results, and (2) assessing the significant influence of each individual study by sequentially excluding one study at a time.

3 Results

3.1 Quality assessment results

After assessing the quality of the 18 included studies, it was found that 6 studies were classified as low risk (7–8 points), 12 studies were classified as medium risk (4–6 points), and no studies were classified as low quality (0–3 points). All 18 studies met the low-risk

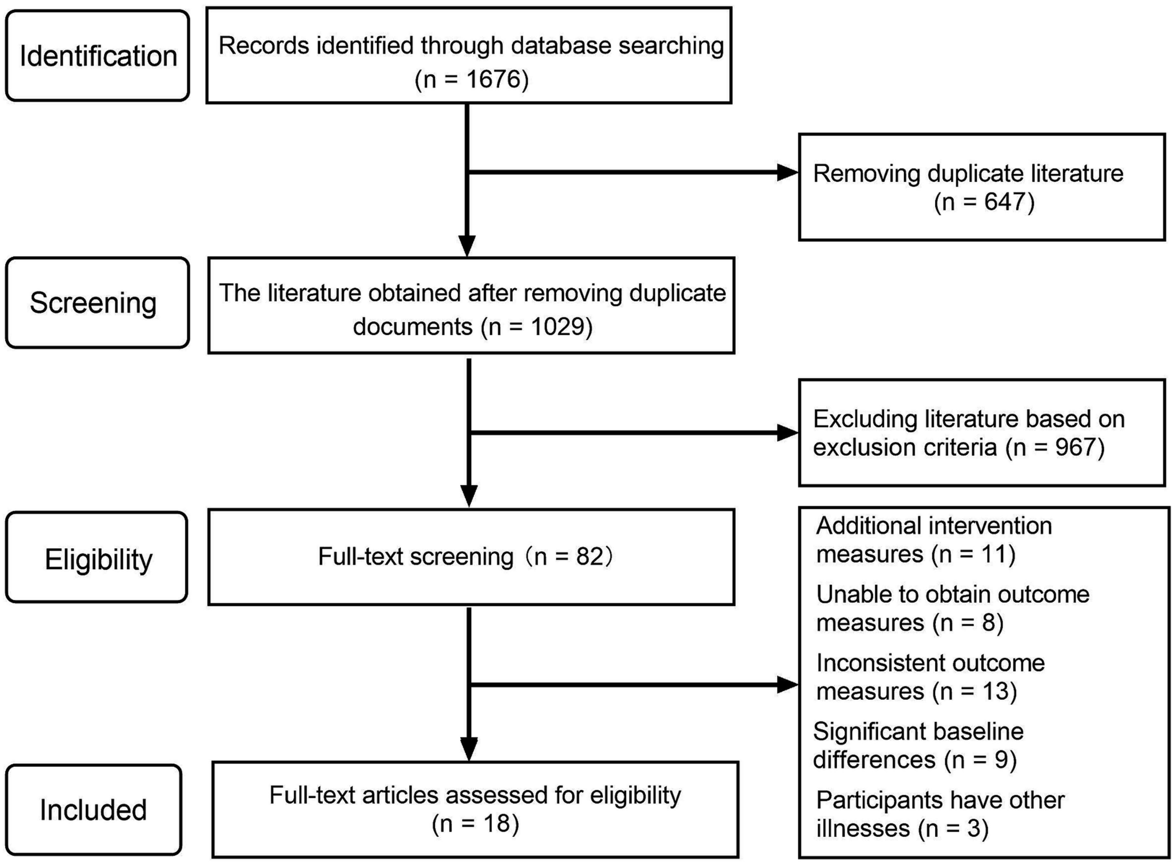

FIGURE 1
PRISMA flow diagram.

requirements in terms of inclusion criteria, random allocation, and baseline comparability. Regarding blinding, only 7 studies implemented blinding of outcome assessors, reducing the potential bias introduced by researchers' subjective intentions. In terms of intervention implementation, only 1 study did not provide a detailed description of the intervention. Regarding dropout and description, all 18 studies reported the number of dropouts and the reasons, but 8 studies had dropout rates exceeding 20% of the original sample size. In terms of reporting results, 8 studies only reported the numerical values of outcome measures before and after the intervention, without reporting the effect size. Overall, the average risk of bias evaluation score for the included studies was 6.1, indicating a medium risk level. This suggests that future experimental studies should control dropout rates and conduct further statistical analysis on the changes in outcome measures, in addition to implementing blinding, to improve the methodological quality of study designs.

3.2 Effect of high-intensity interval training on cardiorespiratory fitness in children and adolescents with overweight or obesity

First, a test for heterogeneity was conducted on the 18 included studies, revealing moderate heterogeneity (I^2 = 46%, $p = 0.02$). Therefore, a random-effects model was used to examine the overall effect size. According to Cohen's criteria, effect sizes of 0.2 indicate a small effect, 0.2–0.8 indicate a moderate effect, and above 0.8 indicate a large effect. The overall pooled effect size of the 18 studies was $d = 0.91$. The two-tailed test result ($p < 0.00001$) and the 95% CI (0.66, 1.15) both indicated statistical significance. These findings demonstrate that high-intensity interval training significantly improves the cardiorespiratory fitness level of children and adolescents with overweight or obesity (Figure 2).

3.3 Sources of heterogeneity

Based on the overall effect size analysis, it was observed that the included studies exhibited moderate heterogeneity ($I^2 = 46\%$, $p = 0.02$). To explore the sources of heterogeneity, this study conducted meta-regression analyses using intervention duration, number of intervention sets, load time, rest time, and load/rest time ratio as independent variables (as shown in Table 3).

The results of the meta-regression analysis indicate that the intervention duration, load time, rest time, and load/rest time ratio subgroups all have p values >0.05, indicating no significant differences. However, the subgroup analysis of the number of intervention sets showed a p value of $0.011 < 0.05$, suggesting that the number of intervention sets is one of the sources of heterogeneity in this study. Additionally, based on the results of the meta-regression, a more detailed subgroup analysis can be conducted to explore the dose–response relationship of high-intensity interval training on improving cardiorespiratory fitness in children and adolescents with overweight or obesity.

TABLE 1 Basic characteristics of included literature.

Author	Sample size(E/C)	Age (M ± SD)	Intervention dosage				outcome measure
			Load time (intensity)	Rest time (intensity)	number of sets	wk	
Dias (23)	48 (22/26)	E:12.4 ± 1.9\ u00B0C:11.8 ± 2.4	4 min (85-95%HRmax)	3 min (50%70%HRmax)	4	12	①
Ingul (24)	48 (22/26)	7–16	4 min (85-95%HRmax)	3 min (50-70%HRmax)	4	12	①
Kargarfard (25)	20 (10/10)	12.36 ± 1.34	4 min (80-90%HRmax)	2 min (40-50%HRmax)	NR	8	①
Murphy (26)	13 (7/6)	E:13.7 ± 2.0\ u00B0C:14.3 ± 1.2	1 min (80-90%HRmax)	2 min (60%HRmax)	10	4	①
Starkoff (20)	27 (14/13)	E:14.9 ± 1.6\ u00B0C:14.5 ± 1.4	2 min (90-95%HRmax)	1 min (55%HRmax)	10	6	①
Lau (22)	27 (15/12)	E:11.0 ± 0.6\ u00B0C:9.9 ± 0.9	15 s (120%MAS)	15 s (Rest)	12	6	②
Racil (27)	23 (11/12)	E:15.6 ± 0.7\ u00B0C:15.9 ± 1.2	30s (100-110%MAS)	30s (Rest)	12–16	12	①
Racil (28)	42 (23/19)	E:16.9 ± 1.0\ u00B0C:16.6 ± 0.9	30s (100%VO_2peak)	30s (50%VO_2peak)	8	12	①
Bogataj (29)	46 (22/24)	E:15.5 ± 0. C:15.7 ± 0.6	30s(NR)	15 s (Rest)	20	8	②
Cvetkovic (30) 2018	25 (11/14)	11–13	3 min (100%MAS)	3 min (Rest)	15	12	②
Farah (31)	19 (9/10)	E:15.4 ± 0.4\ u00B0C:14.8 ± 0.4	30s (120%MAS)	30s (Rest)	NR	24	①
Koubaa (22)	29 (14/15)	E:13.0 ± 0.8\ u00B0C:12.9 ± 0.5	2 min (80–90% MAS)	1 min (Rest)	NR	12	①
Boer (32)	32 (17/15)	E:18.0 ± 3.2\ u00B0C:16.7 ± 3.6	15 s (100% VT)	45 s (50% VT)	10	15	①
Cao (33)	40 (20/20)	E:11.2 ± 0.7\ u00B0C:10.9 ± 0.4	15 s (100%MAS)	15 s (50%MAS)	2	12	①
Cao (34)	25 (15/15)	E:11.4 ± 0.8\ u00B0C:11.0 ± 0.7	15 s (90-100%MAS)	15 s (50%MAS)	2	12	①
Li (15)	32 (16/16)	11.0 ± 0.8	15 s (100-120%MAS)	15 s (50%MAS)	3	12	①
Cao (35)	40 (20/20)	11.0 ± 0.8	15 s (100-120%MAS)	15 s (50%MAS)	3	12	①
Yuan (36)	40 (20/20)	E:16.1 ± 1.2\ u00B0C:15.9 ± 1.2	30s (100-110%MAP)	30s (50%MAP)	2–5	12	①

E, Experimental group; C, Control group; NR, Not reported; HRmax, Maximum heart rate; MAS, Maximum aerobic speed; VO2peak, Peak oxygen uptake; MAP, Maximum aerobic power; VT, Ventilatory threshold; ①VO2max; ②YO-YO test.

3.4 Assessment of publication bias

To ensure the scientific rigor and validity of the research findings, an assessment of publication bias was conducted for the included studies. When the number of studies included in the meta-analysis exceeds 10, publication bias can be assessed using a funnel plot, along with Begg's test and Egger's test for quantitative evaluation. Firstly, based on the distribution of the 18 included studies in the funnel plot (Figures 3, 4), the results show that the effect sizes of most studies are evenly distributed on both sides of the average effect value, indicating a balanced distribution. Although there may be some slight bias toward the right side in a few individual studies, it is unlikely to have a significant impact on the overall results. Secondly, both Begg's test ($Z = 0.72$, $p = 0.472$) and Egger's test ($t = 1.47$, $p = 0.161$) yielded p values greater than 0.05. Therefore, it can be concluded that there is no apparent publication bias among the included studies, and the data analysis results are considered scientifically sound and rigorous.

3.5 Sensitivity analysis quality assessment results

To assess the reliability of this study, a sensitivity analysis was conducted by performing statistical analyses using both random-effects and fixed-effects models. The results showed that there were no significant changes in the statistical results after swapping between the two models. This indicates that the findings of the study are robust and not heavily influenced by the choice of the model.

Furthermore, a leave-one-out sensitivity analysis was conducted to examine the potential impact of each individual study on the overall results. The results showed that after removing each individual study, the range of the pooled effect size (SMD) was between 0.95 and 0.84, which still falls within the range of a large effect. The range of I^2 was between 50 and 34%, and the p values were all less than 0.00001. This indicates that the removal of any single study had minimal impact on the overall effect size, and the results remained statistically significant. The analysis confirms the stability and reliability of this study.

TABLE 2 Risk of bias evaluation of the included literature.

Literature	①	②	③	④	⑤	⑥	⑦	⑧	Total
Dias 2018	√	√	√	√	√	×	√	√	7
Ingul 2018	√	√	√	√	√	×	√	√	7
Kargarfard 2016	√	√	√	×	?	√	√	?	5
Murphy 2015	√	√	√	√	√	?	×	×	5
Starkoff 2014	√	√	√	√	√	√	√	×	7
Lau 2015	√	√	√	?	√	√	?	√	6
Racil 2013	√	√	√	?	√	√	×	√	6
Racil 2015	√	√	√	?	√	√	√	?	6
Bogataj 2021	√	√	√	√	√	√	?	√	7
Cvetkovic 2018	√	√	√	?	√	√	×	√	6
Farah 2014	√	√	√	?	√	×	×	√	5
Koubaa 2013	√	√	√	?	√	?	√	?	5
Boer 2013	√	√	√	?	√	×	√	×	5
Cao 2022(b)	√	√	√	√	√	×	√	√	7
Cao 2022(a)	√	√	√	√	√	√	√	√	8
Li 2023	√	√	√	?	√	×	√	√	6
Cao 2022	√	√	√	?	√	√	√	?	6
Yuan 2021	√	√	√	?	√	√	√	×	6
Total	18	18	18	7	17	10	12	10	

① Clear inclusion criteria were specified. ② Random allocation was performed. ③ There were no significant differences in baseline values between groups. ④ Blinding of outcome assessors was implemented. ⑤ All participants received the intended intervention or intention-to-treat analysis was performed on the experimental results. ⑥ The proportion of dropouts or lost to follow-up was less than 20%, and detailed reasons were provided. ⑦ The sample size met the calculation requirements. ⑧ The study reported the effect size, precision, and results for each group.

3.6 Dose–response relationship of high-intensity interval training to improve cardiorespiratory fitness in children and adolescents with overweight or obesity

After confirming the significant positive effect of high-intensity interval training on cardiorespiratory fitness in children and adolescents with overweight or obesity, this study conducted a subgroup analysis to explore the dose–response relationship between high-intensity interval training and the improvement in cardiorespiratory fitness in this population. The analysis was conducted based on intervention duration, intervention frequency, single-bout exercise duration, single-bout rest duration, and load/rest ratio (Table 4). Since all included studies had an intervention frequency of 3 times per week, intervention frequency was not analyzed as a separate subgroup.

1) Intervention duration: in this subgroup, a total of 581 participants were included. The effect sizes among the three subgroups showed moderate heterogeneity (I^2 = 57.9%), indicating that intervention duration has some influence on the relationship between high-intensity interval training and the improvement in cardiorespiratory fitness among children and adolescents with overweight or obesity. Specifically, high-intensity interval training with a duration of more than 10 weeks produced the largest effect size: SMD = 1.04, 95% CI (0.74, 1.34), p < 0.00001. The subgroup with an intervention

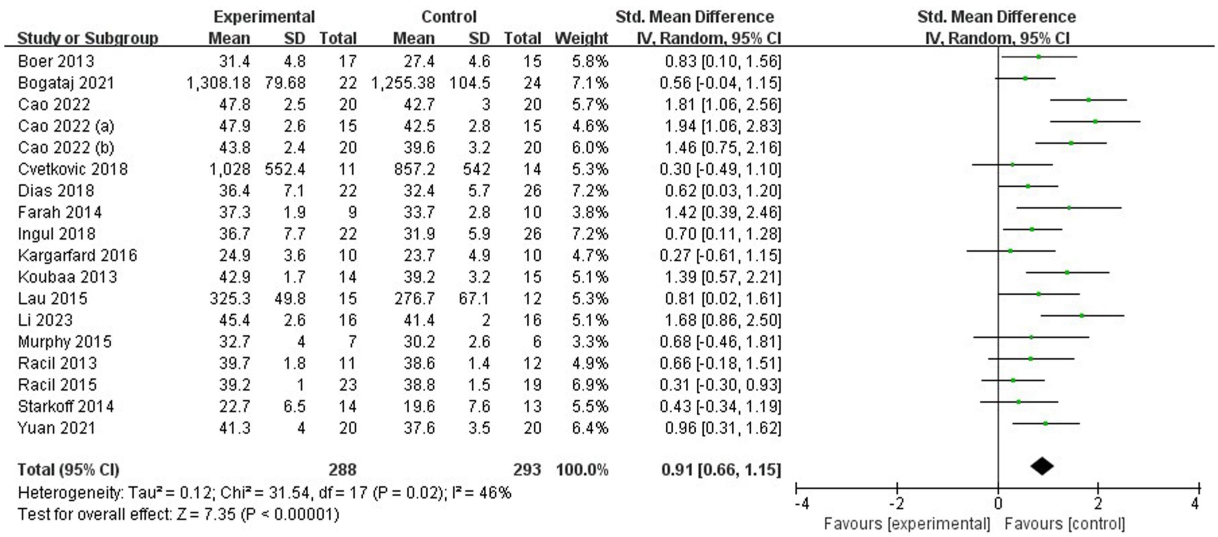

FIGURE 2
Meta-analysis forest plot.

TABLE 3 Overview of meta-regression results.

Explanatory variable	Regression coefficient	SE	Test statistic (*t*)	*P* > |*t*|	95%CI
Intervention period	0.13	0.14	0.89	0.389	−0.18,0.43
Intervention repetitions	−0.36	0.12	−3.01	0.011	−0.60,0.10
Load time	−0.01	0.50	−0.01	0.992	−1.10,1.09
Rest time	−0.31	0.53	−0.60	0.561	−1.46,0.83
Load/Rest ratio	0.03	0,18	0.15	0.881	−0.37,0.42
Intercept	1.67	0.64	2.58	0.024	0.26,3.06

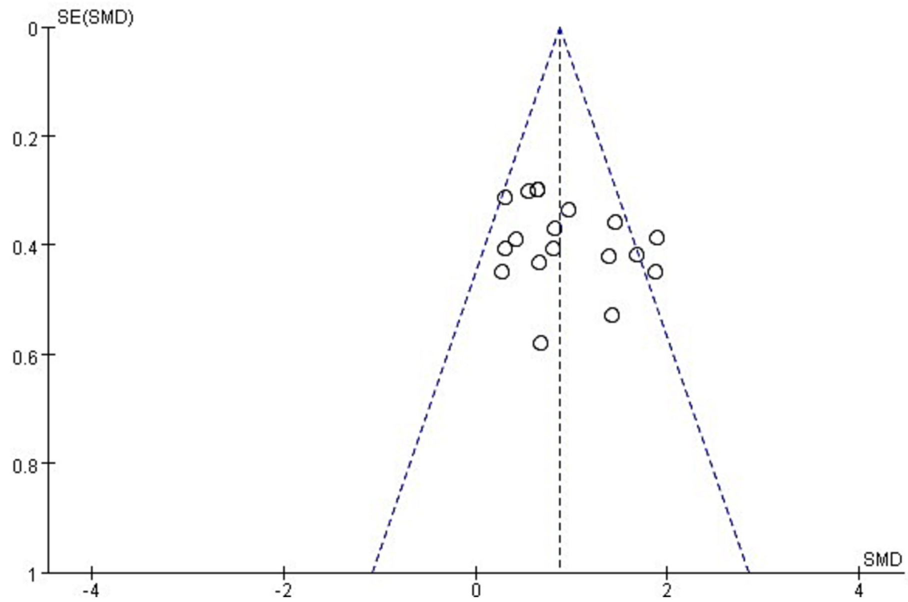

FIGURE 3
Funnel plot of publication bias.

duration of 4–8 weeks had the next highest effect size: SMD = 0.62, 95% CI (0.13, 1.12), $p = 0.01$. The subgroup with an intervention duration of 8–10 weeks had the smallest effect size: SMD = 0.46, 95% CI (−0.03, 0.95), $p = 0.07$, although it was not statistically significant.

2) Intervention frequency: in this subgroup, a total of 581 participants were included. The effect sizes among the three subgroups showed moderate heterogeneity (I^2 = 49.2%), indicating that intervention frequency has some influence on the relationship between high-intensity interval training and the improvement in cardiorespiratory fitness among children and adolescents with overweight or obesity. High-intensity interval training with 2–8 intervention sets per session produced the largest effect size: SMD = 1.13, 95% CI (0.71, 1.15), $p < 0.00001$. The subgroup with 8–12 intervention sets had the next highest effect size: SMD = 0.80, 95% CI (0.47, 1.14), p < 0.00001. The intervention effect gradually decreased as the number of intervention sets increased, with the smallest effect size observed in the subgroup with more than 12 intervention sets: SMD = 0.57, 95% CI (0.23, 0.93), $p < 0.001$.
3) Single bout exercise duration: in this subgroup, a total of 581 participants were included. The effect sizes among the three subgroups showed high heterogeneity (I^2 = 62.7%), indicating that single-bout exercise duration has some influence on the relationship between high-intensity interval training and the improvement in cardiorespiratory fitness among children and adolescents with overweight or obesity. The subgroup with a single bout exercise duration of 15 s to 1 min produced the largest effect size: SMD = 1.09, 95% CI (0.76, 1.42), $p < 0.00001$. The subgroup with a single bout exercise duration of 1–2 min had the next highest effect size: SMD = 0.84, 95% CI (0.22, 1.45), $p = 0.008$. The subgroup with a single bout exercise duration of 3 min or more had the smallest effect size: SMD = 0.53, 95% CI (0.19, 0.87), $p = 0.002$. The trend observed in the effect sizes of these three subgroups suggests that the intervention effect gradually decreases with longer single-bout exercise duration.
4) Single bout rest duration: in this subgroup, a total of 581 participants were included. The effect sizes among the three subgroups showed high heterogeneity (I^2 = 51.3%), indicating that single-bout rest duration has some influence on the relationship between high-intensity interval training and the improvement in cardiorespiratory fitness among children and adolescents with overweight or obesity The subgroup with a

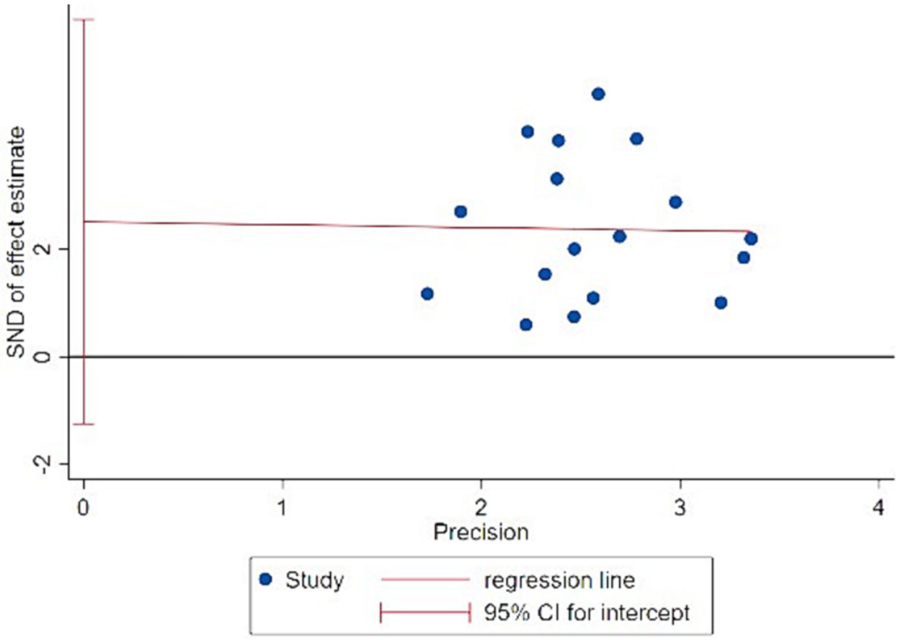

FIGURE 4
Egger test results chart.

TABLE 4 Dose-effect relationship between high-intensity interval exercise pairs and cardiorespiratory fitness in children and adolescents with overweight or obesity.

Subgroup	Heterogeneity test			Category	sample size	effect size and 95%CI	Two-tailed test	
	x^2	I^2	p				Z	p
Intervention period				4 ~ 8 wk	67	0.62(0.13,1.12)	2.47	0.01
	4.75	57.9	0.09	8 ~ 10 wk	66	0.46(−0.03,0.95)	1.83	0.07
				over 10 wk	448	1.04(0.74,1.34)	6.76	<0.00001
Intervention repetitions				2 ~ 8 sets	320	1.13(0.71,1.55)	5.3	<0.00001
	3.94	49.2	0.14	8 ~ 12 sets	151	0.80(0.47,1.14)	4.67	<0.00001
				over 12 sets	133	0.57(0.23,0.93)	3.22	<0.001
Load time				15 s ~ 1 min	371	1.09(0.76,1.42)	6.39	<0.00001
	5.36	62.7	0.07	1 ~ 2 min	69	0.84(0.22,1.45)	2.66	0.008
				over 3 min	141	0.53(0.19,0.87)	3.06	0.002
Rest time				15 s ~ 1 min	371	1.09(0.76,1.42)	6.39	<0.00001
	4.11	51.3	0.13	1 ~ 2 min	89	0.69(0.16,1.21)	2.57	0.01
				3 ~ 4 min	100	0.54(0.08,1.00)	2.31	0.02
Load/rest ratio				ratio<1	45	0.78(0.17,1.40)	2.51	0.01
	3.43	41.6	0.18	ratio = 1	318	1.11(0.73,1.50)	5.65	<0.00001

single bout rest duration of 15 s to 1 min produced the largest effect size: SMD = 10.9, 95% CI (0.76, 1.42), $p < 0.00001$. The subgroup with a single bout rest duration of 1–2 min had the next highest effect size: SMD = 0.69, 95% CI (0.16, 1.21), $p = 0.01$. The subgroup with a single bout rest duration of 3–4 min had the smallest effect size: SMD = 0.54, 95% CI (0.08, 1.00), $p = 0.02$. The trend observed in the effect sizes of these three subgroups suggests that longer single-bout rest duration leads to weaker intervention effects.

5) Load/rest ratio: in this subgroup, a total of 581 participants were included. The effect sizes among the three subgroups showed high heterogeneity (I^2 = 41.6%), indicating that the load/rest ratio has some influence on the relationship between high-intensity interval training and the improvement in cardiorespiratory fitness among children and adolescents with overweight or obesity. The subgroup with a load/rest ratio of 1 produced the largest effect size: SMD = 1.11, 95% CI (0.73, 1.50), $p < 0.00001$. The subgroup with a load/rest ratio less than

1 had the next highest effect size: SMD = 0.78, 95% CI (0.17, 1.40), $p = 0.01$. The subgroup with a load/rest ratio greater than 1 had the smallest effect size: SMD = 0.65, 95% CI (0.34, 0.96), $p < 0.0001$.

4 Discussion

4.1 Analysis of the effect of high-intensity interval training on cardiorespiratory fitness in children and adolescents with overweight or obesity

Overall, high-intensity interval training has a significant positive effect on cardiorespiratory fitness levels in children and adolescents with overweight or obesity. This finding is consistent with previous meta-analyses and systematic reviews (38–40). Based on the synthesis of existing meta-analyses and relevant research evidence, this study concludes that high-intensity interval training has a positive effect on improving cardiorespiratory fitness levels in children and adolescents with overweight or obesity.

Regarding the mechanisms underlying the rapid improvement of cardiorespiratory fitness through high-intensity interval training, studies in the cardiovascular and skeletal muscle domains provide some insights (Figure 5). After high-intensity exercise, plasma parameters, maximal cardiac output, stroke volume, and hemoglobin levels all show significant increases. Research by Jan Helgerud (41) and Ulrik Wisløff (42) found that after a long period of HIIT training, subjects experienced an increase in cardiac output, and their maximal oxygen uptake (VO2max) was approximately 10% higher than the baseline. Furthermore, they observed significant improvements in plasma and hemoglobin levels as well as improved endothelial function in the HIIT intervention group, leading to enhanced oxygen transport efficiency and more efficient training effects in a shorter training time. Increased mitochondrial density and improved oxygen utilization in skeletal muscles may be another important reason for the significant enhancement of cardiorespiratory fitness through HIIT. In fact, related studies have confirmed that HIIT is more effective than traditional training methods in improving skeletal muscle oxidative capacity (43). From the perspective of the molecular adaptive mechanisms of skeletal muscle oxidative capacity, HIIT can activate the activity of AMPK and MAPK exercise-responsive kinases (44, 45), and increase the mRNA quantity of PGC-1α, a transcriptional factor that regulates mitochondrial oxidative function. This joint activation leads to increased transcription of mitochondrial genes and protein accumulation, resulting in the generation of more mitochondrial substances and enhancing the aerobic and anaerobic capacities of the body, ultimately improving cardiorespiratory fitness (46). In addition to the adaptive changes in the cardiovascular system and skeletal muscles, changes in ventilatory function also play a significant role in the improvement of cardiorespiratory fitness through HIIT. In intense exercise, increasing respiratory rate and depth are effective methods to obtain more energy supply. Compared to traditional training methods, HIIT can more closely simulate the respiratory rhythm and pattern of the body under high-intensity exercise scenarios, promoting adaptive improvements in ventilatory function and enhancing cardiorespiratory fitness. Studies by Ana Carolina Corte de Araujo in Brazil and Zu XiuMing in China have supported these observations. They found that obese children and adolescents who underwent HIIT interventions for more than 12 weeks showed significantly lower systolic and diastolic blood pressure and significant improvements in respiratory parameters, such as respiratory rate and alveolar ventilation (47, 48).

