EFFECTIVE STRATEGIES FOR PROMOTING HEALTH-ENHANCING CHILDREN'S PHYSICAL ACTIVITY

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EFFECTIVE STRATEGIES FOR PROMOTING HEALTH-ENHANCING CHILDREN'S PHYSICAL ACTIVITY

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Editorial: "Effective strategies for promoting health-enhancing children's physical activity"

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active lifestyle, exercise, children, health behavior, interventions

Editorial on the Research Topic
Effective strategies for promoting health-enhancing children's physical activity

Introduction

The issue of low children's physical activity (PA) has been important research and professional topic for years (and decades). Its importance increased after the restrictive measures caused by the COVID-19 pandemic (1). PA of children is crucial to the not only physical, but also psychological, social, and cognitive health of children (2, 3). Baring this in mind, there are several gudelines and protocols which recommend that children and youth spend a minimum of 60 min each day in moderate- to vigorous-intensity PA [e.g., (4, 5)]. Researchers tried to explain factors that contribute to modifying behavior (in this context, health behavior) and factors that contribute to formulation of different conceptual models (Bandura's social learning model, Rogers' Innovation Diffusion Theory, etc.) Contemporary society needs a particular scientific focus on the issue of establishment of effective strategies for promoting health-enhancing physical activity for children (6). Explanation of the mechanism of the impact of children's PA and socially appropriate behavior on health is essential for improvement of social interventions strategy. Effective strategies for improving childrens PA and adapting an active lifestyle reduce the spread of mass non-communicable diseases and children's antisocial behavior. Therefore, adopted patterns of children's active behavior can impact their habits over the upcoming years (7).

The topic provides high-quality research on promotion of health-enhancing children's PA, which can offer guidelines for researchers and policymakers at local, regional, national, and international levels. These guidelines can contribute to social intervention by encouraging children's PA with the active role of a certified institution (families, schools, sports organizations, and local communities).

Contribution to the field

This Research Topic has been proposed due to challenges for improvement of children's socially relevant health behavior. It aims to identify existing changes in behavior relevant to health, where PA is an important factor for the change of children's lifestyle. The editorial aimed to scientifically present strategies associated with health-enhancing children's PA and to choose intervention methods for promotion of children's healthy lifestyles. The purpose of the Research Topic was to contribute to cutting-edge knowledge in explaining effective strategies for promoting health-enhancing children's PA. The outcome of this Research Topic is 18 published articles which contribute to the mentioned field from different research aspects.

General insight into the Research Topic shows that the authors of the published manuscripts paid attention to various effective strategies that increase children's PA related to health: (1) active transport to school, (2) family interventions, (3) interventions in school settings and inclusive school environment, (4) academic performance, (5) impact of the geographical and living environment, (6) effectiveness of adequate sport or recreational programs, (7) motor coordination programs improvement, (8) sedentary patterns and health-related physical fitness, and (9) mediator role of sleep.

Firstly, Huang et al. presented valuable findings on the association between active travel to school (ATS) and PA and screen time by individual and parental characteristics among Chinese adolescents. The authors concluded that ATS is a helpful approach in promotion of PA, determined by personal (gender, age, living environment) and parental characteristics (parental educational level and occupations). Yesiltepe et al. considered that cycling, as a way of active transport opportunity, is an individual and social contribution to public health, environmental protection, and climate change control. Therefore, current pandemic conditions could contribute to faster acceptance of cycling as a win-win strategy for individuals, families, and communities. Continuation of that segment of the green agenda and adequately responding to pandemic issues could be children's using outdoor space as an effective solution for PA practice, especially in urban environments proposed by Ma et al. Additionally, the research conducted by Planinšec et al. emphasized that researchers and decision-makers should create and develop an effective strategy for promotion of health-enhancing children's PA in case of similar situations or future lockdown.