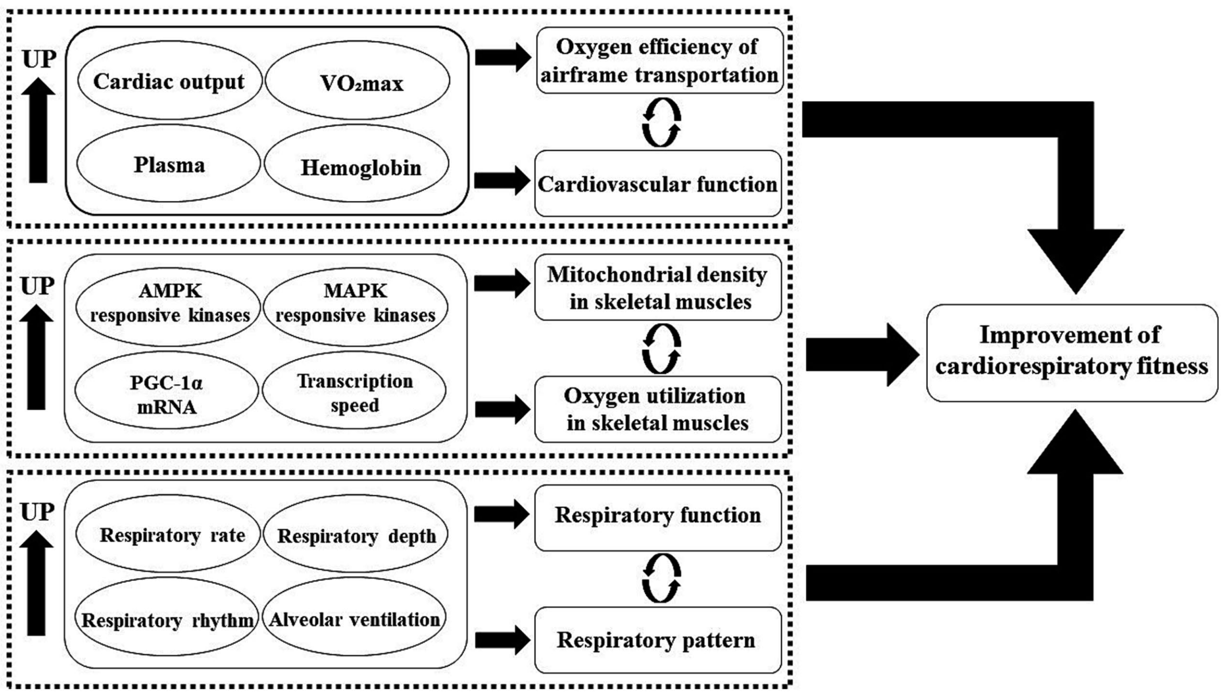

FIGURE 5
Mechanism of high-intensity interval training improving cardiorespiratory fitness in children and adolescents with overweight or obesity.

4.2 Analysis of the dose–response relationship of high-intensity interval training to improve cardiorespiratory fitness in children and adolescents with overweight or obesity

Based on the effects of intervention duration on the improvement of cardiorespiratory fitness in children and adolescents with overweight or obesity, interventions lasting more than 10 weeks had the largest effect size, followed by interventions lasting 4–8 weeks, and interventions lasting 8–10 weeks had the smallest effect size. Previous studies have shown that after a HIIT training period of more than 3 weeks, subjects' cardiorespiratory function can improve by about 3 to 33% (49). As research on the optimal dose–response relationship of HIIT progresses, it has been suggested that the training period should be extended appropriately while ensuring that the total duration of each session is not less than 16 min, and the training intensity should be maintained above 7 METs (50). From the perspective of functional adaptation, long-duration high-intensity interval training can better adjust the high-energy phosphate bonds and reserves in skeletal muscles, leading to an improved oxidative potential. Considering that children and adolescents are still in the growth and development stage, their positive metabolic adaptations to physical exercise occur rapidly but have a relatively short duration. Therefore, this study suggests that high-intensity interval training lasting more than 10 weeks is likely to have the best effect on improving cardiorespiratory fitness in children and adolescents with overweight or obesity, given that other conditions are appropriate.

In terms of the number of intervention sets, 2–8 sets resulted in the largest effect size, while 8–12 sets and more than 12 sets had moderate effect sizes, showing a gradual decrease in effect size with an increasing number of intervention sets. It indicates that the intervention effect does not improve with an increasing number of sets. This may be because excessive exercise and alternating intervals can lead to fatigue in the sympathetic and parasympathetic nervous systems, weakening the central adaptation effect and reducing the intervention effect (14). Additionally, the baseline level of physical activity in most children and adolescents with overweight or obesity is not high, so increasing the number of intervention sets will significantly raise the exercise intensity. This not only fails to enhance their physical fitness and cardiorespiratory fitness but also may harm their health. Therefore, the results suggest that high-intensity interval training with 2–8 sets achieves the best effect on improving cardiorespiratory fitness in children and adolescents with overweight or obesity, and the number of exercise sets should be controlled to avoid excessive exercise.

Regarding the single-bout exercise duration and rest duration, the largest effect sizes were observed within the range of 15 s to 1 min, while durations of 1–2 min and 3 min or more resulted in moderate effect sizes, with a gradual decrease in effect size with longer durations. This indicates that longer exercise and rest durations do not necessarily lead to better results. Prolonged exercise and rest durations deviate from the essence of high-intensity interval training and make it more similar to traditional aerobic training, which hinders the rapid and effective recovery of the body and nervous system, consequently affecting the intervention effect. This is supported by the subgroup analysis of the exercise/rest duration ratio (14). When the ratio was 1:1, the intervention effect reached its maximum. It is evident that solely emphasizing exercise duration, rest duration, or intervention frequency is not scientifically appropriate for improving cardiorespiratory fitness in children and adolescents with overweight or obesity. Only when multiple influencing factors are synergistically adapted can an ideal intervention effect be achieved (38).

Although the meta-analysis suggests that high-intensity interval training interventions lasting over 10 weeks, with a frequency of 3 times per week, 2–8 sets per session, and a ratio of exercise duration to rest duration of approximately 1:1, may be the most effective for improving cardiorespiratory fitness in children and adolescents with overweight or obesity, caution should be exercised in generalizing these dose–response recommendations for the following reasons: (1) The number of included studies in this analysis was limited, and the risk of literature omission exists due to the subjective preferences and limited experience of the researchers. Further validation of the effectiveness of these results is required. (2) The included studies were conducted in different countries and regions, and the effects may vary due to factors such as different races, social backgrounds, cultural differences, and lifestyle habits among participants. Therefore, the broad application of these dose–response recommendations in improving cardiorespiratory fitness in children and adolescents with overweight or obesity needs to be further investigated through future research and experiments, considering controlling other intervention factors, to explore the effects of different intervention doses on cardiorespiratory fitness.

4.3 Limitations and shortcomings of the study health, physics and mathematics references

This study primarily investigated the optimal dose–response relationship of high-intensity interval training for improving cardiorespiratory fitness in children and adolescents with overweight or obesity. Although the study strictly followed the PRISMA guidelines, there are still some limitations and shortcomings: (1) It is possible that not all relevant previous studies were comprehensively and carefully searched and included. (2) Despite the absence of significant result biases based on publication bias tests and sensitivity analyses, there may still be potential risks of bias considering the limited number of included studies, the shortage of intervention methods, and the low proportion of high-quality studies. (3) Some included studies used the Level 1 YO-YO test to measure outcome indicators. Although this measurement method can provide the subjects' VO2max values, the testing process may introduce uncontrollable biases, resulting in some errors in the results of this study.

5 Conclusion and recommendations

After conducting a meta-analysis of published literature to assess the impact and dose–response relationship of high-intensity interval training on cardiorespiratory fitness in children and adolescents with overweight or obesity, the study results indicate the following: (1) High-intensity interval training can significantly enhance cardiorespiratory fitness levels in children and adolescents with overweight or obesity. (2) The research suggests that, to achieve a substantial improvement in cardiorespiratory fitness in a short period, children and adolescents with overweight or obesity should engage in high-intensity interval training for more than 10 weeks, 3 times per week, with 2 to 8 sets each time. The single load time-to-interval time ratio should be maintained at around 1:1.

Additionally, based on the research results, we propose the following three recommendations: (1) Schools should provide students with sufficient space and time for physical activities, especially for children and adolescents with overweight or obesity, who require more attention. For instance, in regular physical education classes, beyond traditional activities, it is essential to integrate short-duration, multi-set, and enjoyable high-intensity interval training, considering the individual characteristics and developmental stages of overweight and obese children and adolescents. This can subtly help them enhance physical fitness and promote health. (2) After school, parents should collaboratively establish detailed plans for extracurricular physical exercises with the school and students. Encouraging and supervising students to complete the designated amount of daily physical exercise, alongside their academic tasks, will sustain and expand the positive impact of school physical education on improving students' physical fitness. (3) In the future, there should be higher-quality and larger-sample experimental studies conducted in schools. Under the premise of ensuring methodological quality, designing more detailed and feasible experimental plans will help identify intervention strategies and long-term mechanisms to enhance cardiorespiratory fitness and overall health in overweight and obese 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.

Author contributions

YD: Conceptualization, Data curation, Formal analysis, Project administration, Resources, Software, Validation, Visualization, Writing – original draft. XW: Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

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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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Body mass composition analysis as a predictor of overweight and obesity in children and adolescents

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Introduction: Body mass composition is directly related to health and its disorders are correlated with diseases such as obesity, diabetes, osteoporosis and sarcopenia. The purpose of this study was to analyze body mass composition among traditional elementary school students and ballet school students.

Methods: A total of 340 students participated in the study, 95 of whom attended ballet school and 245 elementary school students. A Tanita BC-418 MA analyzer was used to analyze body mass composition. Such body composition indices as BMI (Body Mass Index), muscle mass, fat mass, lean body mass and water content were evaluated.

Results: The results show statistical significance for BMI between high school ballet students and elementary school ballet students, as well between high school ballet students and elementary school students. Comparisons in relation to gender and schools BMI, statistical significance was obtained for: BHSw (ballet high school women) and EBSw (elementary ballet school women), BHSw and ESw (elementary school women), BHSm (ballet high school men) and EBSm (elementary ballet school men), and between BHSm and ESw. Comparing muscle mass index (kg) between ballet high school and elementary school, between ballet high school and elementary school, and between ballet high school and elementary school - statistical significance was obtained for all comparisons. Analyzing in pairwise comparisons by gender and school achieved a statistically significant difference for: BHSw and EBSw, BHSm and EBSw, EBSw and ESm. Comparing the fat mass index (kg), no significant differences were observed between the analyzed schools and the school and gender of the children studied. The value of the lean body mass index differed significantly between groups by school and gender. Comparing the water content index, statistically significant differences were obtained for school and gender.

Discussion: The body mass composition of ballet school students differs from that of standard school students.

KEYWORDS

body composition analysis, children's health, overweight and obesity factors, metabolic risk, body weight of growing children

1 Introduction

The composition of human body mass informs about the content of the various components that make up the human body. The basic components that make up human body mass include fat tissue, muscle tissue, skeletal system, organ mass, and water (1). Adequate proportions of the above-mentioned components determine a person's health and nutritional status. Also in children, despite differentiated and dynamic growth, indicators in the composition of body mass can be a predictor of future metabolic problems (2, 3). One of the key components of body composition is total water content. In a healthy person, the ratio of total water content should be 60% in men and 50% in women. In addition to being an indication of proper hydration, this parameter is also important information, for example, when dosing drugs (4). Another component mentioned is lean body mass. Fat-free body mass consists of water content, muscle mass and bone mass (5). Adipose tissue in od-responding amounts is an equally important component of body composition, but its pathological accumulation is intrinsically linked to obesity (6). Studies show that the ratio of body fat to lean body mass is one of the predictors of premature death (7). The ratio of body fat to lean body mass can also be used as one of the diagnostic factors in obesity (8). Muscle mass is an essential element for staying healthy and independent. In the aging process, we lose muscle mass and by the age of 80 we can lose up to 30% of it, and one of the main reasons for this is lack of physical activity (9). Abnormal body mass composition is associated with cardiovascular disease, cancer, diabetes or osteoporosis (10, 11). Detailed analysis of body mass composition can serve as a diagnostic method in disease entities such as obesity or sarcopenia (12) and can be a basic screening test among children and adolescents and detect abnormal weight problems at an early stage. One of the basic tools for universal weight assessment is the Body Mass Index (BMI). It is a ratio formed by dividing body weight given in kilograms by the square of height given in meters (13). The value of the BMI index allows a preliminary assessment of the nutritional status of the examinee and classify him into the appropriate group. The basic states of body mass possible to diagnose with the help of BMI are: underweight (<18.5 kg/m^2), overweight (25.0–29.9 kg/m^2), obesity (>30 kg/m^2) and normal weight (18.5–24.9 kg/m^2) (14). The trend analysis used World Health Organization (WHO) data extracted from the latest (fifth) phase of the European Childhood Obesity Surveillance Initiative (15), conducted between 2018 and 2020. The information was provided by 33 countries. The total number of children surveyed was nearly 411,000. The data collected provides information that 29% of children aged 7–9 are living with overweight or obesity (15). Projections of global rates of overweight and obesity by the World Obesity Federation (WOF) suggest that more than 4 billion individuals could be affected by 2035, compared to more than 2.6 billion in 2020. The prevalence of obesity alone is projected to increase from 14 to 24% of the population over the same period, affecting nearly 2 billion adults, children and adolescents by 2035. The trend of increasing obesity prevalence is expected to be particularly noticeable among children and adolescents, predicting an increase in the percentage of boys from 10 to 20% globally between 2020 and 2035, and a similar increase in the percentage of girls from 8 to 18% globally (16). The overarching goal in the treatment of overweight and obesity is controlled loss of excess body weight. Childhood obesity carries serious health consequences such as hypertension, type 2 diabetes, dyslipidemia, post-natal complications, polycystic ovary syndrome, respiratory dysfunction, musculoskeletal impact, renal complications, neurological complications, and overall impact on adolescence (17). However, it is important to note that underweight is an equally serious problem, as the WHO reports that more than 462 million people worldwide are affected by this problem. In 2016, being underweight contributed to one million deaths worldwide (18). Treatment of obesity should be comprehensive and may consist of factors such as lifestyle changes, cooperation with a nutritionist, pharmacotherapy and in some cases even surgical intervention (19). There are still no drugs with high efficacy in the treatment of obesity, but new ones are constantly being developed that may revolutionize the approach to this disease in the future (20). Bariatric surgery is an effective solution to reduce the risk of death from obesity and its consequences, but it is a highly invasive method and is often a last resort (19). Physical activity is primarily a preventive measure in maintaining health and normal body weight, but also modulating its level in overweight and obese people can effectively increase energy expenditure and consequently lead to the restoration of the expected body weight. Appropriate physical activity is able to improve respiratory, cardiovascular or other metabolic functions which, combined with the loss of excess body weight, will contribute to a significant improvement in overall health (21). The problem of weight disorders among children and adolescents is a global problem, and there is a need for this phenomenon to be explained in depth and precision. We undertook this topic to provide detailed information on the body composition of children of different ages and to find correlations in the various components in relation to overweight and obesity. We decided to include children practicing ballet in the study due to the fact that it is a demanding discipline that forces a high level of physical activity and fitness.

Considering the complexity of the problem, which is overweight and obesity among children and adolescents, the following research hypotheses were established:

1. Body mass index (BMI) values and body mass composition differ between elementary school students and ballet school students.
2. The composition of body weight differs between the sexes and ballet school students will be characterized by a higher incidence of normal body weight.

2 Materials and methods

2.1 Study group

The research was organized in cooperation with elementary schools and high schools. All students from these schools were invited to participate in the study. The study invited 400 participants. 43 (11%) of those invited did not agree to participate in the study, 15 (4%) were absent on the days of the study and 3 (1%) of the results were rejected (Figure 1). A total of 340 students participated in the study, 95 of whom attended ballet school (including 85 girls and 10 boys, aged 14 ± 2) and 245 elementary school students (regular school, including 122 girls and 123 boys, aged 10 ± 2) (Figure 1). In the analysis, students were divided into groups ballet high school (BHS), elementary ballet school (EHS) and elementary school (ES). The study was based on ethical guidelines (22) and the approval of the bioethics committee resolution no. 559/23 dated June 29, 2023 and participants could enter the study after providing written consent from a parent or guardian.

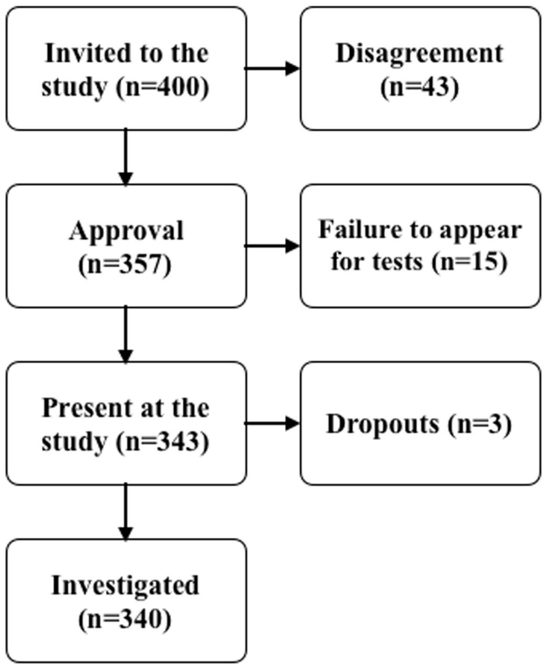

FIGURE 1
Flowchart showing the recruitment of participants.

2.2 Inclusion and exclusion criteria

Inclusion criterion: good health - no diseases of the circulatory, respiratory, digestive, nervous systems. No limitations of the musculoskeletal system that prevent standing, jumping, moving at a fast pace. Participants should be within the assumed age range of 6–18 years. Written consent of parents or guardians for participation of children and adolescents in the study. Exclusion criterion - no consent to participate in the study. The occurrence of diseases that disqualify from the study. Severe limitations of the musculoskeletal system preventing performance of tasks during the study.

2.3 Measurement of body mass composition

The study was performed using a Tanita BC-418 MA body composition analyzer (23). The apparatus used uses a non-invasive electrical bioimpedance method. This method is based on the measurement of the total electrical resistance of the body, which is the result of resistance (passive resistance) and reactance (active resistance). This measurement is carried out using a set of surface electrodes that are connected to a computer analyzer. The process uses a current of a certain frequency and intensity. The study was conducted in the morning (8:00–12:00) to reduce the risk of physical activity affecting the instrument reading. Participants entered the study dressed in light and comfortable sportswear. The test subject's task was to step barefoot onto the testing apparatus (sensors under the feet) and grasp special handles (sensors at the hands), during the measurement the test subject stood upright looking ahead.

2.4 Percentile charts

In order to accurately interpret body mass index (BMI), centile grids created by the OLA and OLAF project, which was conducted in Poland between 2007 and 2013, were used. The centile grid is a statistical tool used in medicine and scientific research to analyze growth patterns, body weight and other developmental indicators of children and adolescents. It is a type of chart or table that shows the distribution of population data according to age and gender. The centile grid helps to assess whether a person's development is in line with population norms (24, 25).

2.5 Statistical analysis

The analysis carefully examined various components of body composition, such as body weight (in kilograms), BMI (body mass divided by the square of height), body fat content (in kilograms), fat-free mass (in kilograms), muscle mass (in kilograms) and water content (in kilograms). Once the data was collected, statistical analysis was undertaken using the R package (26). It was verified whether there is a normal distribution using the Shapiro–Wilk normality test. The acquired data do not follow a normal distribution. Statistical methods and tests were used: descriptive statistics, Shapiro–Wilk test, Kruskal-Wallis test, Dunn test with adjust method Bonferroni. Dunn Test with adjust method Bonferroni was used for detailed comparison of BMI, muscle mass, fat mass and water index between schools. The Kruskal-Wallis test and Dunn test were used for multiple comparisons to compare BMI, muscle mass, fat mass and water indexes for students forming groups by school and gender. The results were presented using tables and graphs.

3 Results

First, descriptive statistics of BMI, water (kg), muscle mass (kg), fat mass (kg) and lean body mass (kg) were determined for ballet school (elementary and high school) and elementary school (Table 1). The next step in the statistical analysis was to use the Dunn test with the Bonferroni adjust method to compare each of the body mass composition indices between schools in detail. A check was then made with the Shapiro–Wilk Normality test to see if the data were subject to a normal distribution. The next step in the analysis was to compare body mass composition indices for students forming groups by school and gender. Basic scoring statistics were determined (Table 2), the assumption of normality of the data was checked, and the Kruskal-Wallis test and Dunn's test of multiple comparisons were applied. Next, it was checked whether the conditions of normal distribution were met for the analyzed indicators by gender. Since the conditions of normal distribution were not met, the Kruskal-Wallis test was applied. Pairwise comparisons were then made for all indicators in relation to gender and schools (Tables 3, 4).

3.1 Body mass index (BMI)

Among ballet school students (elementary and high school), 81% were of normal weight while 19% were underweight. No

TABLE 1 Descriptive statistics of BMI (body mass index), TBW (total body water), LBM (lean body mass), FM (fat mass) MM (muscle mass) students of elementary school, ballet elementary school and ballet high school.

Index	Group	*n*	min	max	Median	iqr	mean	sd	se	ci
BMI	BHS	27	15.5	22.7	19.2	2.25	19.0	1.84	0.353	0.727
	EBS	68	13.2	23.2	17.0	2.52	17.5	2.03	0.246	0.491
	ES	245	12.5	38.3	17.1	4.80	18.5	4.42	0.282	0.556
TBW	BHS	27	29.6	56.0	40.7	3.20	41.4	5.99	1.150	2.370
	EBS	68	21.5	45.1	33.3	9.22	32.2	5.39	0.654	1.310
	ES	245	10.8	48.0	20.6	8.90	22.3	7.22	0.461	0.909
LBM	BHS	27	31.2	58.6	42.9	3.55	43.5	6.23	1.200	2.460
	EBS	68	22.4	47.5	35.0	9.60	33.8	5.67	0.688	1.370
	ES	245	14.7	65.6	28.2	12.2	30.5	9.86	0.630	1.240
FM	BHS	27	5.5	17.2	9.6	3.35	9.8	2.96	0.570	1.170
	EBS	68	4.6	17.3	8.5	3.02	8.9	2.93	0.355	0.709
	ES	245	2.8	46.3	7.7	5.70	9.9	6.79	0.434	0.855
MM	BHS	27	22.8	42.9	31.4	2.55	31.9	4.57	0.879	1.810
	EBS	68	16.4	34.8	25.6	7.00	24.8	4.15	0.503	1.000
	ES	245	14.1	62.6	27.0	11.3	29.2	9.36	0.598	1.180

BHS, ballet high school; EBS, elementary ballet school; ES, elementary school; min, minimum; max, maximum; iqr, interquartile range; sd, standard deviation; se, standard error; ci, confidence interval.

students were observed whose BMI indicated they were overweight or obese. In elementary school, 61% of students were characterized by normal weight, 20% were overweight, 7% were obese while 12% were underweight. Since normal distribution does not occur when comparing the BMI results of the three schools analyzed, the Kruskal-Wallis test was applied and $p = 0.022$ was obtained (Figure 2). The highest number of abnormal BMI results was observed in the elementary school. 3Statistical significance was obtained for BMI between high school ballet students and elementary school ballet students $p = 0.0227$ (Table 5), as well as statistical significance between high school ballet students and elementary school students $p = 0.0301$ (Table 5). In contrast, there is no statistical significance of BMI between sub-primary ballet school students and elementary school students. Analyzing BMI by gender, a $p = 0.04$ value was obtained (Figure 3). For pairwise comparisons in relation to gender and schools BMI, statistical significance was obtained for: BHSw and EBSw ($p = 0.0238$), BHSw and ESw ($p = 0.0153$), BHSm and EBSm ($p = 0.0379$), and between BHSm and ESw ($p = 0.0351$) (Table 3).

3.2 Muscle mass index

Comparing the muscle mass index, a $p = 0.0001$ was obtained (Figure 4). The schools were significantly different from each other and the largest difference was shown between ballet high school and ballet elementary school. In comparing the muscle mass index (kg) between all schools, statistical significance was obtained. Between ballet high school and elementary school $p < 0.05$, ballet high school and elementary school $p = 0.009$, ballet high school and elementary school $p = 0.003$ (Table 5). Analyzing the muscle mass index (kg) pairwise comparisons in relation to gender and schools, three combinations of groups achieved a statistically significant difference: BHSw and EBSw $p = 0.001$, BHSm and EBSw $p = 0.007$, EBSw and ESm $p < 0.001$ (Table 4).

3.3 Fat mass

Comparing the fat mass index, a $p = 0.086$ was obtained (Figure 5). The largest number of results significantly deviating in the fat mass level was recorded in the classical elementary school. Comparing the fat mass index (kg), no significant differences were observed between the analyzed schools (Table 5). There were no significant differences $p = 0.052$ in the comparison of fat mass considering the school and gender of the children studied (Figure 6). However, the most high scores in fat mass (kg) were observed in girls and boys from elementary school. In a comparison of fat mass index (kg), none of the group combinations achieved a difference at the level of statistical significance.

3.4 Lean body mass

Comparing the lean body mass index, a $p < 0.0001$ was obtained (Figure 7). The schools were significantly different from each other and the largest difference was shown between ballet high school and ballet elementary school. Statistical significance was obtained in the comparison of lean body mass index (kg) between all schools. Between ballet high school and ballet elementary school $p < 0.05$, ballet high school and elementary school $p < 0.05$, ballet high school and elementary school $p < 0.05$ (Table 5). The value of the lean body mass index differed significantly between groups by school and gender $p < 0.0001$ (Figure 8). The largest difference was observed between ballet high school girls and elementary school girls and elementary school boys. The results of the lean body mass index (kg) show

TABLE 2 Descriptive statistics for BMI by gender in schools.

Index	Group	*n*	min	max	median	iqr	Mean	sd	se	ci
BMI	BHSw	23	15.5	22.4	19.1	2.25	18.8	1.80	0.375	0.78
	BHSm	4	19.2	22.7	19.8	1.25	20.4	1.58	0.788	2.51
	EBSw	62	13.2	23.2	17.0	2.65	17.4	2.08	0.265	0.53
	EBSm	6	16.5	20.2	17.4	1.48	17.8	1.38	0.564	1.45
	ESw	122	12.6	32.2	17.0	4.18	18.0	3.96	0.358	0.71
	ESm	123	12.5	38.3	17.5	5.10	19.0	4.80	0.433	0.86
TBW	BHSw	23	29.6	48.2	40.5	2.60	39.6	4.14	0.864	1.79
	BHSm	4	46.8	56.0	52.0	6.28	51.7	4.35	2.170	6.92
	EBSw	62	21.5	45.1	32.8	8.82	31.7	5.35	0.679	1.36
	EBSm	6	34.6	40.9	36.8	3.32	37.4	2.45	1.000	2.57
	ESw	122	10.8	40.6	20.5	8.18	21.3	5.92	0.536	1.06
	ESm	123	12.2	48.0	21.4	11.4	23.4	8.20	0.739	1.46
MM	BHSw	23	22.8	37.3	31.3	2.00	30.5	3.22	0.672	1.40
	BHSm	4	35.8	42.9	39.8	4.85	39.6	3.36	1.680	5.35
	EBSw	62	16.4	34.8	25.2	6.88	24.4	4.14	0.526	1.05
	EBSm	6	26.4	31.3	28.0	2.55	28.5	1.90	0.777	2.00
	ESw	122	14.1	52.8	26.6	10.6	27.6	7.64	0.692	1.37
	ESm	123	16.1	62.6	28.0	14.8	30.7	10.6	0.956	1.89
FM	BHSw	23	5.5	17.2	9.7	2.80	10.1	3.00	0.626	1.30
	BHSm	4	6.4	10.9	7.2	2.17	7.92	2.10	1.050	3.34
	EBSw	62	4.6	17.3	8.8	2.78	9.08	2.94	0.373	0.75
	EBSm	6	5.1	10.6	6.4	1.98	6.87	2.06	0.842	2.17
	ESw	122	3.3	35.5	8.0	5.78	9.87	5.77	0.523	1.03
	ESm	123	2.8	46.3	7.3	5.35	9.86	7.70	0.694	1.37
LBM	BHSw	23	31.2	50.9	42.7	2.75	41.7	4.39	0.915	1.90
	BHSm	4	48.9	58.6	54.4	6.55	54.1	4.57	2.280	7.27
	EBSw	62	22.4	47.5	34.4	9.43	33.4	5.65	0.718	1.44
	EBSm	6	36.0	42.8	38.2	3.48	39.0	2.63	1.070	2.76
	ESw	122	14.7	55.5	28.0	11.2	29.0	8.09	0.732	1.45
	ESm	123	16.6	65.6	29.2	15.6	32.0	11.2	1.010	2.00

Blk, ballet high school women; blm, ballet high school men; bpk, ballet elementary school men; bpk, ballet elementary school women; pk, elementary school women; pm, elementary school men; min, minimum; max, maximum; iqr, interquartile range; sd, standard deviation; se, standard error; ci, confidence interval.

significant statistical differences in the following pairs of combinations: between the BHSw group and the ESw group, a *p*-value of $p < 0.05$ was obtained, between the BHSw group and the ESm group, a *p*-value of $p < 0.05$ was obtained, between the BHSm group and the ESw group, a *p*-value of $p < 0.05$ was obtained, between the BHSm group and the ESm group, a *p*-value of $p < 0.05$ was obtained, between the EBSw group and the ESw group, a *p*-value of $p < 0.05$ was obtained, between the EBSw group and the ESm group, a *p*-value of $p < 0.05$ was obtained, between the EBSm group and the ESw group, a *p*-value of $p < 0.05$ was obtained, between the EBSm group and the ESm group, a *p*-value of $p < 0.05$ was obtained (Table 4).

3.5 Total body water

Comparing the water content index, a $p < 0.0001$ was obtained (Figure 9). The schools were significantly different from each other and the largest difference was shown between the two ballet schools and the elementary school. In comparing the water content index (kg) between all schools, statistical significance was obtained. Between ballet high school and ballet elementary school $p < 0.05$, ballet high school and elementary school $p < 0.05$, ballet elementary school and elementary school $p < 0.05$ (Table 5). Comparing water content (kg) by school and gender, a $p < 0.0001$ was obtained (Figure 10). The biggest difference was observed between the group of girls and boys from the ballet high school and elementary school and the group of girls and boys from the primary school. Both boys and girls from the elementary school had the lowest body water content of all the groups studied. There was a significant difference between women from a ballet high school and women from a ballet elementary school, men from a ballet high school and men from a sub-primary ballet school, and between women from a primary ballet school and men from an elementary school $p < 0.0001$ (Figure 11). For the analyzed water quantity index (expressed in kilograms), statistical significance was

TABLE 3 Comparison of BMI and TBW in relation to gender and schools.

Index	group1	group2	n1	n2	Statistic	*p*-value	Significance
BMI	BHSw	BHSm	23	4	0.958	0.338	ns
	BHSw	EBSw	23	62	−2.26	0.024	*
	BHSw	EBSm	23	6	−0.683	0.494	ns
	BHSw	ESw	23	122	−2.43	0.015	*
	BHSw	ESm	23	123	−1.50	0.135	ns
	BHSm	EBSw	4	62	−2.08	0.038	*
	BHSm	EBSm	4	6	−1.29	0.197	ns
	BHSm	ESw	4	122	−2.11	0.035	*
	BHSm	ESm	4	123	−1.69	0.091	ns
	EBSw	EBSm	62	6	0.558	0.577	ns
	EBSw	ESw	62	122	0.0018	0.999	ns
	EBSw	ESm	62	123	1.36	0.174	ns
	EBSm	ESw	6	122	−0.570	0.569	ns
	EBSm	ESm	6	123	−0.0639	0.949	ns
	ESw	ESm	122	123	1.66	0.098	ns
TBW	BHSw	BHSm	23	4	0.583	1.000	ns
	BHSw	EBSw	23	62	−2.60	0.139	ns
	BHSw	EBSm	23	6	−0.265	1.000	ns
	BHSw	ESw	23	122	−8.25	<0.0001	****
	BHSw	ESm	23	123	−7.31	<0.0001	****
	BHSm	EBSw	4	62	−1.84	0.978	ns
	BHSm	EBSm	4	6	−0.678	1.000	ns
	BHSm	ESw	4	122	−4.31	<0.001	***
	BHSm	ESm	4	123	−3.89	0.002	**
	EBSw	EBSm	62	6	1.20	1.000	ns
	EBSw	ESw	62	122	−7.95	<0.0001	****
	EBSw	ESm	62	123	−6.59	<0.0001	****
	EBSm	ESw	6	122	−4.19	<0.0001	***
	EBSm	ESm	6	123	−3.68	0.003	**
	ESw	ESm	122	123	1.67	1.000	ns

BHSw, ballet high school women; BHSm, ballet high school men; EBSm, elementary ballet school men; EBSw, elementary ballet school women; ESw, elementary school women; ESm, elementary school men; *p*, *p*-value; *p*.adj, adjusted *p*-value; *p*.adj.signif, adjusted *p*-value with significance; ns, not significant; *, significant codes; – ****, *p*-value <0.0001; ***, *p*-value <0.001; **, *p*-value <0.01; *, *p*-value <0.05.

obtained in the context of different combinations of variables: BHSw and ESw ($p < 0.05$), BHSw and ESm ($p < 0.05$), BHSm versus ESw ($p < 0.05$), BHSm and ESm ($p < 0.05$), EBSw and ESw ($p < 0.05$), EBSw and ESm ($p < 0.05$), EBSm and ESw ($p < 0.05$) and EBSm and ESm ($p < 0.05$) (Table 3).

4 Discussion

In the face of the pandemic of problems with excessive body weight, constant monitoring of children and adolescents with body composition analyzers is justified. The simplicity of testing with the analyzer with simultaneous broad diagnostic capabilities makes this type of testing an excellent screening tool and provides information about the health of the population.

The results obtained showed that the lowest BMI values were characterized by elementary ballet school students, followed by elementary school students and the highest by high school ballet students. Although the averaged BMI scores did not differ significantly from each other, significantly more scores above the acceptable healthy BMI level and indicative of overweight and obesity were observed in elementary school. Among ballet school students, not a single individual was observed characterized as overweight or obese, but 19% were underweight. The biggest difference was noted in the level of body water content. Children from both high school and elementary ballet school had significantly better hydration status compared to traditional elementary school. There were no significant differences in body fat among all the groups of children studied, but, as with BMI, the largest number of cases with increased body fat mass were found in elementary school. Both the index of muscle mass and

TABLE 4 Comparison of MM and LBM in relation to gender and schools.

Index	Group1	group2	n1	n2	Statistic	p-value	Significance
MM	BHSw	BHSm	23	4	1.48	1.000	ns
	BHSw	EBSw	23	62	−4.11	<0.0001	***
	BHSw	EBSm	23	6	−0.61	1.000	ns
	BHSw	ESw	23	122	−2.63	0.130	ns
	BHSw	ESm	23	123	−1.65	1.000	ns
	BHSm	EBSw	4	62	−3.50	0.007	**
	BHSm	EBSm	4	6	−1.68	1.000	ns
	BHSm	ESw	4	122	−2.75	0.089	ns
	BHSm	ESm	4	123	−2.32	0.309	ns
	EBSw	EBSm	62	6	1.69	1.000	ns
	EBSw	ESw	62	122	2.60	0.138	ns
	EBSw	ESm	62	123	4.04	<0.0001	***
	EBSm	ESw	6	122	−0.76	1.000	ns
	EBSm	ESm	6	123	−0.22	1.000	ns
	ESw	ESm	122	123	1.74	1.000	ns
LBM	BHSw	BHSm	23	4	0.97	1.000	ns
	BHSw	EBSw	23	62	−3.58	0.005	**
	BHSw	EBSm	23	6	−0.47	1,000	ns
	BHSw	ESw	23	122	−6.31	<0.0001	****
	BHSw	ESm	23	123	−5.29	<0.0001	****
	BHSm	EBSw	4	62	−2.71	0.099	ns
	BHSm	EBSm	4	6	−1.15	1.000	ns
	BHSm	ESw	4	122	−3.86	0.002	**
	BHSm	ESm	4	123	−3.40	0.010	*
	EBSw	EBSm	62	6	1.54	1.000	ns
	EBSw	ESw	62	122	−3.59	0.005	**
	EBSw	ESm	62	123	−2.11	0.527	ns
	EBSm	ESw	6	122	−2.91	0.054	ns
	EBSm	ESm	6	123	−2.36	0.274	ns
	ESw	ESm	122	123	1.81	1,000	ns

BHSw, ballet high school women; BHSm, ballet high school men; EBSm, elementary ballet school men; EBSw, elementary ballet school women; ESw, elementary school women; ESm, elementary school men; *p*, *p*-value; *p*.adj, adjusted *p*-value; *p*.adj.signif, adjusted *p*-value with significance; ns, not significant; *, significant.

lean body mass differed significantly in ballet high school boys compared to all other groups. However, these indices reportedly achieved levels among both ballet and traditional elementary school students. Ballet school students (elementary and high school) were more likely to have a more stable body mass composition compared to classical elementary school, which may indicate the positive impact of additional physical activity among students. It should also be noted that greater gender differences were observed in older children (high school) compared to elementary school-aged children.

The study by Karklin et al. examined children aged 9 and 10 years ($n = 320$). The results of this study show that 30% of the children studied were characterized by abnormal body weight. The authors point out that it was not only overweight and obesity that was a problem, but underweight, which was equally common (27). The study by Kobylinska et al. found similar results in terms of BMI in traditional elementary school students, with 57.5% of the subjects having normal body weight, 21.5% overweight, and 21% underweight. The study by Guzel et al. assessed children's physical activity levels ($n = 234$ boys, 224 girls) and body mass composition. They found that higher levels of physical activity were associated with lower body fat mass in each age group regardless of gender which does not match the results obtained in our study (28). In the Mateo-Orcajada study, participants aged 12–16 years ($n = 791$) compared anthropometric characteristics including body composition of physically active and inactive individuals. As in our study, significant differences were noted in almost every indicator between the active and inactive groups (29). The study by Baran et al. evaluated children aged 6–17 years ($n = 69$). They found that higher levels of physical activity were associated with greater muscle mass and lean body mass among the study participants (30). Orntoft et al. studied 544 children aged 10–12 years by assessing

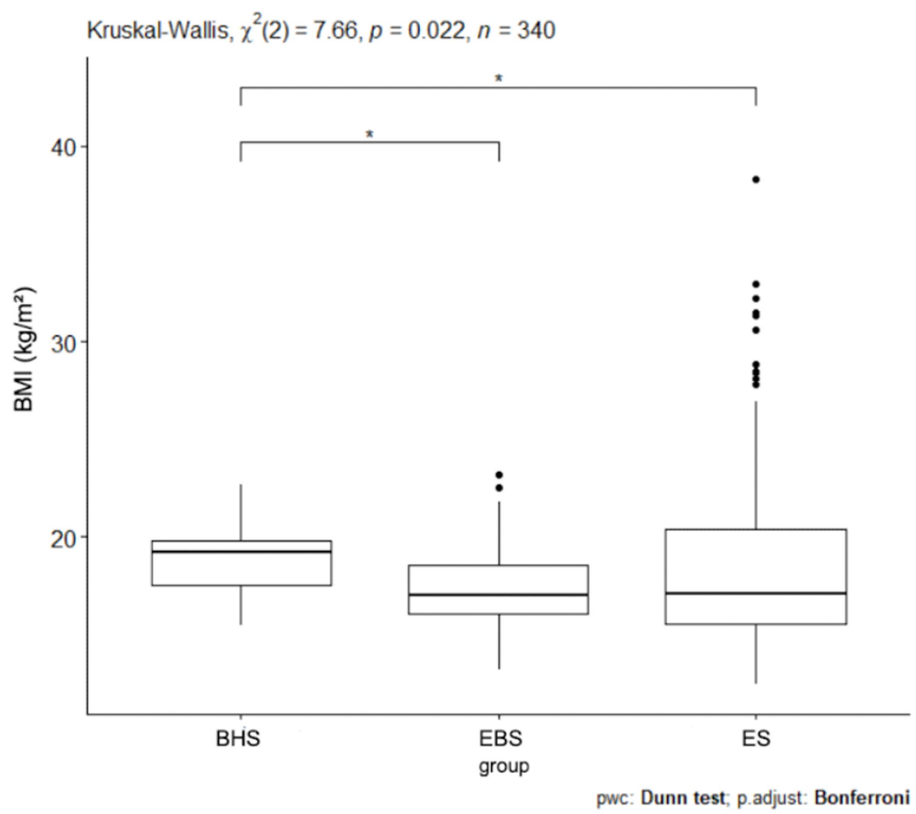

FIGURE 2
BMI values for ballet (elementary and high school) and regular elementary school students. BHS, ballet high school; EBS, elementary ballet school; ES, elementary school; BMI, body mass index.

TABLE 5 Comparison of BMI, TBW, MM, FM, and LMB between schools.

Index	Group 1	group 2	n1	n2	Statistic	*p*-value	Significance
BMI	BHS	EBS	27	68	−2.67	0.023	*
	BHS	ES	27	245	−2.58	0.030	*
	EBS	ES	68	245	0.62	1.000	ns
TBW	BHS	EBS	27	68	−2.80	0.015	*
	BHS	ES	27	245	−8.95	<0.0001	****
	EBS	ES	68	245	−8.59	<0.0001	****
MM	BHS	EBS	27	68	−4.65	<0.0001	****
	BHS	ES	27	245	−2.98	0.009	**
	EBS	ES	68	245	3.31	0.003	**
FM	BHS	EBS	27	68	−1.27	0.612	ns
	BHS	ES	27	245	−2.10	0.107	ns
	EBS	ES	68	245	−1.00	0.952	ns
LBM	BHS	EBS	27	68	−3.93	<0.001	***
	BHS	ES	27	245	−6.88	<0.0001	****
	EBS	ES	68	245	−3.66	<0.001	***

BHS, ballet high school; EBS, elementary ballet school; ES, elementary school; *p*, *p*-value; *p*.adj, adjusted *p*-value; *p*.adj.signif, adjusted *p*-value with significance; ns, not significant, *, significant codes; – ****, *p*-value <0.0001, ***, *p*-value <0.001; **, *p*-value <0.01; *, *p*-value <0.05.

their physical fitness and body mass composition. The subjects were divided into 4 activity groups: soccer, other "ball" sports, other sports or no physical activity. The body mass composition of the subjects did not differ statistically significantly between the groups. The group with the highest BMI, the highest body fat content, and the lowest muscle content was characterized by the group that did not play any sports

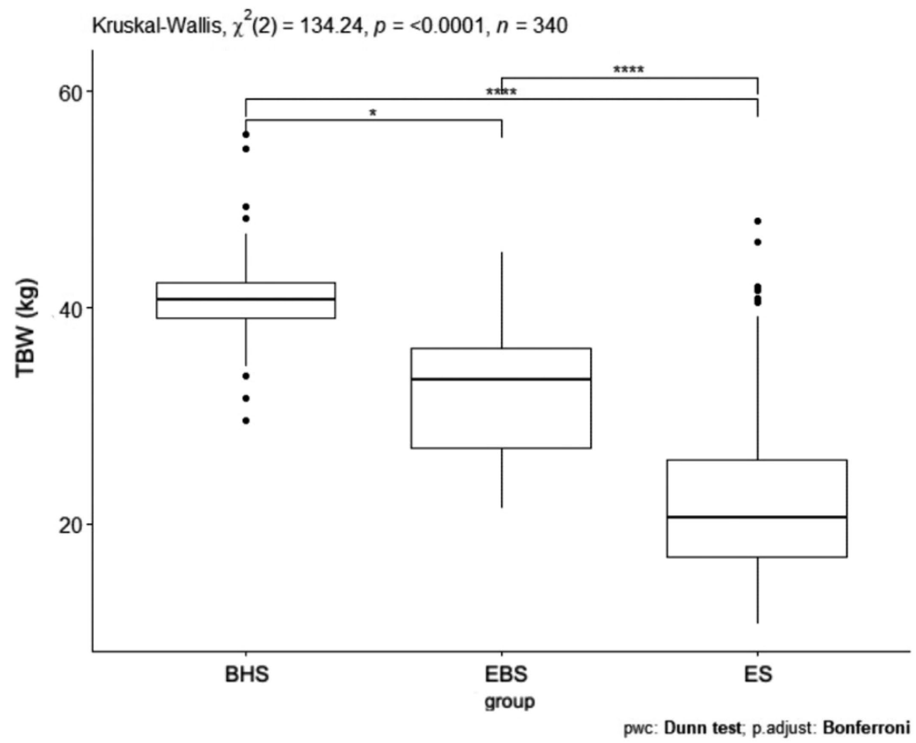

FIGURE 3
BMI values by sex in ballet and regular elementary school, BHSw, high school ballet women; BHSm, high school ballet men; EBSw, elementary ballet school women; EBSm, elementary ballet school men; ESw, elementary school women; ESm, elementary school men.

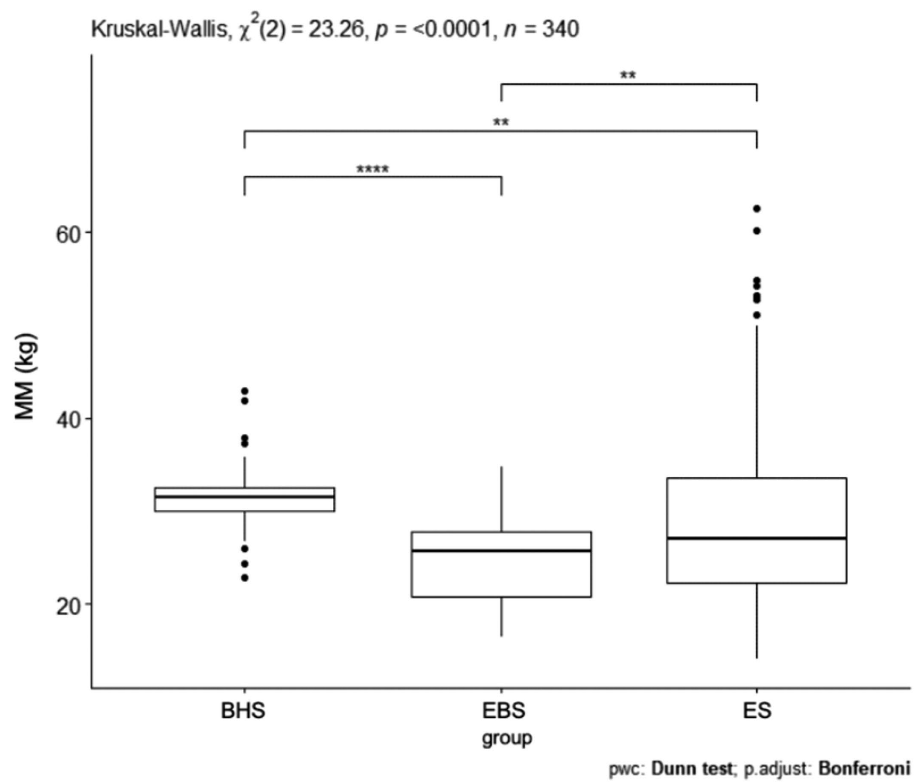

FIGURE 4
MM values for ballet (elementary and high school) and regular elementary school students. BHS, ballet high school; EBS, elementary ballet school; ES, elementary school; MM (muscle mass).

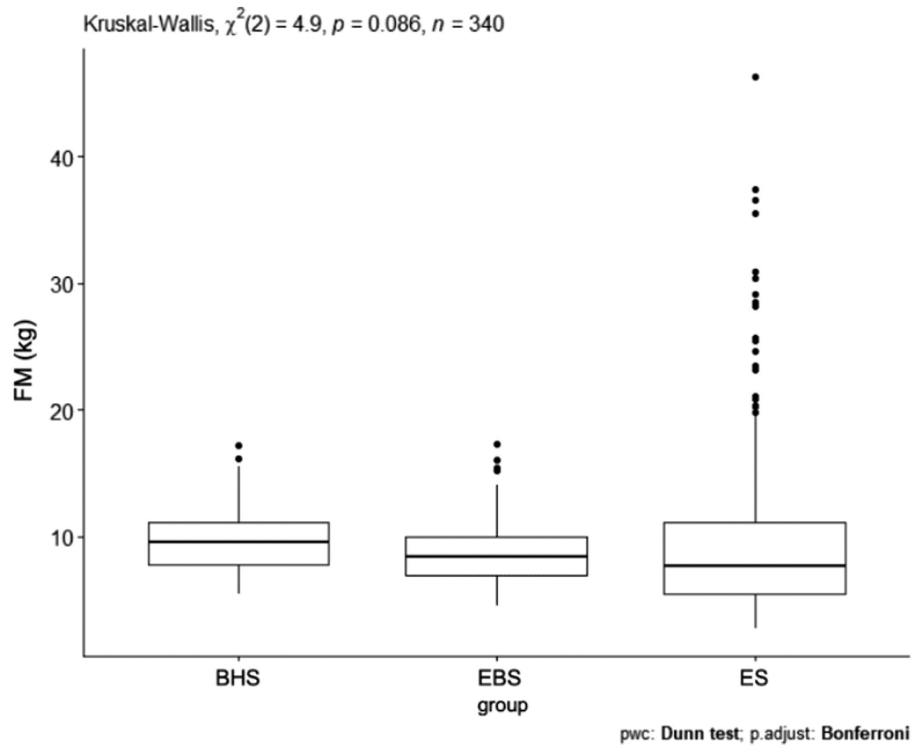

FIGURE 5
FM values for ballet (elementary and high school) and regular elementary school students. BHS, ballet high school; EBS, elementary ballet school; ES, elementary school; FM (fat mass).

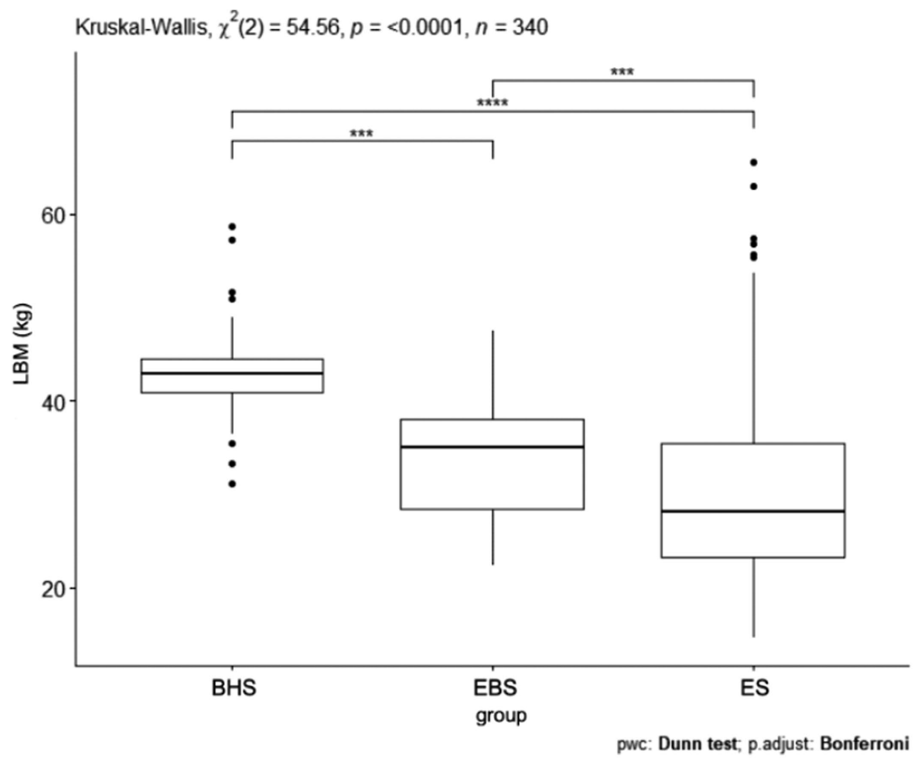

FIGURE 6
FM values by sex in ballet and regular elementary school; BHSw, high school ballet women; BHSm, high school ballet men; EBSw, elementary ballet school women; EBSm, elementary ballet school men; ESw, elementary school women; ESm, elementary school men.

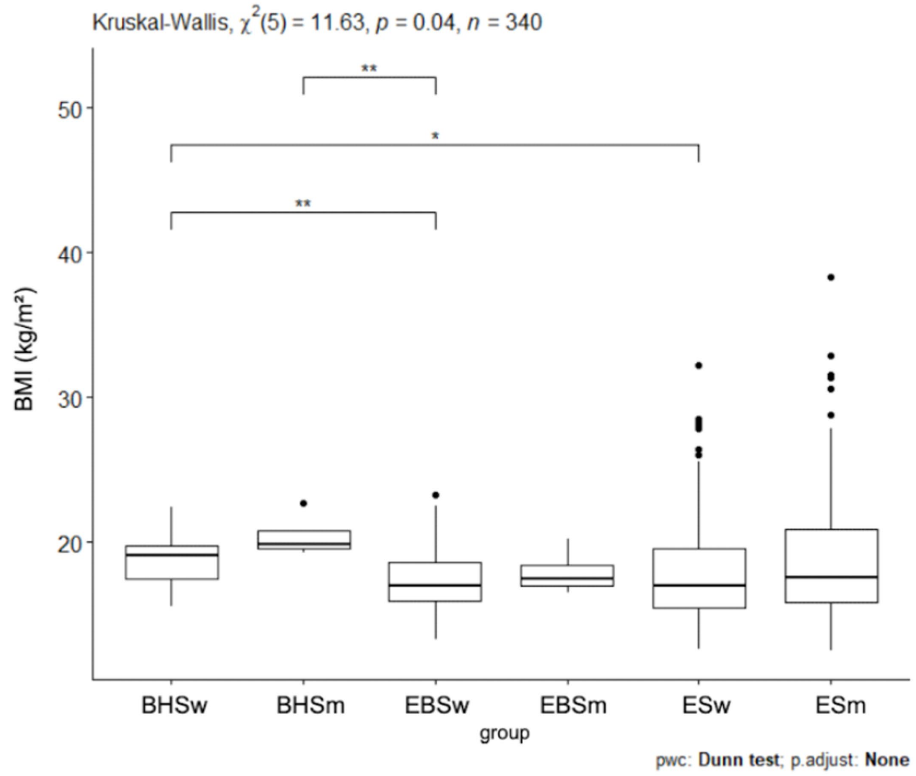

FIGURE 7
LBM values for ballet (elementary and high school) and regular elementary school students. BHS, ballet high school; EBS, elementary ballet school; ES, elementary school; LBM (lean body mass).