Huang et al. conducted a meta-analysis about family interventions to PA and sedentary behavior. Authors included studies published in 2012 and later. They considered the role model of family members to their children and saw family interventions as a promising way of promoting children's PA. Additionally, a systematic review examined PA levels of children and adolescents with or without autism spectrum disorder (ASD) in inclusive schools by Li et al. Liang et al. emphasized the mediating role of sleep between PA and executive function in children with attention to deficit hyperactivity disorder (ADHD), as an essential factor of effective strategies in children's PA Therefore, regular sleep patterns represent a quality base for human health and maintenance of homeostatic needs.

Furthermore, two studies confirmed the significant influence of children's PA on increase of their academic performance (Durić et al.). A systematic review by Petrigna et al. identified that the time spent in PA could encourage their cognitive development and indirectly impact improving academic performance and motor competencies. Learning through movement is suggested as an effective, low-cost, and enjoyable strategy for elementary schoolchildren. On another side, one study (Aleksić Veljković et al.) showed that children's participation in yoga intervention programs increases their motor skills but not their cognitive abilities.

Additionally, when it comes to improvement of motor competencies and health-enhancing children's PA, some studies revealed potential programs that should consist of directions related to gender (Zhang et al.), as well as age and gender (Battaglia et al.), living setting, geographical area, and gender (Gallotta et al.). Progression in physical fitness could be expected with the addition of exercise sessions more than the regular PA curriculum. Therefore, the physical fitness of adolescent girls can be improved with additional school interventions (on the top of regular school physical education activities) by Petrušič et al.

However, the main concern and potential problems are shown in research by Giuriato et al. Namely, authors speculate that nowadays, young people achieve fewer motor experiences than peers in the past, with geographical and sociocultural determinants. Consequently, decreasing sedentary time and promoting physical benefits during sedentary breaks sounds like a possible effective strategy in changing sedentary time patterns proposed by Lu et al. The research conducted by Al-Daghri et al. is compatible with previously mentioned research. It showed that childhood obesity and pediatric

metabolic syndrome (MetS) have steadily increased during the last decade in Saudi Arabia. The authors presented results of intervention programs to prevent cardiometabolic disorders in Arab youth and reported that those programs had modest effects due to COVID-19 imposed lockdowns. Finally, research designed by Feng et al. presents a study protocol article with an in-depth description of the intervention, which is based on a three-arm randomized controlled trial, which will comprise a 12-week intervention and a 12-week follow-up. Authors expect that the proposed study will improve preschoolers' movement behaviors and health outcomes, as well as their parents' movement behaviors.

Conclusion

This Research Topic aimed to identify the effective strategies and good practices for promoting health-enhancing physical activity in childhood. This is due to the fact, that society needs an adequate strategy in maintaining an increasingly active lifestyle for children. This type of societal intervention requires support from institutions from different levels: from the individual (home, family level) to sports organizations (group level) to and finally to the local communities (societal level).The various articles put out on this research topic indicate the complexity of children's activation in physical activity in contemporary society. Implementation of suggested strategies for promoting health-enhancing children's PA is determined by using the comprehensive knowledge and its implementation in family, school settings, sports organizations, and local environments. It can be further developed in different contexts to adapt to conditions that must be fulfilled. It seems that more effective strategies nowadays than ever require the inclusion of more community campaigns, improving access to physical activity infrastructure, and involving more sectors.

Author contributions

RM drafted the editorial. SP, IM, IV, and KA revised and approved the final version. 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 without any commercial or financial relationships that could be construed as a potential conflict of interest.

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SYSTEMATIC REVIEW
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Effects of Family Intervention on Physical Activity and Sedentary Behavior in Children Aged 2.5–12 Years: A Meta-Analysis

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Introduction: To use a quantitative approach to examine the effects of family interventions on physical activity (PA) and sedentary behavior (SB) in children aged 2.5–12 years.

Methods: PubMed, OVID, Web of Science, and others were searched from their inception to May 2020. Intervention studies that examined the effects of family interventions on PA among children aged 2.5–12 years were included in this meta-analysis. Lastly, subgroup analyses were conducted to examine the potential modifying effects of family intervention's characteristics and study quality.