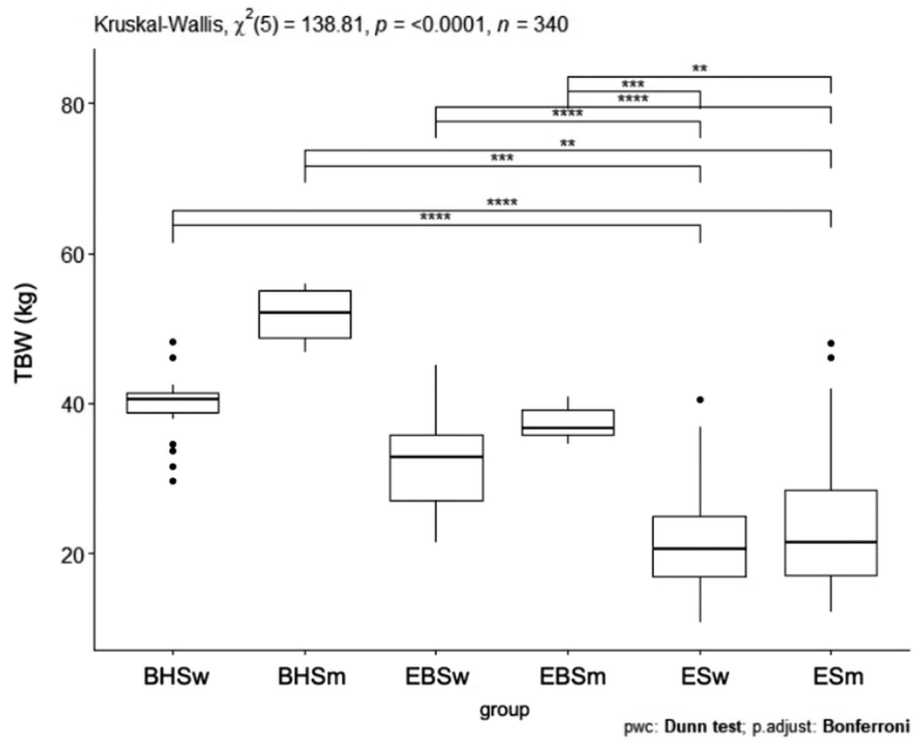

FIGURE 8
LBM values by sex in ballet and regular elementary school; BHSw, high school ballet women; BHSm, high school ballet men; EBSw, elementary ballet school women; EBSm, elementary ballet school men; ESw, elementary school women; ESm, elementary school men.

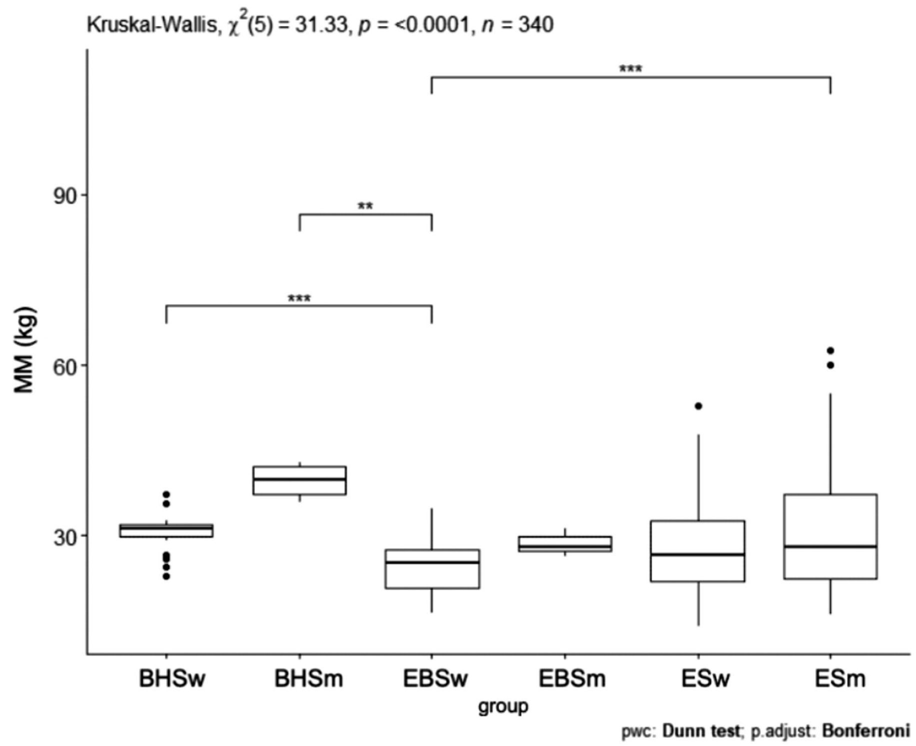

FIGURE 9
TBW values for ballet (elementary and high school) and regular elementary school students. BHS, ballet high school; EBS, elementary ballet school; ES, elementary school; MM (muscle mass).

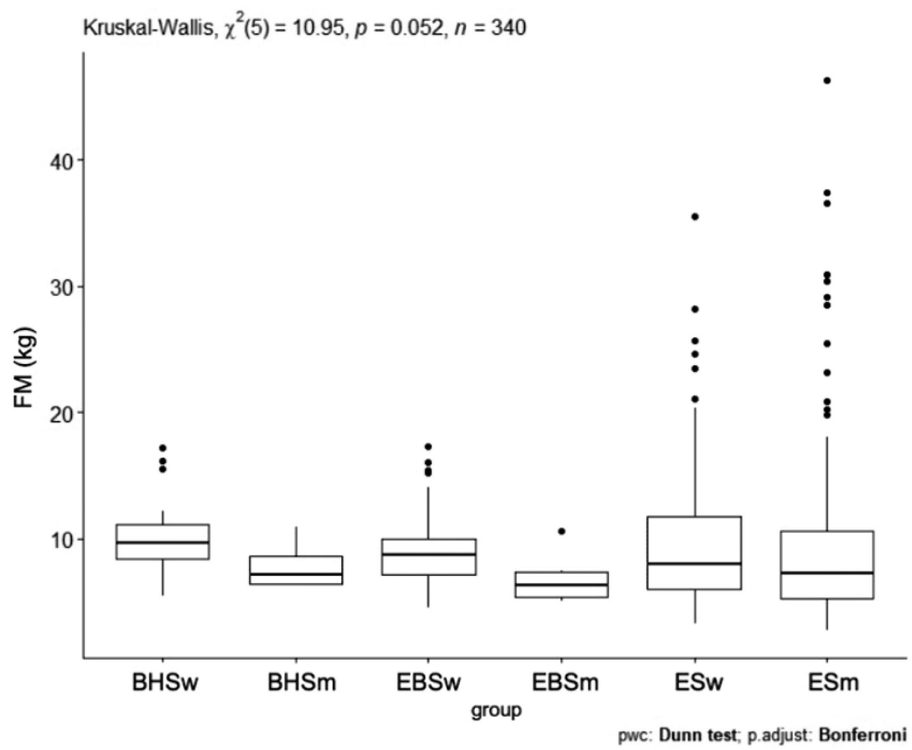

FIGURE 10
TBW values by sex in ballet and regular elementary school; BHSw, high school ballet women; BHSm, high school ballet men; EBSw, elementary ballet school women; EBSm, elementary ballet school men; ESw, elementary school women; ESm, elementary school men.

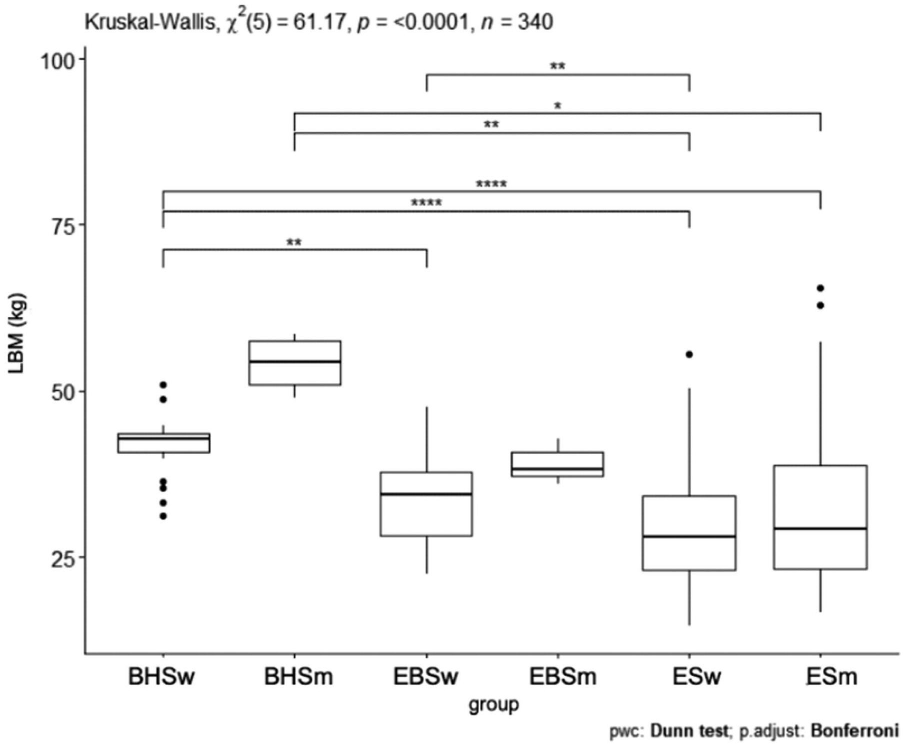

FIGURE 11
MM values by sex in ballet and regular elementary school; BHSw, high school ballet women; BHSm, high school ballet men; EBSw, elementary ballet school women; EBSm, elementary ballet school men; ESw, elementary school women; ESm, elementary school men.

(31). The study by Kazemi et al. included 150 female students (75 active and 75 non-active), in whom they also looked for differences in body mass composition. Statistically significant differences resulted in all body mass composition parameters assessed (32). In a similar study comparing the body mass composition of 337 female students by dividing them into active and inactive also a significant difference was observed in almost all body composition parameters. The difference was not observed only in lean body mass (kg), which is opposite to our work, where lean body mass was one of the most different parameters (33). A meta-analysis by Mateo-Orcajada clearly confirms the inconsistency of results regarding differences in body weight composition among children in different groups (34).

Given the great importance of normal body weight in childhood orkes on the incidence of weight problems in adulthood (35), the results presented here may significantly influence the recognition of the problem. The hypotheses we have put forward have been confirmed. The results presented will provide a better understanding of weight disorders among children and adolescents. In addition, they can be used by researchers and practitioners to plan programs to address weight problems.

5 Limitations

A limitation of the above work was that the group of students attending high school was too small and there was no comparison group of the same age. Another limitation was the lack of reference to other forms of physical activity, which translated into a lack of comparison between children and adolescents who play different sports. In addition, it would be a good idea to take measurements in preschool-aged children and repeat them periodically throughout adolescence.

6 Conclusion

All hypotheses were confirmed. BMI value and body mass composition differed between elementary school students and ballet school students. Body mass composition differed between genders and ballet school students were characterized by a higher prevalence of normal body mass. There is a lack of consistent evidence determining the body mass composition of specific groups in both children and adults, so further research is needed in this area.

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 humans were approved by Komisja Bioetyczna przy Uniwersytecie Medycznym im. Karola Marcinkowskiego w Poznaniu ul. Bukowska 70, pok. A204 60-812

Poznań. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

BA: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. IS: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. MW: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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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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Integrated neuromuscular training intervention applied in schools induces a higher increase in salivary high molecular weight adiponectin and a more favorable body mass index, cardiorespiratory fitness and muscle strength in children as compared to the traditional physical education classes

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Background: High-molecular-weight adiponectin (HMW-adiponectin) is a cardio-metabolic health protector. Objectives: (1) to compare body mass index (BMI), cardiorespiratory fitness (CRF) and muscle strength (MS) in healthy school-children depending on their baseline salivary-HMW-adiponectin concentration; and (2) to apply a 3-month integrated neuromuscular training (INT) and evaluate its effects on salivary-HMW-adiponectin concentration, BMI, CRF and MS in the same children. Additional goal: to identify if any potential changes during the 3-month period may be related to a potential change in salivary-HMW-adiponectin concentration.

Methods: Ninety children (7.4 ± 0.3 years) were recruited in primary schools and randomly allocated into control or intervention group. The intervention consisted of a 3-month INT applied during physical education (PE) classes, twice-weekly, while the control group had traditional PE classes. Body mass and height were measured, BMI was calculated and HMW-adiponectin was quantified in saliva. To assess CRF and MS, 800 m-run and hand-dynamometry were applied, respectively. All measurements were performed twice, at baseline and after 3 months.

Results: Children with higher baseline salivary-HMW-adiponectin have more favorable BMI ($p = 0.006$) and slightly higher CRF ($p = 0.017$) in comparison to the children with lower baseline salivary-HMW-adiponectin. There were no big changes after the 3-month-period neither in the control, nor the INT group. However, it is worthy to note that the INT induced slightly higher increase in salivary-HMW-adiponectin ($p = 0.007$), and a slightly higher improvement in BMI ($p = 0.028$), CRF ($p = 0.043$) and MS ($p = 0.003$), as compared to the traditional PE classes. Finally, the INT-induced improvement in CRF was associated with the increased post-salivary-HMW-adiponectin concentration ($p = 0.022$).

Conclusion: Main findings may suggest the potential utility of an INT as a cost-effective strategy that can be applied in schools to induce cardio-protective effects in school-children.

KEYWORDS

integrated neuromuscular training, schools, high molecular weight adiponectin, saliva, children, cardio-metabolic health

1 Introduction

Adiponectin is a protein encoded by the *Adipoq* gene in humans, mainly produced by the adipose tissue (1, 2), but it can also be secreted by the skeletal muscle, cardiac muscle, salivary gland epithelial cells and other tissues (2–4). Salivary adiponectin is involved in the regulation of the local immune response (5). Nowadays, salivary adiponectin is becoming a promising diagnostic marker for cardio-metabolic diseases especially in children, mainly because saliva collection is a non-invasive diagnostic procedure (6), and it does not require specially trained personnel for sampling procedure (7). Even though there is a modest degree of overlap between salivary and plasma proteomes (only 27%), the analysis of distribution across Gene Ontology categories, including molecular function, biological processes and cellular components, revealed some similarities (8). Moreover, it has been shown that approximately 40% of the proteins identified as candidate markers for cardiovascular diseases, stroke and cancer were detectable in saliva (8). In addition, previous studies reported a weak correlation between salivary and plasma adiponectin levels in patients with metabolic syndrome, and a moderate correlation in healthy adult population, thus requesting further attention in this topic and exploration of the potential utility of salivary adiponectin in diagnostic purposes (9, 10).

Adiponectin can be found in different molecular weight forms among which high-molecular-weight (HMW) adiponectin is considered to be the most biologically active form in terms of glucose homeostasis (11). Moreover, HMW-adiponectin has been shown to be a cardio-metabolic health protector due to its vasodilator, anti-apoptotic and anti-inflammatory effects (12, 13). It acts as a messenger providing an inter-organs crosstalk, regulating lipid and glucose metabolism, modulating thermogenesis and energy expenditure, and increasing insulin sensitivity (1, 14). High HMW-adiponectin levels are related to more favorable body composition (15), whereas overweight individuals, individuals with obesity, and cardiovascular disease patients have low HMW-adiponectin levels (16, 17).

Interestingly, an increase in HMW-adiponectin concentration was observed after acute and chronic physical exercise with intensities ranging from moderate to vigorous (12, 18–20). In addition, higher circulating adiponectin was reported in physically active compared to inactive individuals (21). Therefore, HMW-adiponectin is considered as a potential marker mediating the health-beneficial effects induced by physical exercise (14). However, recent studies provided inconsistent evidence, reporting unchanged adiponectin levels after exercise (14, 22).

Integrated neuromuscular training (INT) is a type of physical exercise—a specifically tailored training program with moderate intensity that improves health and fundamental motor skills (23–25). It has also been recognized as an innovative approach for school-aged children, and an effective strategy for enrichment of their motor learning experience through the combination of efficient cognitive processing, correct movement patterns, and muscle force production (24). The combination of these components may result in improved physical fitness (24). One component of physical fitness is cardiorespiratory fitness (CRF), which is mainly determined by the capacity of the cardio-respiratory system to deliver oxygen to the working muscles while exercising (26). Another component is muscle strength which is defined as the capacity of a muscle, or group of muscles, to exert force under a given set of conditions (27).

Based on the previous findings, we postulated the following hypothesis and objectives for the present study:

(1) Because previous evidence has related plasma HMW-adiponectin with more favorable body composition in adults (15), we hypothesize that school-aged children with higher baseline salivary HMW-adiponectin may also present more favorable body mass index (BMI) in comparison to the children with lower baseline salivary HMW-adiponectin;
(2) Because recent studies reported unchanged adiponectin levels after physical exercise (14, 22) but others reported increased HMW-adiponectin after acute and chronic physical exercise with intensities ranging from moderate to vigorous (12, 18–20), we hypothesize that a 3-month moderate intensity INT applied during physical education (PE) classes may potentially induce a more pronounced increase in salivary HMW-adiponectin in healthy school-aged children than the traditional PE classes.
(3) Because an 8-week INT significantly improved physical fitness in children (24), we hypothesize that a 3-month INT intervention applied during PE classes will also induce higher improvement in CRF and muscle strength in comparison to the traditional PE classes.

Therefore, our objectives were: (1) to compare BMI, CRF and muscle strength in healthy school-aged children depending on their baseline salivary HMW-adiponectin concentration; and then (2) to apply a 3-month INT intervention in schools and evaluate its effects on salivary HMW-adiponectin concentration, BMI, CRF and muscle strength in the same children. Additional goal was to identify if any potential changes in terms of BMI, CRF and muscle strength may be related to a potential change in salivary HMW-adiponectin concentration after the 3-month period.

2 Methods

2.1 Population and ethics

A total of 90 apparently healthy children (44 boys and 46 girls; 7.4 ± 0.3 years) were recruited in schools in Cassà de la Selva and Salt (Girona, Northeastern Spain). Schools were randomly allocated into control ($N = 45$) or INT ($N = 45$) group. Note that children randomization within the same school and during the same PE class was not possible due to ethical reasons, thus we randomly allocated schools as a control on INT group. However, following the completion of the study, the INT was offered to the control school as well. This decision was made to ensure that all children that participated in the study were treated fairly and equally, prevent any perception of discrimination that may have been provoked by the schools randomization process, and finally comply with the ethical guidelines and the good practices in research. Inclusion criteria were: (1) no evidence of chronic or acute illness in the month preceding potential enrollment; and (2) age between 7 and 9 years. Exclusion criteria were: (1) major congenital abnormalities; (2) illness or chronic use of medication; (3) musculoskeletal, neurological disorder and/or certain medication therapy that could alter postural stability and cardiorespiratory function; and finally (4) attending fewer than 80% of the PE classes. The research was approved by the Institutional Review Board of Dr. Josep Trueta Hospital, Girona, Spain (CEIm:2016.134). Signed consent was obtained from the parents of all children included in the study. All measurement procedures and sample collection were conducted on the same day following enrollment and after obtaining signed consent from parents of all participating children. Prior to any measurements, the children underwent familiarization with the test protocols. Only 4% of the children participating in the study did not comply with the recommendations for physical activity at baseline (≥1 h/day) (28). Even though most of the children complied with physical activity recommendations representing a homogenous sample, we observed some heterogeneity in terms of type of sport practiced as extracurricular activity (e.g., biking, basketball, swimming etc.).

Worthy to note is that both schools that participated in this study were in the same province and country, thus ensuring the homogeneity of the curricular content for the PE classes. Prior to the start of the study, the PE teacher that would deliver the INT together with the researcher-expert in INT (25) was familiarized with the intervention and trained to deliver the INT sessions.

2.2 Intervention

PE classes in both groups (control and INT) were held twice per week with duration of 60 min and the following structure: introductory segment (20 min), main segment (30–35 min), and a concluding segment (5–10 min). The main and the concluding segments of the PE classes were the same in both groups. The difference between the control and the INT group was only in the introductory segment of the PE classes, where the INT group received the INT as a warm-up activity, while the control group did not.

During the introductory segment of the PE classes, the control group followed the traditional warm-up consisted of activities designed to prepare the cardiovascular system for the up-coming effort during the class and exercises that increased the range of motion of the particular joints and parts of the body which would be predominantly engaged during the main segment of the PE class (29). On the other hand, the INT group received the INT as a warm-up activity for 3 months. The INT consisted of 24 sessions applying strength, coordination, dynamic stabilization, plyometrics, speed and agility exercises, organized in a progressive circuits and gamified sessions with moderate intensity (25). All sessions were delivered by the previously trained PE teacher and the researcher-expert in INT (25). After the 20-min warm-up during the introductory segment of the class, children continued with the main segment of the PE class.

The main segment of the PE classes in both groups consisted of didactic delivery of the specific curricular content which is outlined in the national curricula for PE, by the PE teacher: (1) aerobic activities (running, jumping a rope) and activities that involve solving motor tasks in environmental conditions (outdoors circuits and polygons, orienteering activities); (2) activities that will induce development of fundamental motor skills, motor abilities and motor competence (motor challenges that contain elements from individual sports: athletics, gymnastics, tennis); (3) activities that will induce development of interaction skills and team-work (cooperative motor challenges that contain elements from sport games: football, basketball, handball, volleyball); (4) traditional and contemporary dances; and (5) outdoor activities in the natural environment (hiking, cycling, rollerblading, skating).

Finally, the concluding segment of the PE classes in both groups consisted of a short period with less dynamic activities that allowed children to recuperate and gradually bring their heart rate back to normal. In the concluding segment, the children had an opportunity to address any potential doubts that surged during the class with their teacher, to reflect on the content covered and the newly acquired skills, as well as to prepare for the following class.

2.3 Biological samples collection

Saliva samples were collected in the morning between 8.00 and 10.00 a.m. in a fasting state and stored at −20°C following the manufacturer's protocol. Participants had to discharge 1–4 mL of saliva into the 5 mL polystyrene specimen tube with lid, after natural accumulation in the oral cavity. Note that children were not allowed to drink water and brush their teeth before sampling (per manufacturer's protocol) with the aim to prevent potential cofounding effects that may be induced by stimulated saliva sampling. The same procedure was performed twice, at baseline and after 3 months.

2.4 Anthropometric measurements

Anthropometric measurements were performed in the schools at the morning hours (between 8.00 and 10.00 a.m.). Body mass was measured through bioelectric impedance analysis using a calibrated digital scale (Portable TANITA, 240MA, Amsterdam, Netherlands). Participants were instructed to stand barefoot on the Tanita 240MA platform wearing light clothes. The researcher in charge was responsible to ensure proper positioning of the participants during the measurement. Following initiation of the measurement, participants remained still until the measurement was complete and their body mass was recorded in kg with the accuracy of one decimal place. Height was measured with a wall-mounted stadiometer (SECA SE206, Hamburg, Germany). Participants were instructed to stand barefoot with their heels against the backboard. The researcher in charge ensured that participant's head was positioned in the Frankfurt plane, and recorded the height in cm. BMI was calculated as body mass in kg divided by the square of height in m. Age-and sex-adjusted standard deviation scores (SDS) for body mass, height and BMI were calculated using regional normative data (30). All measurements were performed twice, at baseline and after 3 months.

2.5 CRF

CRF was assessed by means of a 800 m run test at the end of the measurement sessions (31). The goal was to complete the 800 m running course in a quickest possible time. All participants performed the test at the same time. Before initiation of the test, participants were instructed to maintain a steady pace and run the distance as fast as possible. The test started after a signal (sound of a whistle). Measurement of timing began together with the signal, i.e., when participants start running and ended when they crossed the finish line. The 800 m running course was monitored by 8 researchers with previous experience in CRF evaluation. Participants were being motivated to do their best during the running course. All participants successfully finished the course and the total time to run the course was recorded manually with a stopwatch (in min) by the researchers with previous experience in CRF evaluation. The CRF evaluation was performed twice, at baseline and after 3 months.

2.6 Muscle strength

Muscle strength was assessed by means of an analog hand dynamometer after the anthropometric measurements and saliva collection (TKK 5001, Grip-A, Takei, Tokyo, Japan). The dynamometer grip span was adjusted to 5 cm to accommodate children's hand size, allowing participants to comfortably grasp the dynamometer with their fingers wrapped around the handle and the base placed on the heel of their palm. Children were instructed to hold the dynamometer with their upper arm and forearm forming an angle of approximately 90° while keeping their elbow beside their body, and to squeeze with maximum isometric force for 5 s (32). The researcher monitored the test to ensure proper execution and positioning of the dynamometer, as well as encouraged children to exert maximum effort. The test was repeated if any adjustments or unnecessary movements were observed and the result was recorded (in kg). The muscle strength evaluation was performed twice, at baseline and after 3 months.

2.7 Protein concentration quantification

Before initiation of the study, we used a GRANMO 7.12 program to identify the sample size for inclusion based on a previous study including protein quantification. Accepting an alpha risk of 0.05 and a beta risk of 0.2 in a two-sided test, the estimated sample size for the present study was 30 subjects in each group (33).

HMW-adiponectin was assessed in saliva using the Human HMW-adiponectin ELISA kit (CSB-E13400h; Gentaur, Belgium). Sandwich enzyme-linked immunosorbent assay method was applied with an anti-HMW-adiponectin polyclonal antibody as detection antibody. First, the assay components, samples and standards were prepared according to the manufacturer's instructions. Then, they were loaded onto the pre-coated microplate wells and incubated according to the kit protocol. After the appropriate incubation periods, the wells were washed and the detection reagent was added, accompanied by the substrate solution. Finally, the reaction was stopped as indicated in the protocol, the absorbance was measured at the specified wavelength using a microplate reader, and HMW-adiponectin concentration was calculated following manufacturer's instructions. Lower detection limit was 0.5 ng/mL and intra-and interassay CVs <4%.

2.8 Statistical analysis

Data were analyzed with the statistical package SPSS version 22.0 (SPSS Inc., Chicago, IL, United States). The normality of the data distribution was tested by the Kolmogorov–Smirnov test. Non-normally distributed variables were logarithmically transformed to improve the distribution symmetry. Tertiles were created to compare BMI, CRF and muscle strength among children depending on their baseline salivary HMW-adiponectin concentration. Then, Kruskal Wallis test with *post hoc* pairwise comparisons was applied to examine the differences between children with low, medium and high baseline salivary HMW-adiponectin concentration. Before starting the intervention and after schools were randomly allocated to control or INT group, a t-test, Mann–Whitney U or Chi-squared tests were performed to assure that the two groups of children were comparable at baseline. To assess if an INT induced changes in salivary HMW-adiponectin, BMI, CRF and muscle strength, we first calculated the percentage change of the assessed components in the control and the INT group. The percentage change was calculated as pre-value (baseline) subtracted by the post-value (after 3 months), divided by the pre-value (baseline), and then multiplied by 100. Then, a t-test was applied to test the difference in percentage change induced by the traditional PE classes and the INT. Finally, to identify if changes in terms of BMI, CRF and muscle strength were associated with the post-salivary HMW-adiponectin concentration after the 3-month period, we applied multiple linear regression analyses adjusting for potential confounding variables such as age, sex, BMI and baseline salivary HMW-adiponectin.

3 Results

Descriptive characteristics of the studied population according to tertiles of baseline salivary HMW-adiponectin, as well as comparison

TABLE 1 Baseline characteristics according to tertiles of HMW-adiponectin concentration and comparison between the groups of low, medium and high salivary HMW-adiponectin concentration.

	N = 90	Low HMW adiponectin (*N* = 30)	Medium HMW adiponectin (*N* = 30)	High HMW adiponectin (*N* = 30)	*p*-value
HMW-adiponectin (ng/mL)	5.95 (3.14–9.04)	2.06 (1.20–3.45)†	6.45 (5.43–7.82)†	11.20 (9.26–14.58)†	**<0.0001**
Age (years)	7.4 ± 0.3	7.4 ± 0.3	7.5 ± 0.3	7.5 ± 0.4	0.922
Sex (m/f)	44/46	13/17	12/18	19/11	0.322
Body mass (kg)	25.7 ± 4.2	26.3 ± 5.1	26.1 ± 2.8†	24.7 ± 4.1†	**0.040**
Body mass SDS	−0.28 (−0.80–0.13)	−0.10 (−0.66–0.34)	−0.21 (−0.71–0.13)†	−0.45 (−1.19–0.01)†	**0.032**
Height (cm)	126 ± 6	126 ± 6	128 ± 7	126 ± 5	0.466
Height SDS	−0.10 (−0.56–0.87)	0.13 (−0.50–0.90)	0.19 (−0.56–0.96)	−0.33 (−0.57–0.60)	0.533
BMI (kg/m^2)	16.2 ± 1.9	16.6 ± 2.4	16.5 ± 1.2†	15.5 ± 1.8†	**0.006**
BMI SDS	−0.40 (−0.74–0.02)	−0.40 (−0.76–0.20)	−0.23 (−0.58–0.05)†	−0.56 (−0.98–0.30)†	**0.007**
CRF (min)*	5.31 ± 0.57	5.44 ± 0.70†	5.23 ± 0.54†	5.21 ± 0.26†	**0.017**
Muscle strength (kg)	10.08 ± 1.97	9.57 ± 2.17	9.94 ± 1.77	10.39 ± 1.59	0.120

Data for Gaussian variables is presented as mean ± standard deviation. Data for non-Gaussian variables is presented as median and interquartile range. *p*-value is from Kruskal-Wallis test. The *p*-value for categorical variables is from Chi-squared test. Significance level is set at 0.05 and significant values are marked in bold. Significant differences in post hoc test for pairwise comparisons are presented with †. BMI, body mass index; CRF, cardiorespiratory fitness; HMW, high molecular weight; SDS, standard deviation score; * variable with an opposite metric orientation.

TABLE 2 Participants' characteristics at baseline, after 3 months and comparison of the Δ % between the control and the INT group.

	Control group (*N* = 45)			INT group (*N* = 45)			
	Baseline	After 3 months	Δ %	Baseline	After 3 months	Δ %	*p*-value
HMW-adiponectin (ng/mL)	7.17 (3.56–9.42)	7.26 (2.68–10.97)	21.56	5.66 (2.34–8.32)	7.88 (3.64–10.20)	37.03	**0.007**
Body mass (kg)	25.60 ± 3.81	25.51 ± 3.10	−1.79	25.72 ± 4.70	25.12 ± 3.45	−3.30	**0.004**
Height (cm)	126.37 ± 6.41	127.86 ± 6.34	0.99	126.36 ± 5.84	127.61 ± 6.37	1.30	0.067
BMI (kg/m^2)	16.14 ± 1.68	15.98 ± 1.46	−0.19	16.23 ± 2.28	15.94 ± 1.62	−0.67	**0.028**
CRF* (min)	5.33 ± 0.49	5.30 ± 0.50	−0.20	5.29 ± 0.62	5.20 ± 0.76	−0.35	**0.043**
Muscle strength (kg)	10.46 ± 2.25	11.32 ± 2.27	1.52	9.76 ± 2.19	11.99 ± 1.97	10.56	**0.003**

p-value is from *t*-test comparing Δ % between control and INT group. Significance level is set at 0.05 and significant values are marked in bold. BMI, body mass index; CRF, cardiorespiratory fitness; HMW, high molecular weight; INT, integrated neuromuscular training; Δ %, percentage change (post-value versus pre-value); * variable with an opposite metric orientation.

between children with low, medium and high salivary HMW-adiponectin are presented in Table 1. From the results presented, it can be observed that children with higher baseline salivary HMW-adiponectin have lower body mass SDS ($p = 0.032$), lower BMI SDS ($p = 0.007$) and slightly higher CRF ($p = 0.017$), in comparison to children with lower baseline salivary HMW-adiponectin. No significant differences were observed in height and muscle strength between groups.

Descriptive characteristics of the children and comparison between the control and the INT group at baseline are presented in Supplementary Table S1. Based on the results in Supplementary Table S1, we may conclude that the control and the INT group were comparable at baseline because there are no statistically significant differences between them in any of the studied components ($p > 0.05$; Supplementary Table S1).

Participants' characteristics at baseline, after 3 months and comparison of the percentage change between the control and the INT group are presented in Table 2. In general, we did not observe big changes after the 3-month period neither in the control, nor in the INT group (Table 2). However, it appears that the changes observed after the 3 months were slightly higher in the INT group as compared to the control group (Table 2). For instance, higher increase in salivary HMW-adiponectin concentration was observed in the children who performed the INT during PE classes, compared to the children who did not (15.47% more, $p = 0.007$). It seems that the INT also induced a higher decrease in body mass (−1.51% more, $p = 0.004$) and BMI (−0.48% more, $p = 0.028$) in comparison to the traditional PE classes. However, these results must be interpreted with caution because the small changes in body mass and BMI in both groups may also be affected by growth. Finally, a higher improvement in CRF (−0.15% more, $p = 0.043$) and muscle strength (9.04% more, $p = 0.003$) were observed after the INT as compared to the traditional PE classes. No significant differences between changes in the control and the INT group were observed in terms of height of the children (Table 2).

Beta values, *p*-values and adjusted R^2 of multiple linear regression analyses representing the associations between the changes in BMI, CRF and muscle strength after the 3-month period with the post-salivary HMW-adiponectin concentration are presented in Table 3. According to the results in Table 3, it seems that none of the changes in the control group was associated with the post-salivary HMW-adiponectin concentration (Beta = −0.394 to Beta = 0.003, $p = 0.993$ to $p = 0.061$,

TABLE 3 Regression analyses representing the associations of the Δ % in BMI, CRF and muscle strength with post-salivary HMW-adiponenctin concentration.

	HMW-adiponectin post log					
	Control group (*N* = 45)			INT group (*N* = 45)		
	Beta	*p*-value	Adjusted R squared	Beta	*p*-value	Adjusted R squared
BMI Δ %	−0.394	0.061	0.120	0.095	0.527	0.251
CRF* Δ %	0.003	0.993	0.501	−0.335	**0.022**	0.336
Muscle strength Δ %	−0.371	0.544	0.779	−0.028	0.855	0.232

Adjusted for age, sex, BMI and baseline salivary HMW-adiponectin. Significance level is set at 0.05 and significant values are marked in bold. BMI, body mass index; CRF, cardiorespiratory fitness; HMW, high molecular weight; INT, integrated neuromuscular training; Δ %: percentage change (post-value versus pre-value); *: variable with an opposite metric orientation.

adjusted $R^2=0.120$ to adjusted $R^2=0.779$). However, in the INT group the slight improvement in CRF was positively associated with the increased post-salivary HMW-adiponectin concentration (Beta = −0.335, $p=0.022$, adjusted $R^2=0.336$). Furthermore, the improvement in CRF induced by the INT explained 34% of the variance of post-salivary HMW-adiponectin concentration. Finally, there were no associations between the change in BMI and muscle strength with post-salivary HMW-adiponectin concentration (Beta = 0.095, $p=0.527$, adjusted $R^2=0.251$; Beta = −0.028, $p=0.855$, adjusted $R^2=0.232$ respectively; Table 3).

4 Discussion

Main findings of the present study are indicating that children with higher baseline salivary HMW-adiponectin have more favorable BMI and slightly higher CRF than children with lower baseline salivary HMW-adiponectin. Furthermore, we observed only modest changes during the 3-month INT. However, the 3-month INT induced higher increase in salivary HMW-adiponectin concentration, and more favorable changes in BMI, CRF and muscle strength in comparison to the traditional PE classes. Note that changes related to BMI must be interpreted with caution because they could also be affected by growth. Finally, the improvement in CRF induced by the INT was related to the increased post-salivary HMW-adiponectin concentration in these children, explaining 34% of its variance.

In line with the present results that show more favorable BMI in children with higher baseline salivary HMW-adiponectin compared to children with lower baseline salivary HMW-adiponectin, lower plasma adiponectin levels were observed in women with obesity compared to non-obese women (16, 34). Additionally, a previous study in adults has reported that higher plasma adiponectin levels were related to more favorable body composition (15). Studies in children have also shown significantly lower adiponectin concentration in children with overweight and obesity, as compared to non-obese children (35). Considering that the results obtained at the present study are in line with the previous findings, we will accept the first hypothesis and conclude that school-aged children with higher salivary HMW-adiponectin have lower body mass and more favorable BMI than children with lower salivary HMW-adiponectin.

To the best of our knowledge, no previous studies have compared CRF in children depending on their salivary HMW-adiponectin concentration. However, supporting our findings, increased adiponectin concentration was observed in endurance athletes, during the race and at the recovery period (14). The energetic demands of a race require high CRF, which refers to the ability of the cardiorespiratory system to supply oxygen (36), mainly relying on aerobic metabolic pathway for energy production such as oxidative phosphorylation (32). Therefore, more efficient oxidative phosphorylation would result in higher CRF (32). In addition, oxidative phosphorylation has been positively associated with adiponectin concentration (37). In line with previous findings, we assume that the slightly higher CRF in children with higher baseline salivary HMW-adiponectin concentration may have been potentially mediated by the ability for more efficient oxidative phosphorylation (32, 37). However, further experimental studies are necessary to clarify the exact mechanisms and examine the role of oxidative phosphorylation in adiponectin secretion.

We observed only modest changes during the 3-month period in both groups. However, the 3-month INT induced higher increase in salivary HMW-adiponectin as compared to the traditional PE classes, which aligns with the second hypothesis of the present study. To the best of our knowledge, this is the first study to evaluate the effects of an INT program on salivary HMW-adiponectin concentration. INT is a physical exercise program with moderate intensity that improved health and fundamental motor skills in female badminton players (23). Generally, acute and chronic physical exercise with intensities ranging from moderate to vigorous have been shown to induce an increase in adiponectin concentration (12, 18–21). However, some studies reported no significant change in adiponectin levels after physical exercise (14, 22). It was suggested that the different outcomes in the scientific literature may be explained by differences in physical exercise intensity (38). A previous study showed that exercise induced changes in adiponectin concentration in an intensity-dependent manner, with more favorable effects observed after exercise with higher intensity (38). In this line, we believe that the replacement of the traditional warm-up activities during the PE classes in the INT group with the INT program, contributed to an increase from light to moderate intensity, therefore leading to a higher increase in salivary HMW-adiponectin concentration, as compared to the traditional PE classes. Furthermore, a previous study comparing the effects of exercise interventions with different intensities on adiponectin concentration in older adult population has reported that physical exercise-induced changes after the intervention with higher intensity were evident even after 6 months of detraining period (38). This evidence may raise the need for developing further studies that will investigate whether INT-induced increase in HMW-adiponectin concentration in school-aged children would persist after the completion of the INT program. This may be especially relevant, mainly because adiponectin is a cardio-metabolic health protector (12, 13), and the 3-month INT applied in the present study is a cost-effective strategy that can be easily introduced at schools as a strategy for cardio-metabolic health protection and disease prevention.

In addition, the results of the present study indicate that the 3-month INT induced higher improvements in BMI, CRF and muscle strength as compared to the traditional PE classes, which aligns with the third hypothesis of the present study. Even though the higher decrease in body mass and BMI observed in the INT group may result from increased energy expenditure due to higher exercise intensity leading to enhanced lipolysis (39), increased fat oxidation, improved insulin sensitivity and increased glucose uptake by the skeletal muscles (40), we should also consider that these changes may be affected by growth and growth related alterations. On the other hand, the slight improvements in terms of CRF are highly-dependent on the exercise intensity (24). The increased oxygen intake and oxygen delivery induced by exercise intervention with higher intensity may lead to more effective oxygen utilization rate and improved CRF because of the greater muscle capillarization and mitochondrial density (41). Furthermore, strength-related exercises that formed part of the INT program have contributed to slightly higher improvement in muscle strength in the INT group, as compared to the control group which had the traditional PE classes. In this line, a previous study employing a 2-month INT in school-aged children has also reported an increase in upper body muscle strength (24).

With regard to the additional goal of the present study, none of the changes observed in the control group after the 3-month period was related to the post-salivary HMW-adiponectin concentration. Conversely, the slightly higher improvement in CRF induced by the 3-month INT was related to the increased post-salivary HMW-adiponectin concentration in the children from the INT group. Moreover, the improvement in CRF induced by the INT explained 34% of the variance of post-salivary HMW-adiponectin concentration. To the best of our knowledge, there are no studies that explored the direct association between HMW-adiponectin and CRF. However, previous evidence reported that higher adiponectin levels are related to increased maximal oxygen consumption (VO_2 max) in patients with chronic spinal cord injury (15). VO_2 max is the total amount of oxygen consumption attainable during physical exertion (42). It is a reliable index measuring the limits of the cardiorespiratory system ability for oxygen transport, and a relevant indicator of CRF (36). Thus, an improvement in CRF is mediated and highly-dependent on the increase in VO_2 max (36). Based on the previous evidence, we assume that the association between the change in CRF and the increased post-salivary HMW-adiponectin concentration in the children from the INT group, may have been potentially mediated by VO_2 max (15, 36, 42). We suggest that the slightly higher improvement in CRF in the INT group as compared to the control group, may have been followed by a sufficient increase in VO_2 max that was enough to induce changes in salivary HMW-adiponectin concentration (15, 36). On the other hand, the intensity of the traditional PE classes in the control group was probably insufficient to induce higher changes in CRF and VO_2 max that are necessary to impact HMW-adiponectin concentration (24, 38). However, further studies are needed to evaluate the VO_2 max capacity in laboratory settings and investigate its potential mediatory role in the association between CRF and HMW-adiponectin concentration.

5 Conclusion

Children with higher baseline salivary HMW-adiponectin have more favorable BMI and slightly higher CRF than children with lower baseline salivary HMW-adiponectin. Furthermore, big changes after the 3-month period were not observed neither with the traditional PE classes, nor with the INT. However, it might be worthy to note that the INT seems to induce slightly higher increase in salivary HMW-adiponectin, and more favorable changes in BMI, CRF and muscle strength as compared to the traditional PE classes. Finally, the INT-induced improvement in CRF appears to be related to the increased post-salivary HMW-adiponectin concentration after the intervention.

5.1 Practical applications

Present findings may serve as a starting point for future research, raising the need for designing studies that may further explore the utility of an INT intervention applied in schools as a strategy to promote health and potentially evoke cardio-protective effects in school-aged children.

These findings may also encourage some modifications in the PE curricula such as the incorporation of an INT in schools with the aim to maintain and potentially enhance the cardio-metabolic health of the children. PE teachers and coaches might also benefit from this study when tailoring exercise programs and training interventions that should provide the optimal conditions for cardio-metabolic health improvement.

5.2 Limitations and future research

Nevertheless, the present findings must be interpreted under the consideration of the potential study limitations.

Even though participants complied with the recommendations for physical activity at baseline representing a homogenous sample, there is heterogeneity in terms of type of sport practiced as extracurricular activity (e.g., biking, basketball, swimming etc.). Thus, we must consider this as a potential limitation of the present study. Further interventional studies should consider this and compare the potential effects induced by different sports and extracurricular activities on HMW-adiponectin concentration. These studies may offer new insights into the physiological responses induced by different types of exercise and contribute to the optimization of training interventions that may potentially increase HMW-adiponectin concentration.

Besides the fact that CRF evaluation was performed by experienced researchers in the present study, the timing was manual, thus it should be considered as a potential study limitation as well. Future studies should consider including automatic timing in CRF evaluation.

Another limitation could be the nature of the present study which does not allow us to elucidate further the molecular mechanisms underlying the relation between CRF and post-salivary HMW adiponectin concentration. However, obtained results are raising the need for designing future studies that will investigate the VO_2 max capacity in laboratory settings and examine its role in mediating the association between CRF and salivary HMW adiponectin concentration. We also believe that further animal studies may provide even more valuable insights into the exact physiological pathways that are involved in regulation of the HMW-adiponectin secretion.

Finally, we also believe that larger comparative studies in the future should focus on sex-specific comparisons in HMW-adiponectin concentration. This kind of studies may provide insights into the biological mechanisms that underlie HMW-adiponectin regulation, and potentially contribute to more effective and personalized therapeutic interventions.

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.

Ethics statement

The studies involving humans were approved by Institutional Review Board of Dr. Josep Trueta Hospital, Girona, Spain. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

FV: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft. RF-L: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Software, Supervision, Writing – review & editing. GC-B: Formal analysis, Methodology, Software, Writing – review & editing. JC-G: Data curation, Formal analysis, Methodology, Writing – review & editing. AL-B: Formal analysis, Investigation, Methodology, Supervision, Writing – review & editing. AP-P: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Software, Supervision, Writing – review & editing.

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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

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1337958/full#supplementary-material

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Association between meeting 24-h movement guidelines and health in children and adolescents aged 5–17 years: a systematic review and meta-analysis

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Twenty-four-hour movement behaviors have significant implications for physical and mental health throughout one's lifespan. Consistent with movement behaviors, several countries have formulated and published 24-h movement guidelines. This review summarized the studies related to 24-h movement guidelines among children and adolescents from six databases (MEDLINE, EMBASE, PubMed, Web of Science, CINAHL, and SPORTDiscus). In a total of 61 studies that discussed compliance with 24-h movement guidelines, the overall adherence rate was very low (7.6%), with boys exceeding girls, children surpassing adolescents, and regional differences. A total of 39 studies examined the associations between 24-h movement guidelines and health indicators. Findings indicated that meeting all three guidelines was favorably associated with adiposity, cardiometabolic health, mental and social health, physical fitness, health-related quality of life, academic achievement, cognitive development, perceived health, dietary patterns, and myopia. Future research should utilize longitudinal and experimental designs to enhance our understanding of the associations between 24-h movement guidelines and health indicators, thereby aiding the formulation and refinement of such guidelines.

Systematic review registration: https://www.crd.york.ac.uk/prospero/, CRD42023481230.

KEYWORDS

physical activity, screen time, sleep, 24-h movement guidelines, health indicators, children and adolescents

1 Introduction

The 24-h day encompasses physical activity (PA), sedentary behavior (SB), and sleep, collectively referred to as movement behaviors, which span a wide range of energy expenditure levels (1). Over the past decades, studies have traditionally examined the health effects of these behaviors in isolation. Higher levels of PA, lower SB, and adequate sleep are favorably associated with adiposity, motor development, and other health indicators in children and adolescents (2, 3). Conversely, lack of PA, prolonged SB, or excessive screen time (ST), and insufficient sleep have been linked to adverse health outcomes (2, 3). More recently, researchers have begun to examine the combined effects of 24-h movement behaviors on health. Studies have shown different general combinations (e.g., all three, none) and special combinations (e.g., high PA and high SB; high PA and low sleep) (4).

In 2016 and 2017, Canada and Australia developed 24-h movement guidelines for children and youth aged 5–17 years (5–7). Subsequently, the World Health Organization, the United Kingdom, New Zealand, South Africa (8–11), the Asia-Pacific region, and New Zealand (12, 13) have adopted the 24-h movement guidelines. These guidelines recommend that children and adolescents spend ≥60 min/day engaged in moderate-to-vigorous physical activity (MVPA) on ≥5 days/week, limit recreational ST to ≤2 h/day, and get between 9 and 11 h of sleep per night (aged 5–13 years) or between 8 and 10 h per night (aged 14–18 years) (5–7).

Despite countries being currently engaged in the development of 24-h movement guidelines, there remains a lack of comprehensive data and systematic reviews specifically on children and adolescents. Therefore, this review aimed to synthesize existing evidence for children and adolescents 1) to assess adherence and conduct a meta-analysis of global 24-h movement guidelines and 2) to determine the association between meeting both the general combination and the specific combination of 24-h movement guidelines with health outcomes.

2 Methods

2.1 Data source and search strategy

The review was registered with the International Prospective Register of Systematic Review (PROSPERP) (Registration ID CRD42023481230) and conducted using the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) (14). Two researchers (HHZ and NW) searched six databases (MEDLINE, EMBASE, PubMed, Web of Science, CINAHL, and SPORTDiscus) using the following search strategy: ((24 h*)OR(movement behavio*) OR(movement guidelin*)OR(physical activit* AND sedentary behavio* AND slee*)). The research terms were customized for each research database. Detailed search terms and procedures can be found in Supplementary Table S1.

2.2 Inclusion criteria

The eligibility criteria included: (1) data restricted to the period from 2016 to 2022, as this timeframe encompasses the release of influential 24-h movement guidelines in 2016 (5), (2) study design: cross-sectional and longitudinal study, with separate analysis, (3) participants: aged 5–18 years children (aged 5–12 years) and adolescent (aged 13–18 years), (4) exposure: including two or more behaviors from 24-h movement guidelines, specifically MVPA, ST, and sleep, assessed by either wearable devices or self-report measurements, and (5) health outcome: at least 1 health indicator, including adiposity, cardiometabolic health, physical fitness, mental and social health, health-related quality of life, academic achievement, cognitive development, dietary patterns, and myopia.

2.3 Study selection and data extraction

After the identification of studies through database searching, all acquired articles were stored in an EndNote X9 reference manager (Thompson ISI Research Soft, Philadelphia, PA, United States). Initially, duplicate records were removed with automated deduplication inside the software. Following this, two researchers (HHZ and NW) screened title, abstract, and full-text articles independently for potentially relevant records. Two researchers (HHZ and NW) examined all full-text articles to determine eligibility. Disagreements between the two researchers were resolved by discussion or with a third researcher (YG). In addition to searching the database, the review team checked their personal reference lists and Google Scholar for potential studies. A flowchart regarding the procedure can be found in Figure 1.

All included articles were summarized in table format using Microsoft Excel and described the following study characteristics: author, publication year, country, study design, population, sample size (Table 1), exposure, exposure measures, outcomes, and results (Supplementary Tables S2, S3).

2.4 Data synthesis

Stata was planned for the meta-analyses (Version 17, StataCorp., College Station, TX, United States) using the “metan” command and Metaprop tests. Metaprop was implemented to perform meta-analyses pooling adherence to 24-h movement guidelines in Stata. Heterogeneity was calculated using the I-square (I^2) values. If $I^2 > 50\%$, the random-effects model was selected, and if $I^2 < 50\%$, the fixed-effects model was chosen. Sub-group analyses were conducted based on age groups, gender, and geographical region. The “metan” command was used to pool effects [odds ratios (ORs)] between 24-h movement guidelines and health indicators in Stata. Random-effects models were used in the data analysis to combine effects and calculate 95% confidence intervals (95% CI) when a sufficient number of studies reported associations for the same outcomes.

3 Result

3.1 Description of studies

A total of 61 studies (15–75) assessed adherence to 24-h movement guidelines (Supplementary Table S4). Out of these, 44 (16–25, 27–34, 36, 37, 40, 42, 43, 46–59, 61–65, 67, 69–74) reported the proportions of participants meeting none of the guidelines, 30 studies (17–25, 28–31, 36, 40, 42, 43, 46, 49–51, 53, 55, 61, 63, 65, 69, 71, 72, 74) reported meeting only one guideline, 30 studies (17–22, 24, 25, 28–31, 36, 40, 42, 43, 45, 46, 49–51, 53, 55, 61, 63, 65, 69, 71, 72, 74) reported meeting two guidelines, and 60 studies (16–75) reported meeting all three guidelines. For the specific combination of 24-h movement guidelines, 61 studies (15–75) reported meeting the MVPA guidelines only, 60 studies (15–35, 37–75) reported meeting the ST guidelines only, 61 studies (15–75) reported meeting the sleep guidelines only, and 45 studies (16, 17, 19, 20, 22–29, 31–37, 39, 42, 43, 47, 48, 50–61, 65–67, 70–75) reported meeting any two combinations.

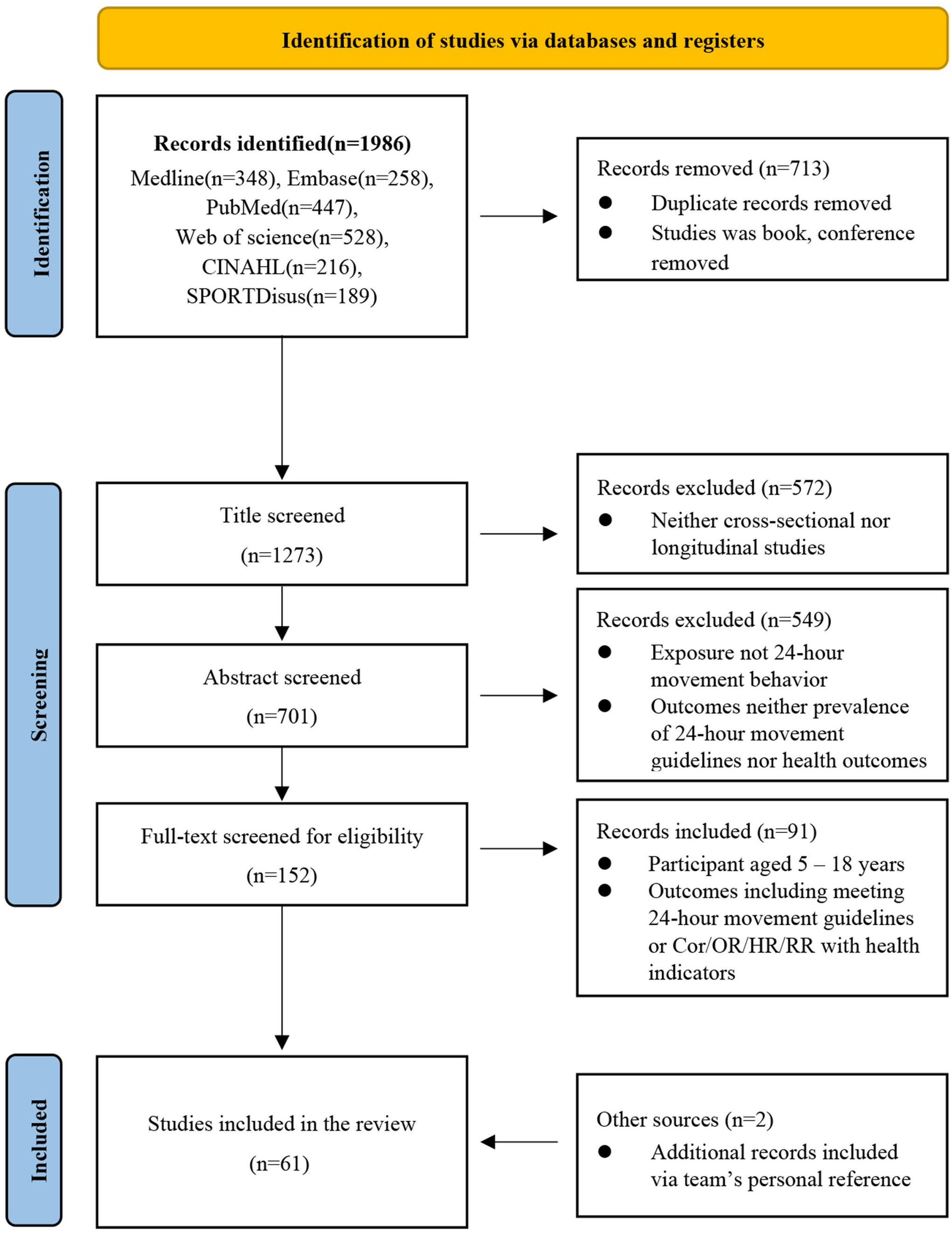

FIGURE 1
The flow chart of research results.