Results: Eleven articles met the inclusion criteria for this review. Studies investigated a range of PA outcomes, including moderate-to-vigorous PA (MVPA), total PA (TPA), daily steps, and SB levels. Meta-analysis showed that family intervention had a significant effect on PA [standardized mean difference (SMD) = 0.10; 95% CI = 0.01–0.19], especially for daily steps [weight means difference (WMD) = 1,006; 95% CI = 209–1,803], but not for SB (WMD = −0.38; 95% CI = −7.21–6.46). Subgroup analyses indicated the improvements in PA occurred when children were 6–12 years old, intervention focused on PA only, intervention duration ≤ 10 weeks, and "low risk of bias" study performed.

Conclusions: Family intervention may be a promising way to promote children's PA levels, especially for daily steps.

Trial Registration: Meta-analysis protocol was registered on PROSPERO: CRD42020193667.

Keywords: physical activity, family intervention, meta-analytic review, parents, children

INTRODUCTION

Physical activity (PA) is a key factor in children's physical and mental health development (1–3), playing a crucial role in bone development (4, 5), motor ability development (6), and self-esteem cultivation (7, 8). Previous studies have shown that a low PA level and high sedentary behavior (SB) level lead to poor health (9), increase the risk of obesity (10) and coronary heart disease (11) from childhood to adolescence, and raise the risk of PA deficiency in adulthood (12, 13). However, advances in technology, automated household appliances, and convenient ways of traffic have led to a decline in PA and an increase in SB (14). Eighty percent of the world's children do not meet the PA recommendation from the World Health Organization (15). Therefore, identifying the effective ways to promote children's PA levels has great public health significance.

The family-centered intervention model is designed to interact, purposefully and systematically, with participants and their family members in family settings, to help prevent and respond to various physical and mental health problems (16). Potential mechanisms of intervention effectiveness include the construct of familial or parental social support, the theoretical and practical guidance of PA and SB to families, the technical and logistical support for parents and children activities, and the role modeling and supervision of parents. Family System Theory also believes that the PA and SB behaviors of family members influence each other (17), and parental involvement is crucial in supporting and managing children's related behaviors (PA, SB, diet, screen time, sleep) (18–22). Based on the Family System Theory, some scholars tried to apply family intervention in the field of PA promotion in children (23–25). Some studies found that family interventions can have a significant effect on increasing children's PA and decreasing SB levels (26–28), but in other studies the positive effect was not observed (29–32). Although previous qualitative reviews examined the effects of family intervention on PA and SB levels in children (22, 33), no quantitative review based on experimental studies has been conducted. Therefore, this study aims to identify the effects of family interventions on PA and SB levels in children aged 2–12 years by a using meta-analytic approach. The findings of this study will provide a reference for children's health care work.

METHODS

Protocol and Registration

This research program has been registered on the PROSPERO System Evaluation Registration Platform, registration number: CRD42020193667. This study has been reported according to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (34).

Data Sources and Search Strategy

Studies were identified by structured database searching from inception until May 2020. Studies were gathered using the following databases: PubMed, OVID, Web of Science, Scopus, and China National Knowledge Internet (CNKI). The following search strings were employed:

(1) Participants: "child*," "preschool," "kindergar*," "pediatric," "young child*," "schoolage*," "nursery school*," "primary school*," "grade school*," "elementary school," "school*," "elementary student*," etc.
(2) Interventions: "intervention," "health promotion," "family," "family-based," "parent*," "parent-based," "home-based," "mother*," "father*," "primary care giver*," "preventi*," "behavio*," "behavior Change*," "treatment," "methods," etc.
(3) Outcome: "physical activity," "exercise*," "sport*," "healthy lifestyle*," "activity*," "inactivity*," "step," etc.
(4) Study design: search words include "random*," "control*," "trial," "comparison," "RCT (randomized controlled trials)," etc.