A total of 39 studies (16–75) reported overall adherence to 24-h movement guidelines. Regarding age group, 26 studies (16, 20, 21, 23–25, 27, 28, 31, 33–37, 48, 54, 56, 59–62, 66, 67, 70, 71, 74) focused on children and 22 studies (20, 22, 26, 28, 30–32, 38, 46, 48, 52, 53, 56–58, 62, 64, 66, 69, 72–74) focused on adolescents. In terms of gender, 19 studies (15, 20, 29, 30, 32, 33, 36, 37, 41, 42, 45, 47, 51, 53, 55, 62, 63, 65, 75) included both boys and girls. In terms of geographical region, 18 different countries were identified, including 3 in Africa (16, 25, 54), 20 in Asia (16, 22, 30, 34, 37, 39, 41, 44, 51–53, 55, 56, 58, 59, 62, 70–72, 75), 10 in Europe (16, 26, 42, 48, 50, 60, 62, 63, 68, 70), 4 in Oceania (16, 35, 43, 45), and 22 in North America (16–20, 23, 24, 28, 29, 31–33, 38, 40, 46, 47, 49, 64, 66, 67, 69, 73).

A total of 47 cross-sectional studies (15–19, 21–24, 27–29, 31–35, 37, 40, 41, 43–47, 50–53, 55, 56, 59–61, 64–67, 69–77) examined the association between 24-h movement guidelines and health indicators (Supplementary Table S2). The health outcomes described were adiposity ($n = 17$) (15–19, 29, 31, 37, 41, 44, 46, 52, 60, 70, 73–75), cardiometabolic health ($n = 5$) (17, 19, 60, 65, 74), physical fitness ($n = 6$) (17, 34, 53, 69, 76, 77), mental and social health ($n = 17$) (17, 18, 22, 24, 28, 32, 33, 40, 46, 47, 55, 61, 66, 67, 69, 71, 72), health-related quality of life ($n = 4$) (21, 43, 46), academic achievement ($n = 4$) (35,

TABLE 1 Association between 24-h movement guidelines and health-related indicators.

Author, year	Study design and sample	PA	Sleep	ST	Health-related indicators	General combination	Specific combination
Laruson, 2016	Cross-sectional, United States, grades 9–12, *N* = 9,589	Self-reported	Self-reported	Self-reported	Adiposity	✓	✓
Roman-vainas, 2016	Cross-sectional, 12 countries, aged 9–11, *N* = 6,129	4–7d by ACC	3–7d by ACC	Self-reported	Adiposity	✓	✓
Carson, 2017	Cross-sectional, Canada, aged 6–17, *N* = 4,157	4–7d by ACC	Self- or parent-reported	Self- or parent-reported	Adiposity, cardiometabolic, physical fitness, mental health	✓	✓
Jassen, 2017	Cross-sectional, Canada, aged 10–17, *N* = 17,000	Self-reported	Self-reported	Self-reported	Adiposity, mental and social health	✓	✓
Katzmaryzk, 2017	Cross-sectional, United States, aged 5–18, *N* = 357	Self- or parent-reported	Self- or parent-reported	Self- or parent-reported	Adiposity, cardiometabolic	✓	✓
Sampasa, 2017	Cross-sectional, 12 countries, aged 9–11, *N* = 6,106	4–7d by ACC	3–7d by ACC	Self-reported	Health-related quality of life	✗	✓
Lee, 2018	Cross-sectional, Korea, aged 12–17, *N* = 50,987	Self-reported	Self-reported	Self-reported	Psychological	✓	✓
Walsh, 2018	Cross-sectional, United States, aged 9–10, *N* = 4,524	Self-reported	Self-reported	Self- or parent-reported	Global cognitions	✓	✓
Guerrero, 2019	Cross-sectional, Canada, aged 8–11, *N* = 4,524	Self-reported	Self-reported	Self- or parent-reported	Mental health	✗	✓
Thivel, 2019	Cross-sectional,12 countries, aged 9–11, *N* = 5,973	4–7d by ACC	3–7d by ACC	Self-reported	Dietary patterns	✗	✓
Zhu, 2019	Cross-sectional, United States, aged 6–17, *N* = 35,688	Self- or parent-reported	Self- or parent-reported	Self- or parent-reported	Mental health	✓	✓
Zhu, 2020	Cross-sectional, United States, aged 10–17, *N* = 30,478	Parent-reported	Parent-reported	Parent-reported	Body weight	✓	✓
Chemtob, 2021	Longitudinal, Canada, aged 8–10, N = 630, aged 10–12, *N* = 564, aged 15–17, *N* = 377	4–7d by ACC	Self-reported	Self-reported	Adiposity	✓	✗
Hui, 2020	Cross-sectional, 8 cities, aged 13.63 ± 1.01, *N* = 12,590	Self-reported	Self-reported	Self-reported	Body fat percentage	✓	✓
Sampasa, 2021	Cross-sectional, Canada, aged 11–20, *N* = 10,236	Self-reported	Self-reported	Self-reported	Substance use	✓	✓
Sampasa, 2021	Cross-sectional, United States, aged 9–11, *N* = 11,875	Self-reported	Self-reported	Parent-reported	Mental health	✓	✓
Tanaka, 2020	Cross-sectional, Japanese, aged −12, *N* = 243	3–7d by ACC	Self- and parent-reported	Self- and parent-reported	Physical fitness	✓	✓
Watson, 2022	Cross-sectional, Australia, aged 11–12, *N* = 1,279	Self-reported or 4–8d by ACC	Self-reported or 4–8d by ACC	Self-reported	Academic achievement	✓	✓

(Continued)

TABLE 1 (Continued)

Author, year	Study design and sample	PA	Sleep	ST	Health-related indicators	General combination	Specific combination
Tanaka, 2021	Cross-sectional, Japanese, aged 6–12, $N=902$	3–7d by ACC	Self-reported	Self-reported	Adiposity	✓	✓
Chen, 2021	Cross-sectional, China, grades 4–12, $N=114{,}072$	Self-reported	Self-reported	Self-reported	Adiposity	✓	✓
Burns, 2020	Cross-sectional, United States, grades 9–12, $N=1849$	Self-reported	Self-reported	Self-reported	Mental health	✓	✓
Khan, 2021	Cross-sectional, Australia, aged 12–13, N = 3,096	Self-reported	Self-reported	Parent-reported	Quality of life	✓	✓
Shi, 2020	Cross-sectional, Hong Kong, aged 11–18, $N=1{,}039$	ACC	ACC	Self-reported	Adiposity	✓	✓
Howie, 2020	Cross-sectional, Australia, grades 5–12, $N=934$	Self-reported	Self-reported	Self-reported	Academic achievement	✓	✓
Guimaraes, 2020	Cross-sectional, Canada, aged 12–17, $N=276$	Self-reported	Self-reported	Self-reported	Adiposity, quality of life, mental health	✓	✓
Sampasa, 2020	Cross-sectional, Canada, grades 7–12, $N=10{,}183$	Self-reported	Self-reported	Self-reported	Mental health	✓	✓
Samapsa, 2022	Cross-sectional, Spanish, aged 11–16, N = 1,290	Self-reported	Self-reported	Self-reported	Academic achievement	✓	✓
Chen, 2022	Cross-sectional, China, aged 11–17, $N=3{,}870$	Self-reported	Self-reported	Self-reported	Physical fitness	✓	✓
Tapia-serrano, 2022	Cross-sectional, Spanish, aged 11–16, $N=1{,}276$	Self-reported	Self-reported	Self-reported	Physical fitness	✗	✓
Zeng, 2022	Cross-sectional, China, aged 7–12, $N=376$	4–7d by ACC	Self-reported	Self-reported	Executive function	✓	✓
Jakubec, 2020	Cross-sectional, Czech, aged 8–18, $N=679$	ACC	Acc	Parent- or self-reported	Adiposity	✓	✓
Yang, 2022	Cross-sectional, China, aged 6–18, $N=34{,}887$	Parent- or self-reported	Parent- or self-reported	Parent- or self-reported	Adiposity, cardiometabolic	✓	✓
Cai, 2023	Cross-sectional, China, aged 13–15, $N=48{,}698$, aged 16–18, $N=47{,}147$	Self-reported	Self-reported	Self-reported	Physical fitness	✓	✓
Swindell, 2022	Cross-sectional, Kenya, aged 11.1 ± 0.8, $N=539$	ACC	Self-reported	Acc	–	✗	✗
Lu, 2021	Cross-sectional, China, grades 4 and 5, $N=5{,}537$	Self-reported	Self-reported	Self-reported	Depressive and anxiety	✓	✓
Kyan, 2022	Cross-sectional, Japan, aged 10–11, $N=2{,}408$, aged 13–14, $N=4{,}360$	Self-reported	Self-reported	Self-reported	Self-rated health	✗	✓
Costa, 2021	Cross-sectional, Brazil, aged 14–18, $N=867$	Self-reported	Self-reported	Self-reported	–	✗	✗
Lu, 2023	Cross-sectional, China, aged 14–17, $N=6{,}032$	self-reported	Self-reported	Self-reported	Cognitive difficulties	✗	✓
Zhao, 2023	Cross-sectional, China, aged 5–13, $N=1{,}423$	Parent-reported	Parent-reported	Parent-reported	Myopia	✓	✓
Leppanen, 2021	Cross-sectional and Longitudinal, Finland, aged 6–8, $N=485$	Heart rate and Actiheart	Parent- or self-reported	Heart rate and Actiheart	Cardiometabolic risk	✓	✓

(Continued)

TABLE 1 (Continued)

Author, year	Study design and sample	PA	Sleep	ST	Health-related indicators	General combination	Specific combination
Sun, 2023	Cross-sectional, China, aged 11.6 ± 0.8, *N* = 1,098	Self-reported	Self-reported	Self-reported	Subjective wellbeing	✓	✓
Hansen, 2022	Cross-sectional, German, aged 9–12, *N* = 6,451, aged 13–18, *N* = 9,335	Self-reported	Self-reported	Self-reported	–	✗	✗
Lien, 2020	Cross-sectional, Canada, grades 7–12, *N* = 10,160	Self-reported	Self-reported	Self-reported	Academic achievement	✗	✓
Guedes, 2022	Cross-sectional, Brazil, aged 14–18, *N* = 306	Self-reported	Self-reported	Self-reported	Cardiometabolic health markers	✓	✓
Bang, 2020	Cross-sectional, Canada, aged 5–11, *N* = 2,773, aged 12–17, *N* = 1,477	ACC	Parent- or self-reported	Parent- or self-reported	Psychosocial health	✓	✓
Fung, 2023	Cross-sectional and longitudinal, United States, aged 9–14, *N* = 10,574	Parent- or self-reported	Parent- or self-reported	Parent- or self-reported	Cognitive development	✗	✓
Suchert, 2023	Cross-sectional, German, aged 9–17, *N* = 17,433	Self-reported	Self-reported	Self-reported	–	✗	✗
Sampasa, 2022	Cross-sectional, Canada, grades 7–9, *N* = 5739/6960	Self-reported	Self-reported	Self-reported	Self-rated physical and mental health	✓	✓
Zhou, 2022	Cross-sectional, China, grades 1–6, *N* = 978	Self-reported	Self-reported	Self-reported	Body composition	✓	✓
Ma, 2022	Cross-sectional, China, grades 4–5, *N* = 2,405	Self-reported	Self-reported	Self-reported	Internet addiction	✓	✓
Zhang, 2022	Cross-sectional and longitudinal, China, grades 7–12, *N* = 6,984	Self-reported	Self-reported	Self-reported	Mental health problem	✓	✗
Garcia, 2023	Cross-sectional, United States, grades 7–12, *N* = 6,984	Self-reported	Self-reported	Self-reported	Obesity	✗	✓

ACC, accelerometer.

45, 50, 64), cognitive development (*n* = 4) (23, 51, 58, 67), dietary patterns (*n* = 1) (27), perceived health (*n* = 2) (46, 56), and myopia (n = 1) (59).

A total of four longitudinal studies (31, 60, 67, 72) examined the association between 24-h movement guidelines and health indicators (Supplementary Table S3), including adiposity (*n* = 3) (31, 60, 67), cardiometabolic health (*n* = 1) (60), and mental and social health (*n* = 2) (67, 72).

3.2 Compliance with 24-h movement guidelines

Figure 2 shows the proportions of children and adolescents meeting the special combination and the general combination of 24-h movement guidelines. 28.8 ± 3.8, 35.3 ± 4.0, 52.8 ± 3.8% meeting the MVPA, ST, sleep guidelines and 18.5 ± 2.1, 45.4 ± 2.5, 29.1 ± 2.0, 7.1 ± 1.0% meeting None, One, Two, Three guidelines, respectively.

Figure 3 illustrates overall adherence to 24-h movement guidelines across age groups, geographical regions, and gender. Adherence to guidelines was higher in male subjects than in female subjects and in children than in adolescents. Regarding geographical regions, we noted variations in overall adherence, with lower rates observed in South America (3.2%) (95% CI:1.3–5.2%) and higher in Europe (14.3%) (95% CI,10.1–18.6%).

3.3 Association between meeting 24-h movement guidelines and health indicators

3.3.1 Adiposity

In this review, adiposity indicators included body mass index (BMI)/ body mass index z-score (BMIz), waist circumference (WC), body fat (BF/BF%/FM/FM%), and waist-to-height ratio (WHtR). The investigation into the associations between adherence to 24-h movement guidelines and BMI/BMIz was conducted in 15 cross-sectional studies (15–19, 29, 31, 37, 41, 44, 46, 60, 73–75), including

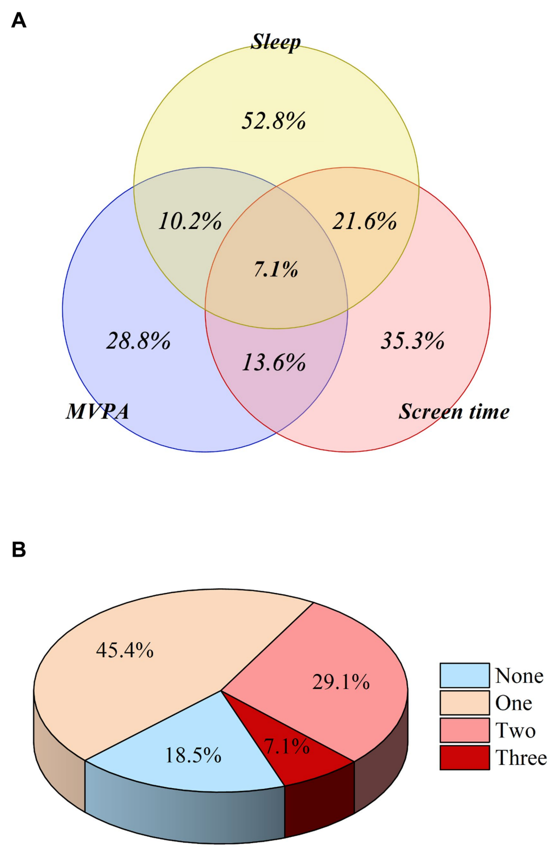

FIGURE 2
Proportion of children and adolescents meeting the specific combination **(A)** and general combination **(B)** of 24-h movement guidelines.

14 studies adhering to the general combination and 14 studies adhering to the specific combination. Of these studies, 10 of 14 reported that meeting the general combination was associated with a lower risk of BMI or BMIz or being obese or overweight. By conducting meta-analyses on five studies (15, 17, 29, 31, 41) with consistent exposures and outcomes, the pooled analysis revealed a significant association. Individuals not meeting any guidelines, compared to meeting all three guidelines, exhibited increased odds of BMI/BMIz (OR = 1.39, 95% CI 1.3–1.49, I^2 = 93.9% p = 0.000) (see Supplementary Figure S1). Furthermore, 10 of 14 studies reported that meeting specific combinations was associated with lower BMI or BMIz or lower risk of being obese or overweight. The majority of studies (8/10) support adhering to MVPA guidelines or combining with MVPA to result in lower levels of adiposity/BMI, etc.

The associations between adherence to 24-h movement guidelines and WC were examined in five cross-sectional studies (17, 19, 31, 60, 73), including four studies that adhered to the general combination and four studies that adhered to the specific combination. Out of these, three of four studies reported that adherence to general combinations was associated with lower WC, whereas the other studies (31) reported meeting none of the guidelines was not associated with WC among children aged 8–10 years and early adolescents aged 10–12 years. Among the specific combinations, one study (17) found that meeting specific combinations was not significantly associated with WC. In contrast, a separate study demonstrated a significant association between meeting MVPA or ST and sleep guidelines and lower WC.

The associations between adherence to 24-h movement guidelines and BF were examined in five cross-sectional studies (19, 31, 52, 70, 74). Three of five studies conducted on meeting general combinations presented an association with lower BF, and two of five studies showed no association. In addition, three of five studies reported insignificant associations between meeting the specific combinations and BF, with the MVPA, ST, or combination specifically showing lower risk.

The associations between adherence to 24-h movement guidelines and WHtR were examined in one cross-sectional study (31). Meeting none of the guidelines was cross-sectionally associated with a higher WHtR among children aged 8–10 years, but no association was observed among early adolescents aged 10–12 years.

Three longitudinal studies (31, 60, 67) investigated the associations between adherence to 24-h movement guidelines and adiposity, including BMI/zBMI, BF%, WC, and WHtR. All studies conducted on meeting all three guidelines at baseline were inversely associated with adiposity at 2-year follow-up, with specific combinations emphasizing the MVPA and sleep guidelines.

3.3.2 Cardiometabolic health

The associations between adherence to 24-h movement guidelines and cardiometabolic biomarkers were investigated in four cross-sectional studies (17, 19, 65, 74). Cardiometabolic biomarkers included systolic blood pressure (SBP), diastolic blood pressure (DBP), subcutaneous adipose tissue (SAT), visceral adipose tissue (VAT), triglycerides, HDL cholesterol, C-reactive protein (CRP), insulin, and glucose. Findings from the general combinations of 24-h movement guidelines indicated that meeting none of the guidelines was associated with higher SBP, higher triglycerides, lower HDL cholesterol, higher CRP, and higher Insulin (17), and meeting all three guidelines was associated with lower SAT, lower VAT, lower triglycerides, and lower glucose (19). Regarding adherence to the specific combinations, all four studies suggested that meeting either the individual or combined guidelines did not show significant associations with most cardiometabolic biomarkers, such as BP, SAT, VAT, triglycerides, HDL cholesterol, insulin, and glucose levels (17, 19).

One longitudinal study (60) explored the associations between adherence to 24-h movement guidelines and cardiometabolic health. The study revealed that meeting all three guidelines at baseline was inversely associated with insulin and CRS, with no association found for glucose, triglycerides, HDL cholesterol, SBP, or DBP at 2-year follow-up. The specific combination emphasized MVPA and MVPA and ST guidelines.

3.3.3 Physical fitness

Six cross-sectional studies (17, 34, 53, 69, 76, 77) examined the associations between adherence to 24-h movement guidelines and physical fitness. Among the general combination and physical fitness, it was found that meeting all six was associated with a higher level of general fitness, cardiorespiratory fitness, muscular strength, speed, and agility; it was not associated with grip strength, sit-up, sit-and-reach, 20-m shuttle run, or flexibility (34). In terms of specific combinations, five of six studies emphasized the importance of MVPA.

3.3.4 Mental and social health

The associations between adherence to 24-h movement guidelines and mental and social health were examined in 15

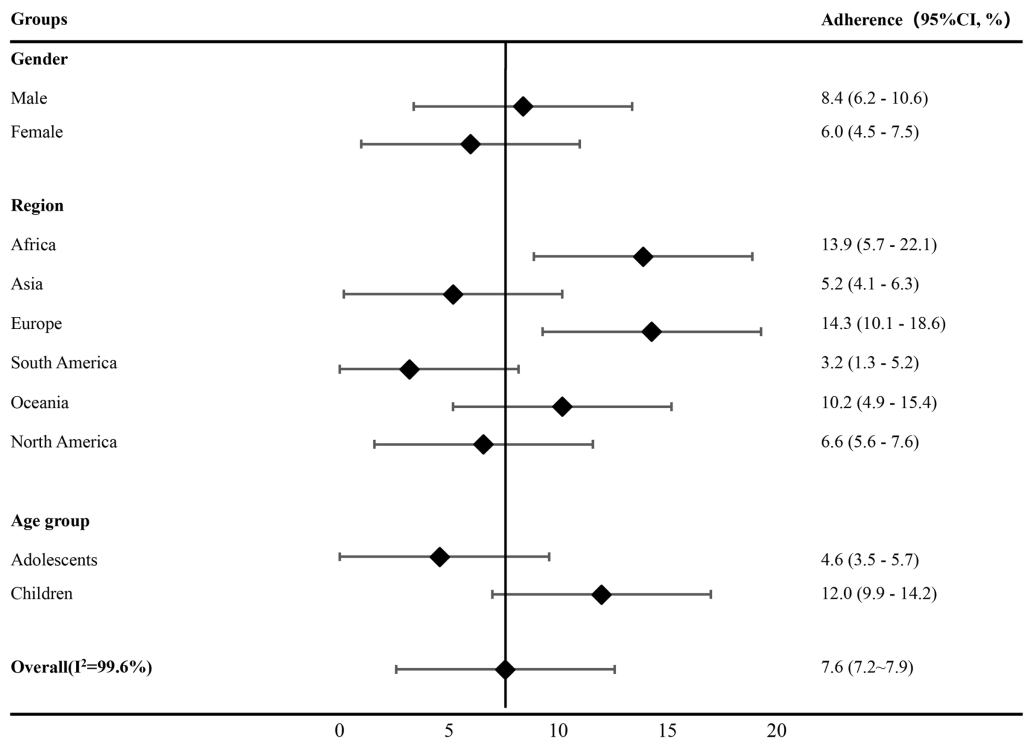

FIGURE 3
Forest plot of the overall adherence to 24-h movement guidelines by gender group, geographical region, and age group; 95% CI, 95% confidence interval.

cross-sectional studies (17, 18, 22, 28, 32, 40, 46, 47, 55, 61, 66, 67, 69, 71, 72). Of those studies, 13 investigated adherence to the general combinations and 14 investigated specific combinations. Eight of thirteen studies showed that meeting all three guidelines was associated with lower emotional problems, not feeling stressed, fewer internalizing and externalizing behaviors, decreased loneliness and sadness, higher perceived self-efficacy, fewer suicidal ideation and suicide attempts, higher positive psychosocial health, higher prosocial behavior, higher satisfaction, lower depressive symptoms, and anxiety. Additionally, five studies indicated that non-compliance with any of the guidelines was associated with higher scores in strengths and difficulties, increased prosocial behavior, lower life satisfaction, little happiness, higher risk of internet addiction, elevated levels of anxiety, and depression. Among the specific combinations, all 14 of 14 studies reported that meeting specific combinations was associated with better mental and social health, with the importance of meeting MVPA only, ST only, sleep only, or ST and sleep.

The associations between adherence to 24-h movement guidelines and mental and social health exhibited differences based on gender and age groups. In Zhu et al. (28) study, it was reported that meeting none of the guidelines was associated with significantly increased odds of anxiety and depression in adolescents aged 12–17, but not in children aged 6–12. Sampasa's study (47) found that meeting all three guidelines was associated with lower suicidal ideation among those aged 15–20 years, but not younger aged 11–14 years. Furthermore, the study demonstrated that meeting all three guidelines had a statistically significant association with suicidal ideation and attempts among boys, while no significant association was observed among girls.

Two longitudinal studies (67, 72) explored the associations between adherence to 24-h movement guidelines and mental and social health. One study (72) revealed adolescents who met all three guidelines at baseline displayed lower anxiety and depression symptoms at 6 months. Another study (67) emphasized that MVPA and sleep at baseline was inversely associated with cognition, psychosocial, and gray matter volumes at 2-year follow-up.

3.3.5 Health-related quality of life

Three cross-sectional studies (21, 43, 46) examined the associations between adherence to 24-h movement guidelines and health-related quality of life, including two studies that met the general combination and three studies that met the specific combination. Both studies reported that adherence to meeting all three guidelines had better HRQoL. Regarding specific combinations, meeting any individual guideline or any combination was associated with higher scores in HRQoL outcomes, as indicated by three studies.

3.3.6 Academic achievement

Four cross-sectional studies (35, 45, 50, 64) examined the associations between adherence to 24-h movement guidelines and academic achievement, with three studies meeting the general combination and four studies meeting the specific combination. As for the general combination, two studies (35, 50) reported that meeting all three guidelines was associated with higher academic achievement, and one study (45) showed that meeting at least two out of the three guidelines was associated with better academic achievement. Regarding specific combinations, one study (35) highlighted the significance of meeting MVPA guidelines for numeracy achievement, meeting the ST and sleep guidelines demonstrated the strongest positive association with literacy achievement. Another study (45) found that meeting the ST guidelines was associated with higher average academic index and English scores. Additionally, one study (50) that reported meeting the MVPA and sleep guidelines, both independently or together, was associated with higher academic achievement. Another study (64) showed that students who met ST or sleep displayed better academic achievement.

3.3.7 Cognitive development

Four cross-sectional studies (23, 51, 58, 67) examined the associations between adherence to 24-h movement guidelines and cognitive development. Of this, two studies evaluated the general combination and four studies explored the specific combination. Two of the studies found that meeting the general combination was associated with superior cognitive development. Among the specific combinations, studies emphasized the importance of MVPA and ST and ST and sleep guidelines to promote better cognition.

3.3.8 Perceived health

Two cross-sectional studies (46, 56) examined the associations between adherence to 24-h movement guidelines and perceived health. It was found that meeting all three guidelines did not show any association with perceived health when compared to meeting none. However, meeting the MVPA or MVPA and sleep or ST and sleep was associated with better-perceived health.

3.3.9 Dietary patterns

The associations between adherence to the 24-h movement guidelines and dietary patterns were examined in one cross-sectional study (27). The findings revealed that meeting a higher number of guidelines was linked to improved dietary patterns, while meeting ST guidelines showed a particularly strong association with desirable dietary patterns.

3.3.10 Myopia

One cross-sectional study (59) examined the associations between adherence to 24-h movement guidelines and myopia, revealing that meeting the general combination was negatively associated with a reduced risk of myopia. Among the specific combinations, encouraging sleep or ST and sleep was recommended to reduce the risk of myopia.

4 Discussion

We found that only 7.6% of children and adolescents met all three guidelines of the 24-h movement guidelines. This meta-analysis identified several correlates that could account for the low adherence. First, a significant association was observed between gender and meeting all three guidelines, with a higher proportion of male subjects compared to female subjects. Second, the association between the age group and meeting all three guidelines indicated that a higher proportion of children compared to adolescents fulfilled the guidelines. Third, the adherence to all three guidelines varied by region, with children from South Africa having a lower proportion.

Our study revealed low overall adherence to 24-h movement guidelines among children and adolescents. These findings are consistent with previous meta-analyses conducted in children and adolescents, reporting adherence to the guidelines ranging from 7.1 to 13% (78, 79). Compared with previous studies, the current study included similar criteria, which combined results from subjective (e.g., self-report or proxy-reported questionnaire and diary) and objective (e.g., accelerometer) measurements. Previous studies have revealed a strong correlation between different instruments that measured MVPA/sleep (80, 81). For the proportion of subjects meeting 24-h movement guidelines, adherence to all three guidelines was 3% with self-reported and 0.2% with accelerometer data (57). It seems that self-reported results may overestimate the prevalence. Further studies should separate self-reported and accelerometer measures for the 24-h movement guidelines.

Larger and more consistent evidence across studies revealed the health implications of adhering to the general combination of 24-h movement guidelines among children and adolescents. Significantly, our findings highlight the favorable health indicators associated with meeting all three guidelines as well as the unfavorable indicators associated with meeting none. Nevertheless, the evidence regarding the associations between meeting 24-h movement guidelines and improved adiposity, cardiometabolic biomarkers, and mental and social health was inconclusive across studies. For example, Shi (44), Jakubec (74), and Guimaraes (46) showed that meeting all three guidelines was not associated with BMIz (44, 46, 74) and FM% (74). It is possible that the results could be explained by almost all participants being adolescents in three studies and the lower proportion meeting all three guidelines. In the context of physical fitness, the majority of studies (34, 53, 69, 77) emphasized the importance of PA. It is known that engaging in regular PA, such as endurance activity, can improve cardiac output, oxygen-carrying capacity, and stroke volume (82). This improvement is a direct result of enhanced cardiorespiratory fitness. Resistance training potently causes increased muscle hypertrophy through an increase in myofibril size and the number of fast- and slow-twitch fibers (83), leading to improved muscular fitness.

Moreover, the neuromuscular performance (84) and reaction time (85) induced by regular PA play a central role in determining agility. Mental and social health in children and adolescents are crucial aspects. Our study observed differences in the association between 24-h movement guidelines and mental and social health based on gender and age. Reasons may vary from environment to social. One reason is that preferences for certain types of PA vary between gender groups. For example, boys might be more inclined toward team sports, while girls may prefer activities with creative components (86). These preferences can influence the association. Another reason is the increase in academic pressure (87), which is more pronounced during adolescence and impacts the association.

Meeting a general combination or specific combination may have positive implications for health indicators. Considering that children and adolescents spend most of their time in school or at home, these settings present ideal opportunities to promote holistic adherence to the 24-h movement guidelines for fostering a healthy lifestyle. Future interventions should consider targeting structured PA in the school setting. Utilizing physical education classes and recess provides opportunities for students to engage in exercise, especially given the strong association of MVPA with adiposity (15, 16, 29, 39, 44, 46, 75), and physical fitness (17, 34, 51). Moreover, home is another setting that should be considered. The modeling of parents plays an important role in promoting sufficient sleep time and limiting ST. This involves creating a conducive sleep environment, establishing consistent bedtime routines, and managing excessive screen-based device use. Encouraging ST and sleep also contributes to better-perceived health, substance use, and executive function (32, 45, 51). Significantly, a positive correlation was observed between meeting a higher number of guidelines and experiencing more favorable health indicators. Consequently, the partnership between the school and home environments holds substantial potential for generating a synergistic influence on the health outcomes of children and adolescents.

Our results need to be interpreted in light of several limitations. The major limitation of our findings was the insufficient evidence to conclude a consistent association between 24-h movement guidelines and exposure variables (e.g., academic achievement). Several plausible explanations may account for the observed associations. To address this gap, more research is needed to investigate and confirm this association. Another constraint is that most of the studies included in this analysis utilized a cross-sectional design, which precludes establishing causal associations. To address this limitation, future research should incorporate longitudinal and experimental designs to provide more robust evidence.

5 Conclusion

The outcomes of this review contribute to the existing body of evidence regarding adherence to the 24-h movement guidelines and their associations with health indicators in children and adolescents. The overall adherence rate is alarmingly low (7.6%), exhibiting notable disparities across age groups, genders, and geographical regions. Meeting 24-h movement guidelines was associated with favorable adiposity, cardiometabolic health, mental and social health, physical fitness, health-related quality of life, academic achievement, cognitive development, perceived health, dietary patterns, and myopia. Presently, the available evidence on health indicators is limited and inconclusive. Given that most of the included studies utilized a cross-sectional design, further research incorporating longitudinal and experimental designs is warranted to enhance comprehension of the association between 24-h movement guidelines and health indicators, as well as facilitate the development of comprehensive 24-h movement guidelines.

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.

Author contributions

HHZ: Writing – original draft, Data curation, Investigation, Methodology. NW: Data curation, Investigation, Methodology, Writing – review & editing. EH: Writing – review & editing, Conceptualization, Project administration. YG: Writing – review & editing, Conceptualization, Supervision, Funding acquisition, Investigation, Project administration, Data curation.

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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

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1351972/full#supplementary-material

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Temporal changes in the physical fitness of Chinese adolescents aged 13-18 years: an analysis of eight national successive surveys over three decades

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Objective: The aim of this study was to assess temporal changes in physical fitness of Chinese adolescents aged 13–18 years from 1985 to 2019.

Methods: Body size /composition and physical fitness indicators, including body height, weight, body mass index (BMI), speed, power, flexibility, muscular endurance, and cardiorespiratory fitness (CRF), were selected from Chinese boys and girls aged 13–18years from eight Chinese National Surveillance on Students' Constitution and Health from 1985 to 2019. Temporal changes in means were estimated by sample-weighted linear regression at the test × sex × age level, and national trends were estimated by a post-stratification population weighting procedure.

Results: Overall mean body height, weight and BMI increased significantly for Chinese adolescents over 34years. There was a small improvement for boys in speed (Effect size [ES]=−0.21, 95% confidence interval [CI]=−0.44~0.02), a small improvement for boys in power (ES=0.24, 95% CI=−0.20~0.69), a small improvement for girls in flexibility (ES=0.45, 95% CI=0.15~0.76), a moderate decline for boys (ES=-0.53 95% CI=−0.84~−0.21) and a moderate improvement for girls (ES=0.61, 95% CI=−0.03~1.26) in muscular endurance, and large declines in cardiorespiratory fitness (CRF) for boys (ES=0.93, 95% CI=0.64~1.21) and girls (ES=0.93, 95% CI=0.58~1.27) from 1985 to 2019. These trends in each component of fitness were more positive for adolescents aged 13–15years than that of adolescents aged 16–18years in both sexes, except for girls in flexibility.

Conclusion: The decline in CRF was most pronounced among Chinese children and adolescents from 1985 to 2019, suggesting a future decline in population health that needs attention.

KEYWORDS

adolescents, physical fitness, body size, temporal changes, public health

1 Introduction

Physical fitness has multiple components, all of which are closely related to the ability to perform physical activity (1). These components span the different functions and structures of body exercise, including musculoskeletal, cardiopulmonary, circulatory, endocrine metabolic and psychoneurological functions (2). Cardiorespiratory fitness

(CRF) reflects the ability of the body to transport oxygen from the atmosphere to the mitochondria for physical activity (3). In children and adolescents, CRF was demonstrated to be an independent predictor of all-cause and cardiovascular mortality (4) and was also recognized as an important predictor of executive function (5), academic performance (6), and psychological well-being (7).

Musculoskeletal fitness (MSF) reflects the ability of a muscle or group of muscles to exert force maximally, explosively, or continuously without fatigue (representing maximal muscular strength, power, and muscular endurance, respectively), as well as the ability to move a joint throughout the range of motion (flexibility) (8). In children and adolescents, low MSF is significantly associated with an increased risk of cardiovascular disease and chronic disability due to cardiovascular disease, as well as all-cause mortality in adulthood (9, 10). Speed has been associated with improved motor skills and their performance-related markers of physical fitness (11). Recent studies have pointed out that sport speed mediates the relationship between obesity and cardiometabolic risk factors. In obese children, increased sport speed was associated with lower blood pressure (12).

Adolescence is a critical period for the healthy development of individuals and the accumulation of human resources, and adolescent health and development not only affects itself but also influences adulthood and the next generation (13). Previous studies have shown that physical fitness among Chinese children and adolescents declined from 1985 to 2014, with significant improvements observed only in the first 10 years (2). Several systematic reviews of trends in physical fitness among adolescents have shown that in recent years, muscular strength, measured by grip strength, has improved in some countries (14), and sit-ups, which reflect muscular endurance worsened (15), and standing long jump, which reflects explosive strength, continued to decline (16). Although these studies provide temporal trends in the physical fitness of Chinese adolescents, they lack some components of fitness and the data are relatively old. Moreover, some studies have found that the prevalence of obesity among Chinese adolescents has accelerated in the last decade, with a reversal of the high prevalence of obesity from childhood to adolescence (17). Given an inverted U-shaped relationship between BMI and physical fitness (2, 18), it is necessary to investigate the temporal changes in physical fitness of Chinese adolescents over the past few decades. Due to the currently observed worldwide decline in physical fitness in adolescents and the potential association between physical fitness and nutritional and health status in adulthood, timely monitoring and feedback on physical fitness status is important for improving population health and developing public health policies.

We assumed that some components of physical fitness among Chinese adolescents have improved over the past 34 years, with sex and age disparities. Therefore, this study analyzed the temporal changes in physical fitness among Chinese children and adolescents over the past 34 years by using the Chinese National Surveillance on Students' Constitution and Health (CNSSCH) surveys in 1985, 1991, 1995, 2000, 2005, 2010, 2014 and 2019.

2 Methods

2.1 Study design and subjects

Data were derived from eight successive cross-sectional CNSSCHs from 1985 to 2019 (19–26), and we extracted physical fitness test results for Chinese Han adolescents aged 7–18 years (who make up 91% of China's total population.) The CNSSCH is a national largest and most representative survey of students' physical fitness and health that is conducted approximately every 5 years using a multistage stratified cluster sampling methodology that maintains consistent sampling and assessment methods throughout each survey year. Twenty-nine provinces/autonomous regions/municipalities (34 in total) were included in the survey in 1985, except for Hong Kong, Macao, Taiwan, Hainan and Chongqing. Hainan has been included in the survey since 1991, Chongqing has been included in the survey since 2000, and Qinghai did not participate in the 1995 survey. Detailed sampling procedures have been described in previous studies (2). In brief, children and adolescents in all provinces except Tibet have been categorized into three levels (high, medium and low) according to their socioeconomic status since 1985 and then stratified according to their place of residence by urban and rural areas, with at least 50 Han Chinese students in each age group participating in the survey. All participants were grouped by sex and age. From 1985 to 2019, 462,960, 462,960, 272,920, 461,975, 462,387, 462,082, 462,022 and 459,386 boys aged 13–18 years and 461,650, 461,650, 272,361, 460,497, 460,796, 460,738, 460,693 and 459,075 girls aged 13–18 years were tested for height, weight, BMI, speed, power, flexibility, muscular strength and CRF, respectively. The ratio of each age group was approximately 1:1, as detailed in Table 1.

2.2 Measures

2.2.1 Body size/component

Body height was measured by a stadiometer to the nearest 0.1 cm. Participants were barefooted, wearing shorts for boys and shorts and short sleeves for girls, and stood with their backs to a column on the base of the stadiometer with their bodies naturally straight and their eyes looking straight ahead. Body weight was measured by an electronic weight scale to the nearest 0.1 kg. Boys wore shorts and girls wore shorts and short sleeves and both stood barefoot in the center of the weight measuring plate, keeping their bodies steady. BMI = [weight(kg)/height(cm)2].

2.2.2 Speed

Speed was measured by a 50-m run to the nearest 0.1 s. Participants in groups of at least 2, using a standing start, recorded the time it took to run 50 m on a flat, straight track (each track 1.22 m wide). Timing was stopped when the participant's chest reached the vertical plane of the finish line. Manual timekeeping in seconds, retaining one decimal place and recording by adding "1" to the first decimal place if the second decimal place is not "0." For example, a reading of 10.11 s should be recorded as 10.2 s.

TABLE 1 Sample size of each CNSSCH by test and sex.

Sex	Tests	Survey years							
		1985	1991	1995	2000	2005	2010	2014	2019
Boys	Height (cm)	102,404	35,333	52,303	53,977	58,984	53,824	53,449	52,686
	Weight (kg)	102,404	35,333	52,303	53,977	58,984	53,824	53,449	52,686
	Body mass index (kg/m^2)				53,977	58,984	53,824	53,449	52,686
	50-m dash (s)	102,404	35,333	52,291	53,894	58,891	53,707	53,321	52,134
	Standing long jump (cm)	102,404	35,333	52,290	53,988	58,946	53,789	53,373	52,264
	Stand/sit-and-reach (cm)	102,404	35,333	52,303	53,537	58,924	53,770	53,368	52,443
	Body pull-ups (reps.)	102,404	35,333	52,303	53,960	58,915	53,651	53,349	52,107
	1,000-m running (s)	102,404	35,333	52,269	52,727	58,302	53,224	53,352	51,775
Girls	Height (cm)	102,149	35,017	52,123	54,153	58,848	53,754	53,432	52,174
	Weight (kg)	102,149	35,017	52,123	54,153	58,848	53,754	53,432	52,174
	Body mass index (kg/m^2)				54,153	58,848	53,754	53,432	52,174
	50-m dash (s)	102,149	35,017	52,096	54,089	58,675	53,639	53,308	51,524
	Standing long jump (cm)	102,149	35,017	52,104	54,171	58,718	53,668	53,332	51,637
	Stand/sit-and-reach (cm)	102,149	35,017	52,123	53,728	58,696	53,649	53,340	52,036
	Sit-ups 60 s (reps.)	102,149	35,017	52,123	54,145	58,731	53,632	53,336	51,560
	800-m running (s)	102,149	35,017	52,056	53,400	58,567	53,601	53,295	50,990

2.2.3 Power

Power was measured by the standing long jump to the nearest 1 cm and performed in a sandpit or on a flat surface with soft soil. The distance from the starting line to the proximal end of the sandpit must not be less than 30 cm. The participant stands behind the jumping line with his/her feet naturally apart, and his/her toes must not step on the line. They take off at the same time with both feet in place and measure the vertical distance between the start line and the post line of the nearest landing spot. Three attempts will be made by each person and the best score will be recorded.

2.2.4 Flexibility

Flexibility was measured by sit-and-reach to the nearest 1 cm. With the electronic sitting forward bending meter, the participant faces toward the instrument, sits on a cushion, and straightens his/her legs forward; the heels are brought together and stomped on the tester's baffle. During the test, the examinee keeps his/her hands together, palms down and flat, knees straight, upper body bent forward, and pushes the cursor smoothly forward with the tips of the middle fingers of both hands until it cannot be pushed. The test is performed twice and the maximum value is recorded.

2.2.5 Muscular endurance

Muscular endurance was measured by using, pull-ups for boys aged 13–18 years, and 1-min sit-ups for girls aged 13–18 years.

2.2.5.1 Oblique pull-ups

The staff adjusts or chooses a low-height bar so that the bar is at the same height as the chest (nipple) of the participants. The participant faces the bar and overhand grips the bar with his/her hands shoulder-width apart, with his/her legs on the ground in front of him/her, keeping his/her arms at 90° to his/her trunk, and his/her trunk and legs in a straight line. Then, the bent arm was pulled up, when the jaw could touch or exceed the horizontal bar, the arms were extended to recover. For the completion of one, the total completion time was recorded.

2.2.5.2 Pull-ups

At the beginning of the pull-ups, the participant's hands are separated shoulder-width apart, positively gripping the bar, and the body is in a straight-armed hanging position. No additional movement is allowed during the pull-up process. When the participant's jaw exceeds the upper edge of the bar, the participant returns to the starting position, thus completing one pull-up and recording the total number completed times.

2.2.5.3 Sit-ups

The participant lies on a cushion with his/her whole body on his/her back, legs slightly apart, knees bent at an angle of approximately 90°, and fingers crossed behind his/her head. When upping, both elbows touched or exceeded both knees as completion of one sitting. Both shoulder blades must touch the cushion when lying on the back. The number of completions in 1 min was recorded.

2.2.6 CRF

CRF was assessed by 1,000-m running for boys aged 13–18 years and 800-m running for girls aged 13–18 years. 1,000-m running or 800-m running: the time when running 1,000 m or 800 m on a flat runway, accurate to 0.01 s.

A group of trained investigators measured five components of physical fitness according to standardized procedures. Specific testing procedures and details are described in previous studies (2). The same measurement program was used at all survey sites and points in time. All the measurement instruments used were consistent in each survey year and were calibrated before use. The measurement was conducted from March to June from 1985 to 1995 and from September to November in subsequent survey years.

2.3 Statistical analysis

Using the published summary dataset, all results for body size/component and physical fitness indicators are expressed as the mean and standard deviation (SD). Temporal changes in body shape and physical fitness were estimated for each test × sex × age group by sample-weighted linear regression. Linear models were used because they naturally summarize overall trends (8). We expressed change as absolute change (i.e., the slope B of the regression), percentage change (% per year, i.e., the slope of the regression as a percentage of the sample-weighted mean of all means in the regression), and standardized (Cohen's) effect size (ES) (i.e., the slope of the regression divided by the combined SD of all SDs in the regression). The 95% confidence interval (CI) for absolute change was calculated as the slope of the regression ±1.96 standard error (27). From the above calculations, we obtained three annual changes, where the overall absolute change is the absolute annual change multiplied by 34, and the overall relative change, the overall effect size, and their 95% CIs were calculated in the same way. Following the procedure described by Tomkinson et al., (15, 16) we calculated population-weighted mean changes for boys and girls aged 7–18 years by combining test × sex × age-specific changes using stratified population weights. The population weights were derived from the United Nations' 2000 Chinese sex-age-specific population data (28), with 2000 being close to the median year for the entire period of the survey and the test year included in most studies worldwide (16). To account for the magnitude of changes in the mean, ESs of 0.2, 0.5, and 0.8 were used as thresholds for small, medium, and large, respectively, with ESs of <0.2 considered negligible changes (27). Positive ESs indicate an increase in mean over time, showing a positive trend (opposite for speed and CRF); negative ESs indicate a decrease in mean over time, showing a negative trend (opposite for speed and CRF). All statistical analyses were performed by Excel 2016 and SPSS 27.0, and graphs were plotted using GraphPad Prism 9.3.1.

3 Results

3.1 Changes in body size/composition

The linear regression results in Figure 1 reveals that height, weight and BMI increased in all age groups for both sexes from 1985 to 2019. There was a large increase for overall boys in the mean height (absolute change = 7.97 cm, 95% CI = 7.10 ~ 8.84; percentage change = 4.86, 95% CI = 4.32 ~ 5.39; ES = 1.01, 95% CI = 0.90 ~ 1.11) and weight (absolute change = 12.34 kg, 95% CI = 10.98 ~ 13.70; percentage change = 23.31, 95% CI = 20.80 ~ 25.82; ES = 1.13, 95% CI = 1.00 ~ 1.25) from 1985 to 2019. There was a large increase for overall boys in the mean BMI (absolute change = 3.35 kg/m2, 95% CI = 2.55 ~ 4.15; percentage change = 16.67, 95% CI = 12.75 ~ 20.59; ES = 0.98, 95% CI = 0.74 ~ 1.21) from 2000 to 2019. According to the ESs, the increase was larger in the age group of 13 to 15 years than in the age group of 16 to 18 years. The results for girls were similar to those for boys during the 34 years (Table 2).

3.2 Changes in speed

The linear regression results in Figure 2 reveals that 50-m run performance of boys and girls in each age group showed different linear trends from 1985 to 2019. There was a small improvement in 50-m run performance for overall boys from 1985 to 2019 (absolute change = −0.17 s, 95% CI = −0.34 ~ 0.01; percentage change = −2.03, 95% CI = −4.20 ~ 0.15; ES = −0.21, 95% CI = −0.44 ~ 0.02). There was a negligible change for boys aged 16–18 years, and a small improvement for boys aged 13–18 years (ES = −0.37, 95% CI = −0.60 ~ −0.13). There was a small decline in 50-m run performance for overall girls (absolute change = 0.29 s, 95% CI = 0.01 ~ 0.56; percentage change = 3.04, 95% CI = 0.13 ~ 5.96; ES = 0.31, 95% CI = 0.01 ~ 0.60), as well as for both age categories (Table 3).

3.3 Changes in power

The linear regression results in Figure 3 reveals that standing long jump performance decreased for girls aged 13–15 and 18 years, increased for girls aged 16–17 years and increased for boys in all age groups from 1985 to 2019. There was a small improvement in standing long jump performance for overall boys from 1985 to 2019 (absolute change = 5.64 cm, 95% CI = −4.52 ~ 15.80; percentage change = 2.74, 95% CI = −2.13 ~ 7.61; ES = 0.24, 95% CI = −0.20 ~ 0.69). There was a small improvement for boys aged 13–15 years (ES = 0.30, 95% CI = −0.13 ~ 0.73) and a negligible change for boys aged 16–18 years (ES = 0.18, 95% CI = −0.28 ~ 0.64). There was a negligible change in overall standing long jump performance for girls (absolute change = −1.61 cm, 95% CI = −9.93 ~ 6.71; percentage change = −1.01, 95% CI = −6.07 ~ 4.06; ES = −0.08, 95% CI = −0.52 ~ 0.35), as well as for both age categories (Table 3).

3.4 Changes in flexibility

The linear regression results in Figure 4 reveals that sit-and-reach performance increased for girls in all age groups and decreased for boys in all age groups from 1985 to 2019. There was a negligible change in sit-and-reach performance for overall boys (absolute change = −1.31 cm, 95% CI = −2.72 ~ 0.11; percentage change = −12.72, 95% CI = −27.87 ~ 2.43; ES = −0.19, 95% CI = −0.39 ~ 0.02) and a small decline for boys aged 16–18 years (ES = −0.29, 95% CI = −0.51 ~ −0.07). There was a small improvement in sit-and-reach performance for overall girls (absolute change = 2.96 cm, 95% CI = 0.97 ~ 4.95; percentage change = 26.89, 95% CI = 8.99 ~ 44.80; ES = 0.45, 95% CI = 0.15 ~ 0.76), as well as for both age categories (Table 3).

3.5 Changes in muscular endurance

The linear regression results in Figure 5 reveals that muscular endurance performance worsened for boys in all age groups and improved for girls in all age groups from 1985 to 2019. There was a moderate decline in pull-up performance for overall boys (absolute change = −2.34 cm, 95% CI = −3.69 ~ −0.98; percentage change = −45.51, 95% CI = −78.04 ~ −12.97; ES = -0.53 95% CI = −0.84 ~ −0.21), a small decline for boys aged 13–15 years (ES = −0.26, 95% CI = −0.57 ~ 0.05), and a large decline for boys aged 16–18 years (ES = −0.82, 95% CI = −1.14 ~ −0.50). There was a moderate improvement in one-minute sit-up performance for overall

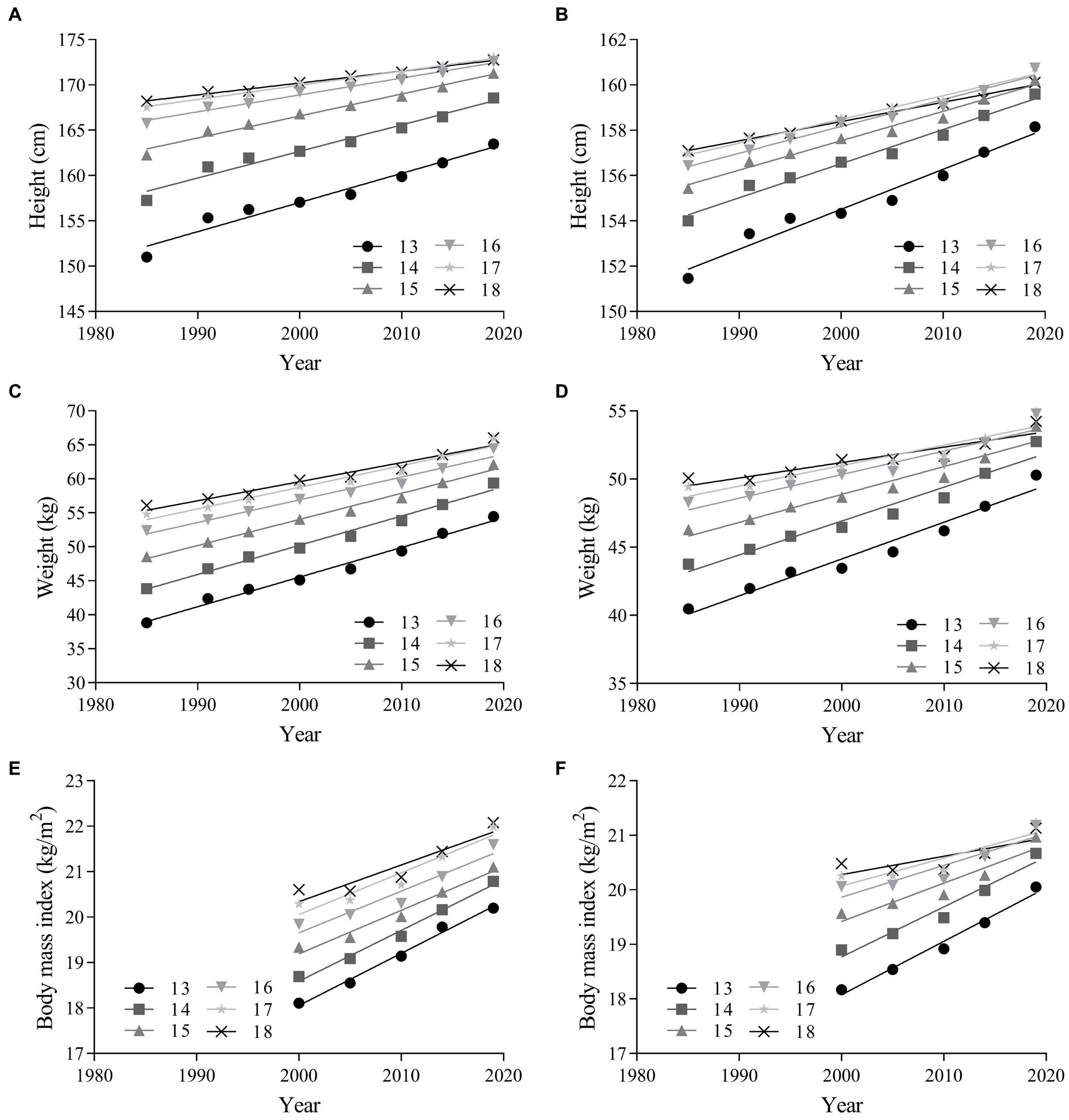

FIGURE 1
Linear regressions of the mean height, weight and body mass index of Chinese adolescents aged 13–18 years from 1985 to 2019. Boys: **(A,C,E)**; girls: **(B,D,F)**.

girls (absolute change = 6.58 reps., 95% CI = −0.28 ~ 13.44; percentage change = 22.59, 95% CI = −1.02 ~ 46.20; ES = 0.61, 95% CI = −0.03 ~ 1.26), as well as for both age categories (Table 3).

3.6 Changes in CRF

The linear regression results in Figure 6 revealed that the mean endurance running performance of boys and girls in each age group increased from 1985 to 2019, which represented decline in CRF. There was a large decline in CRF performance for overall boys (absolute change = 31.98 s, 95% CI = 21.88 ~ 42.07; percentage change = 12.24, 95% CI = 8.43 ~ 16.05; ES = 0.93, 95% CI = 0.64 ~ 1.21), as well as for both age categories (13–15 years: ES = 0.84, 95% CI = 0.48 ~ 1.20; 16–18 years: ES = 1.03, 95% CI = 0.82 ~ 1.23). There was a large decline in CRF performance for overall girls (absolute change = 29.98 s, 95% CI = 18.74 ~ 41.22; percentage change = 12.00, 95% CI = 7.50 ~ 16.49; ES = 0.93, 95% CI = 0.58 ~ 1.27), as well as for both age categories (13–15 years, ES = 0.92, 95% CI = 0.50 ~ 1.34; 16–18 years: ES = 0.94, 95% CI = 0.68 ~ 1.20) (Table 3).

4 Discussion

This study assessed the temporal changes in physical fitness among Chinese adolescents aged 7–18 years from 1985 to 2019. In

TABLE 2 Temporal changes in mean physical size/composition for Chinese adolescents from 1985 to 2019 according to age and sex.

Sexes	Tests	Age categories	*N*	M ± SD	Change in means (95% CI)		
					Absolute	Percent (%)	Standardized ES
Boys	Height (cm)	13 to 15	231,931	162.26 ± 9.59	10.27 (8.96, 11.58)	6.36 (5.55, 7.17)	1.17 (1.02, 1.32)
		16 to 18	231,029	169.82 ± 6.54	5.43 (5.05, 5.82)	3.20 (2.97, 3.43)	0.83 (0.77, 0.89)
		Total	462,960	166.03 ± 9.04	7.97 (7.10, 8.84)	4.86 (4.32, 5.39)	1.01 (0.90, 1.11)
	Weight (kg)	13 to 15	231,926	50.35 ± 12.00	14.22 (13.02, 15.42)	28.61 (26.19, 31.03)	1.24 (1.13, 1.34)
		16 to 18	231,023	58.78 ± 10.23	10.25 (8.72, 11.79)	17.47 (14.86, 20.08)	1.01 (0.86, 1.16)
		Total	462,949	54.56 ± 11.92	12.34 (10.98, 13.70)	23.31 (20.80, 25.82)	1.13 (1.00, 1.25)
	Body mass index (kg/m^2)	13 to 15	136,722	19.63 ± 3.53	3.67 (3.15, 4.20)	18.75 (16.09, 21.42)	1.05 (0.90, 1.20)
		16 to 18	136,168	20.84 ± 3.33	2.99 (1.89, 4.10)	14.37 (9.06, 19.67)	0.90 (0.57, 1.23)
		Total	272,890	20.24 ± 3.48	3.35 (2.55, 4.15)	16.67 (12.75, 20.59)	0.98 (0.74, 1.21)
Girls	Height (cm)	13 to 15	231,770	156.30 ± 6.32	5.36 (4.77, 5.96)	3.43 (3.05, 3.82)	0.86 (0.77, 0.96)
		16 to 18	229,880	158.45 ± 5.73	3.47 (3.15, 3.79)	2.19 (1.99, 2.39)	0.61 (0.55, 0.66)
		Total	461,650	157.37 ± 6.13	4.46 (3.99, 4.92)	2.84 (2.54, 3.14)	0.74 (0.66, 0.81)
	Weight (kg)	13 to 15	231,785	46.93 ± 8.37	8.04 (6.67, 9.41)	17.29 (14.35, 20.21)	0.98 (0.82, 1.15)
		16 to 18	229,880	51.05 ± 7.26	4.63 (3.34, 5.91)	9.07 (6.56, 11.59)	0.64 (0.46, 0.81)
		Total	461,665	48.98 ± 8.10	6.41 (5.08, 7.74)	13.35 (10.62, 16.09)	0.82 (0.65, 0.99)
	Body mass index (kg/m^2)	13 to 15	136,481	19.58 ± 3.02	2.97 (2.23, 3.70)	15.22 (11.49, 18.96)	0.99 (0.74, 1.24)
		16 to 18	135,390	20.52 ± 2.73	1.61 (0.61, 2.60)	7.83 (2.98, 12.69)	0.59 (0.22, 0.95)
		Total	271,871	20.05 ± 2.92	2.32 (1.46, 3.17)	11.69 (7.42, 15.96)	0.80 (0.49, 1.10)

Positive trends indicated temporal increases in means and negative trends indicated temporal declines in means. Standardized changes in means of 0.2, 0.5, and 0.8 were used as thresholds for small, moderate, and large, respectively, with an ES of < 0.2 considered to be negligible.
N is the sample size, M is the mean, SD is the standard deviation, CI is the confidence interval and ES is effect size.

addition, changes in body size/composition were also investigated, which may help to understand potential influencing factors (29, 30). The main findings during the 34 years were that (a) mean height, weight and BMI increased significantly for both sexes, (b) there was a small improvement for boys and a negligible change for girls in speed, (c) there was a small improvement for boys and a negligible change for girls in power, (d) there was a negligible change for boys and a small improvement for girls in flexibility, (e) there was a moderate decline for boys and a moderate improvement for girls in muscular endurance, (f) there were large declines in CRF in both sexes, and (g) the trends in each component of fitness were more positive for adolescents aged 13–15 years than that for adolescents aged 16–18 years in both sexes, except for girls in flexibility.

The study found a large decline in CRF for Chinese adolescents over 34 years, which was consistent with other studies in China (2, 31–33). A systematic review by Lang et al. (34) found that CRF levels (measured by 20-m shuttle run) of Chinese children and adolescents aged 9–17 years, when compared with international standards, were at a level of moderate and ranked 25th among 50 countries. A systematic review of trends in physical fitness in children and adolescents in many countries, pooled by Tomkinson et al. showed that global CRF (mainly measured by 20-m shuttle run) worsened from 1975 until it stabilized at the beginning of the 21st century (35–37). Führer (38) et al. found that CRF (as measured by different tests) improved in children and adolescents globally from 1972 to 1986, then declined continuously until approximately 2010, stabilized and even improved again. In summary, there is evidence that global CRF in children and adolescents declined and stabilized by the turn of the century, especially in Western industrialized countries. However, several studies that included the most recent 10-year span found that CRF in children and adolescents continued to decline (39, 40). This indicates that although the decline in CRF has been restrained globally, it continues to decline in some countries.

We found that there was a small improvement for boys and a negligible change for girls in power. The results of other domestic studies were more negative compared with our study (2, 33), which may be due to different research methods and the improvement of physical fitness for children and adolescents nationwide in recent years. A review on standing long jump performance of 10,940,801 children and adolescents from 29 countries showed negligible international improvement from 1960 to 2017 (16) and a 38% improvement in international sit-up performance from 1964 to 2017 (15), similar to our findings. Changes in flexibility are not consistent between boys and girls. Decrease in flexibility in boys and increase in girls was found in Hong Kong (8) and Slovenia (38), decreases in Poland for both sexes (41), and slight increases in Germany for both sexes (42). The trend of flexibility is not yet consistent across countries, but it can be found that girls perform relatively better.

A systematic review by Führer et al. (42) found an increase in speed for adolescents worldwide since 2002. Other unquantified systematic reviews have shown inconsistent speed trends across countries (43, 44). In addition, we found significant differences between countries in items tested for speed. Short-distance sprints (e.g., 30/50/60-m runs) are associated with the ability to move quickly, and speed agility (e.g., 10 × 5-m shuttle runs) also includes the ability to react quickly to stimuli and to change body position/direction (11). A study in Italy chose three different programs to test speed, and they found that performance in short-distance sprints stabilized over the

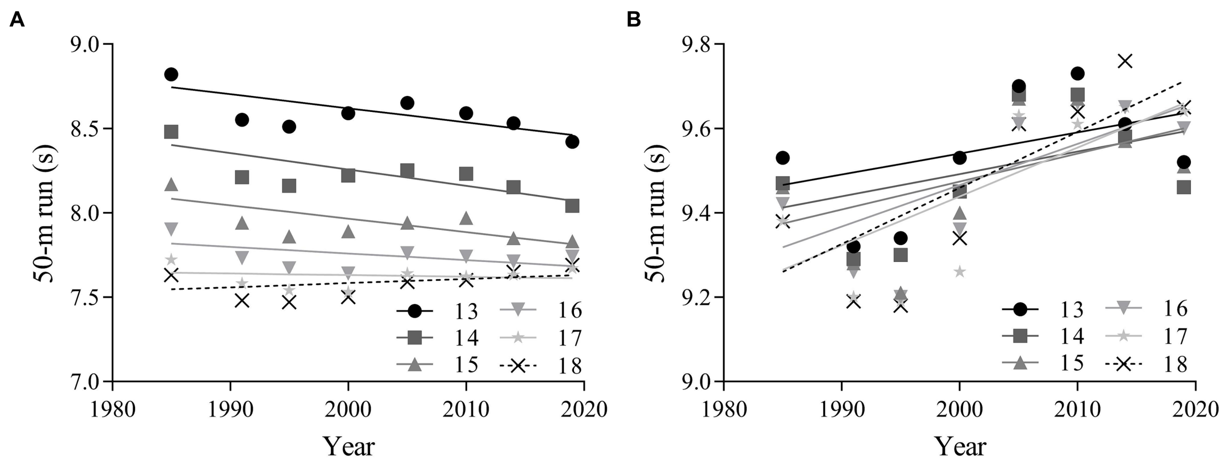

FIGURE 2
Linear regressions of the 50-m run performance of Chinese adolescents aged 13–18 years from 1985 to 2019. Boys: **(A)**; girls: **(B)**.

last 30 years, but performance in shuttle runs declined (45). Therefore, we estimate that differences in temporal changes in speed across countries may be related to different programs, although speed is highly genetically determined (43). In short, current trends in worldwide speed vary across countries.

Explanations about trends in physical fitness may be related to several factors, including social, behavioral, physical, psychosocial, and physiological factors (15, 16). This paper found that there a large increase in weight and BMI in both sexes. Previous studies have shown an inverted U-shaped relationship between BMI and physical fitness, suggesting that malnutrition and overweight/obesity may have a negative impact on physical fitness (2, 18). Roth (46) reported that taller people should also be allowed a higher BMI to be considered fit. This paper revealed a concurrent increase in height and BMI, which suggested that a portion of the increase in BMI might be beneficial. Unfortunately, the threshold for this increase in this paper was currently unknown and needed to be explored in additional research. Moreover, this study was unable to provide the trend of the prevalence of overweight/obesity, and some studies using the same survey may provide some evidence. Since the reform and opening up in 1978, China's economy, diet and social structure have been transformed, and people's living conditions have improved significantly. According to a survey from CNSSCH, the prevalence of thinness among Chinese children and adolescents decreased from 16.4% in 1985 to 2.3% in 2014 (47) and continued to decrease through 2019 (48). The prevalence of overweight and obesity increased from 1.2% in 1985 to 23.4% in 2019, an increase of 18.1 times, and the prevalence of obesity increased from 0.1% in 1985 to 9.6% in 1985, an increase of 75.6 times (48). This could be the reason for the decline in physical fitness. Meanwhile, CRF declined significantly, which may be due to the stronger correlation between body size/composition and CRF. Previous studies have estimated that the increased prevalence of overweight and obesity in the last few years explains 35%~70% of CRF performance in children and adolescents (37).

Trends in physical fitness performance may be influenced by concurrent trends in biological maturation (16, 37), which, along with trends in body size, are thought to be influenced by improved standards of living (e.g., nutrition, education, and income) and more effective prevention and treatment of disease, although it is difficult to quantify the impact of these factors on trends in physical fitness. Older children and adolescents typically perform better than younger counterparts (49), which may be due to increased physical and neuromuscular maturity. A CNSSCH survey showed that the age at spermarche for Chinese boys and the age at menarche for Chinese girls declined from 1985 to 2019 (50, 51), which may be related to the decline in physical fitness in adolescents. The relationship between trends in maturation and trends in physical fitness performance may be mediated by psychosocial factors (52). Girls may be more socially self-conscious during adolescence and therefore more susceptible to peer responses to maturing bodies, decreasing physical activity participation and negatively affecting physical fitness (52, 53). The rate of inadequate moderate to high intensity physical activity (MVPA) among Chinese adolescents aged 13–18 years was 83.4% in 2010 and increased to 83.8% in 2019 (54). MVPA was positively associated with CRF, whereas sedentary time (ST) was negatively associated with CRF (55), and the decline in physical activity level may also be one of the reasons for the decline in physical fitness, especially for CRF.

We also found relatively positive trends in physical fitness among adolescents aged 13–15 years compared to those of adolescents aged 16–18 years. Recognizing the specificity of schools in promoting adolescent health, the Chinese government used "examinations" as a mandatory tool to promote physical fitness among Chinese adolescents. The most typical of these is the Physical Education Entrance Examination for Senior High School (PEESHS) (56). Piloting from the 21st century, most districts in China started the PEESHS in 2007 (57), signifying the full implementation of the policy. Surveys from CNSSCH show that the proportion of Chinese adolescents aged 13–15 and 16–18 with excellent and good physical fitness status has declined by 2.7, 18.5 and 47.1%, 46.7%, respectively, over the past 30 years, and the attainment rate of adolescents aged 13–15 has been higher than that of adolescents aged 16–18 (58, 59). As Wang (60) found that in the past 30 years, Chinese adolescents' academic burden has become increasingly heavier, physical education classes have been marginalized, and technological advances (Internet, smartphones, video games, etc.) have compressed the time for adolescents to engage in physical exercise, and the lack of accessibility to sports places has limited their participation in physical exercise. These factors have a tendency to have an increased role with age, as

TABLE 3 Temporal changes in mean physical fitness for Chinese children and adolescents from 1985 to 2019 according to age and sex.

Sexes	Tests	Age categories	*N*	M ± SD	Change in means (95% CI)		
					Absolute	Percent (%)	Standardized ES
Boys	50-m dash (s)	13 to 15	231,422	8.27 ± 0.85	−0.29 (−0.48, −0.11)	−3.56 (−5.82, −1.30)	−0.37 (−0.60, −0.13)
		16 to 18	230,553	7.66 ± 0.69	−0.03 (−0.18, 0.13)	−0.33 (−2.40, 1.75)	−0.04 (−0.27, 0.20)
		Total	461,975	7.96 ± 0.83	−0.17 (−0.34, 0.01)	−2.03 (−4.20, 0.15)	−0.21 (−0.44, 0.02)
	Standing long jump (cm)	13 to 15	231,593	198.41 ± 25.84	7.12 (−3.12, 17.36)	3.58 (−1.61, 8.77)	0.30 (−0.13, 0.73)
		16 to 18	230,794	222.98 ± 21.99	4.01 (−6.06, 14.07)	1.81 (−2.71, 6.33)	0.18 (−0.28, 0.64)
		Total	462,387	210.68 ± 26.96	5.64 (−4.52, 15.80)	2.74 (−2.13, 7.61)	0.24 (−0.20, 0.69)
	Stand/sit-and-reach (cm)	13 to 15	231,461	7.90 ± 6.68	−0.63 (−1.89, 0.63)	−8.25 (−24.77, 8.26)	−0.10 (−0.29, 0.10)
		16 to 18	230,621	11.55 ± 7.10	−2.05 (−3.63, −0.48)	−17.64 (−31.29, −4.00)	−0.29 (−0.51, −0.07)
		Total	462,082	9.72 ± 7.13	−1.31 (−2.72, 0.11)	−12.72 (−27.87, 2.43)	−0.19 (−0.39, 0.02)
	Body pull-ups (n)	13 to 15	231,321	3.37 ± 4.07	−1.06 (−2.30, 0.19)	−29.87 (−69.33, 9.60)	−0.26 (−0.57, 0.05)
		16 to 18	230,701	5.93 ± 4.59	−3.75 (−5.22, −2.27)	−62.77 (−87.66, −37.87)	−0.82 (−1.14, −0.50)
		Total	462,022	4.65 ± 4.52	−2.34 (−3.69, −0.98)	−45.51 (−78.04, −12.97)	−0.53 (−0.84, −0.21)
	1,000-m run (s)	13 to 15	229,447	270.45 ± 38.08	31.21 (17.86, 44.56)	11.46 (6.54, 16.38)	0.84 (0.48, 1.20)
		16 to 18	229,939	250.83 ± 32.06	32.83 (26.33, 39.33)	13.10 (10.50, 15.69)	1.03 (0.82, 1.23)
		Total	459,386	260.63 ± 47.30	31.98 (21.88, 42.07)	12.24 (8.43, 16.05)	0.93 (0.64, 1.21)
Girls	50-m dash (s)	13 to 15	231,209	9.51 ± 0.92	0.19 (−0.08, 0.47)	2.01 (−0.87, 4.89)	0.21 (−0.09, 0.51)
		16 to 18	229,288	9.46 ± 0.96	0.39 (0.12, 0.67)	4.17 (1.22, 7.12)	0.41 (0.12, 0.70)
		Total	461,975	9.49 ± 0.94	0.29 (0.01, 0.56)	3.04 (0.13, 5.96)	0.31 (0.01, 0.60)
	Standing long jump (cm)	13 to 15	231,341	161.92 ± 19.45	−3.40 (−11.58, 4.78)	−2.11 (−7.17, 2.94)	−0.18 (−0.60, 0.25)
		16 to 18	229,455	166.75 ± 19.00	0.33 (−8.14, 8.81)	0.20 (−4.88, 5.28)	0.02 (−0.43, 0.46)
		Total	462,387	164.32 ± 19.38	−1.61 (−9.93, 6.71)	−1.01 (−6.07, 4.06)	−0.08 (−0.52, 0.35)
	Stand/sit-and-reach (cm)	13 to 15	231,330	10.28 ± 6.51	3.21 (1.27, 5.15)	31.33 (12.41, 50.25)	0.50 (0.20, 0.79)
		16 to 18	229,408	12.18 ± 6.57	2.68 (0.64, 4.73)	22.06 (5.26, 38.87)	0.41 (0.10, 0.72)
		Total	462,082	11.23 ± 6.61	2.96 (0.97, 4.95)	26.89 (8.99, 44.80)	0.45 (0.15, 0.76)
	1-min sit-ups (n)	13 to 15	231,338	28.54 ± 10.68	5.76 (−0.59, 12.12)	20.14 (−2.14, 42.41)	0.54 (−0.06, 1.13)
		16 to 18	229,355	29.58 ± 10.72	7.48 (0.06, 14.89)	25.27 (0.21, 50.33)	0.70 (0.01, 1.39)
		Total	462,022	29.06 ± 10.71	6.58 (−0.28, 13.44)	22.59 (−1.02, 46.20)	0.61 (−0.03, 1.26)
	800-m run (s)	13 to 15	230,384	250.60 ± 33.58	30.91 (16.80, 45.02)	12.32 (6.69, 17.94)	0.92 (0.50, 1.34)
		16 to 18	228,691	248.68 ± 30.84	28.96 (20.85, 37.07)	11.65 (8.38, 14.91)	0.94 (0.68, 1.20)
		Total	459,386	249.64 ± 32.26	29.98 (18.74, 41.22)	12.00 (7.50, 16.49)	0.93 (0.58, 1.27)

Positive trends indicated temporal increases in means and negative trends indicated temporal declines in means. Standardized changes in means of 0.2, 0.5, and 0.8 were used as thresholds for small, moderate, and large, respectively, with an ES of < 0.2 considered to be negligible.
N is the sample size, M is the mean, SD is the standard deviation, CI is the confidence interval and ES is effect size.

demonstrated by the fact that adolescents' physical exercise behavior decreases with age (61).

This study is the first to investigate temporal changes in the physical fitness of Chinese adolescents over the past three decades. We collected data from repeated cross-sectional national surveys that were representative of the population and used a trained measurement team. We include potential demographic characteristics in our estimates, while stratified analyses helped to control for confounding effects of sex and age. We also estimated changes in the mean body size/composition of children and adolescents, providing some support for the interpretation of trends in physical fitness. This study has several limitations. First, because we could only estimate temporal changes from descriptive data, we were unable to statistically adjust for trends in underlying mechanistic factors (e.g., physical activity

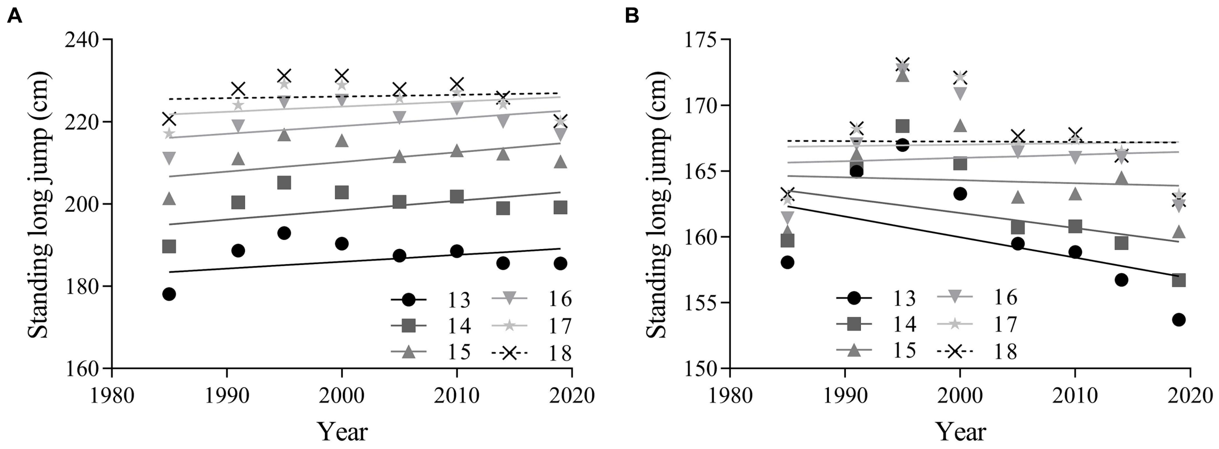

FIGURE 3
Linear regressions in standing long jump performance of Chinese adolescents aged 13–18 years from 1985 to 2019. Boys: **(A)**; girls: **(B)**.

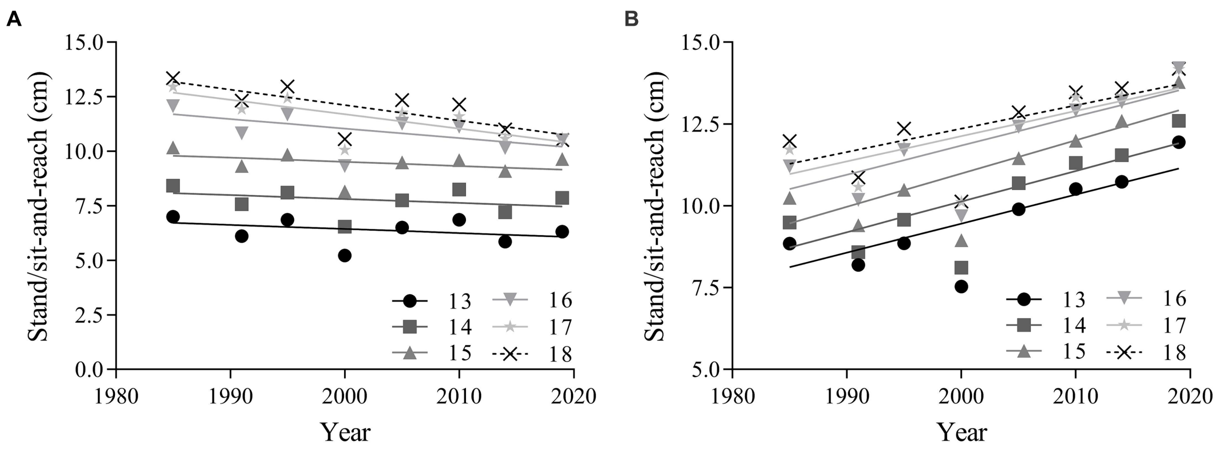

FIGURE 4
Linear regressions in sit-and-reach performance of Chinese adolescents aged 13–18 years from 1985 to 2019. Boys: **(A)**; girls: **(B)**. From 1985 to 2000, the flexibility test was stand-and-reach. Since 2005, sit-and-reach has been used to measure flexibility.

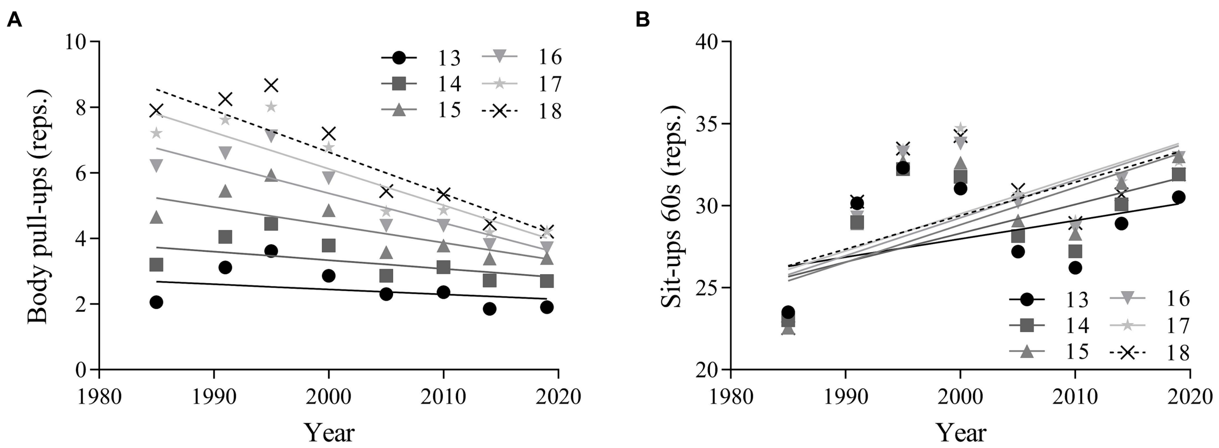

FIGURE 5
Linear regressions in muscular endurance performance of Chinese adolescents aged 13–18 years from 1985 to 2019. Boys: **(A)**; girls: **(B)**. Muscular endurance is assessed by pull-ups for boys aged 13–18 years, and 1-min sit-ups for girls aged 13–18 years.

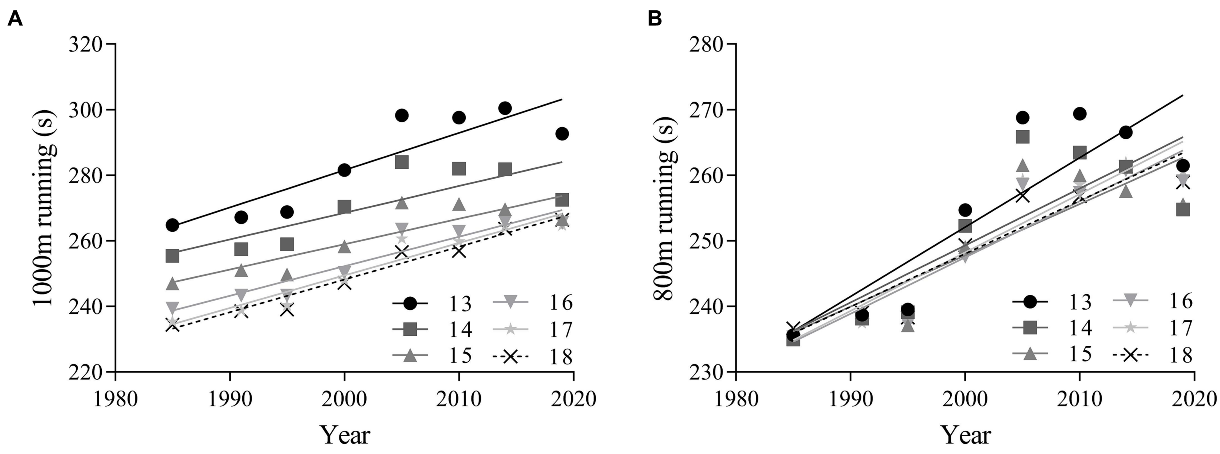

FIGURE 6
Linear regressions of the endurance running performance of Chinese adolescents aged 13–18 years from 1985 to 2019. Boys: **(A)**; girls: **(B)**. Cardiorespiratory fitness is assessed by 1,000-m running for boys aged 13–18 years, and 800-m running for girls aged 13–18 years.

level, biological maturity). In addition, our study focuses on long-term trends in physical fitness among in-school adolescents and does not include analyses of the out-of-school group, which prevents us from extending the results to the entire population of Chinese adolescents.

5 Conclusion

The height, weight and BMI of Chinese adolescents aged 13–18 years increased significantly from 1985 to 2019. Except for a significant decrease in CRF, the other components of fitness changed little or improved slightly, which may lead to a decline in the health of the population in the future. These trends may have been influenced by nutritional status, biological maturity, physical activity levels or national policies. Recent national efforts to promote physical fitness levels in adolescents have begun to bear fruit, and there is still a need to continue to implement and pursue health promotion strategies to improve the health of the population. We also recommend that physical fitness improvement measures be incorporated into national health surveillance systems to help monitor the progress of physical fitness and public health policies that have been implemented.

Data availability statement

Publicly available datasets were analyzed in this study. The data analyzed during our study from CNSSCH have been published openly and are freely available. The references where these data can be found are: references 19–26.

Ethics statement

This study was based on publicly available datasets. Ethical review and approval was not required for the study, in accordance with the local legislation and institutional requirements.

Author contributions

HR: Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. RT: Funding acquisition, Project administration, Resources, Supervision, Validation, Conceptualization, Software, Writing – review & editing.

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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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