The exact terms were searched by "OR," different terms were searched by "AND". Then the references in the retrieved documents were browsed and conducted a manual retrieval, and supplemented the missing documents in the retrieval process.

Inclusion and Exclusion Criteria

Inclusion criteria: (1) Participants: children aged 2.5–12 years, basing on PubMed MeSH term definition of preschoolers (2–5 years) and children (6–12 years); (2) Interventions: family Interventions (e.g., intervene in the family, intervene with parents); (3) Outcomes: indicators include PA (including any intensities PA or steps) and SB levels; (4) Study design: randomized controlled trials (RCT) or clinical controlled trials (CCT); (5) published in peer-review journals; and (6) written in English or Chinese.

Exclusion criteria: (1) studies were review article; (2) studies were missing data of PA level as an outcome; (3) participants had physical diseases or dyskinesia; and (4) publications from the same project with a relatively small sample size.

Data Extraction and Management

Two authors (TH and ZH) and a trained research assistant separately categorized all articles and extracted data. Disagreements were resolved through discussion until there was 100% agreement. The following information was extracted: (1) studies characteristics (e.g., title, authors, publication year); (2) participant's characteristics [e.g., age, body mass index (BMI), sample size]; (3) measuring methods and outcomes; (4) types of interventions; (5) intervention focus; (6) intervention duration; and (7) the mean and standard deviation values of pre- to post-intervention differences between treatment and control groups. If there were multiple results of the same study (e.g., report both any intensities PA and steps), their data were considered as an independent study for data analysis. In the case of missing data, this information was requested from the authors a minimum of three times over four weeks.

Quality Assessment

Risk assessment was carried out using the Cochrane Risk of Bias tool (35). The evaluation included (1) Random sequence generation, (2) Allocation concealment, (3) Blinding of personnel, (4) Blinding of outcome assessment, (5) Incomplete outcome data, (6) Selective reporting, and (7) Other bias. The evaluation criteria are as follows: the "√" judgment is a low

risk of bias, the "×" judgment is a high risk of bias, and the "?" judgment is an unclear risk of bias. Each study was based on an overall assessment of seven items, with a rating of high, moderate, and low risk. Two authors (TH and ZH) and a trained research assistant separately estimate and cross-audit all articles using unified standards. Disagreements were resolved through discussion until there was 100% agreement. Statistical charts of risk bias were generated by RevMan 5.3 software.

Statistical Analysis

In this review, a random-effect model was used for meta-analysis of the included studies, and STATA was used for analysis. The primary analysis processes included forest map analysis, heterogeneity test, and subgroup analysis. Statistical analysis of data from different units was performed using a 95% confidence interval (95% CI) standardized mean difference (SMD). The values of the effect size were quantified as large (≥0.8 SMD), medium (0.5 SMD–<0.8 SMD), small (0.2 SMD–<0.5 SMD), or non-significant (<0.2 SMD) (36). The weight means difference (WMD) of 95% CI was used for statistical analysis of data of the same unit. $P < 0.05$ was regarded as a significant difference. Depending on the characteristics of included studies, the subgroup analysis was conducted by outcomes, age, BMI, types of intervention, contents of intervention, intervention duration, measuring methods, and study quality to test whether there were differences in the effects among different subgroups.

I^2 statistics were used to test the between-study heterogeneity. When I^2 < 25%, 25–< 50%, 50– <75% and ≥75% (37), it was defined as very low, low, moderate, and high heterogeneity, respectively. The Egger's test examined publication bias. Sensitivity analysis was conducted to test the robustness of the results, by replacing the fixed-effects model with the random-effects model and removing one study at a time to test whether a single study significantly modified the pooled effect.

RESULTS

Study Selection

A total of 1,596 articles were searched from each database, 1,585 articles were excluded according to the inclusion and exclusion criteria. Finally, 11 articles were included in this study (31, 38–47) (**Figure 1**).

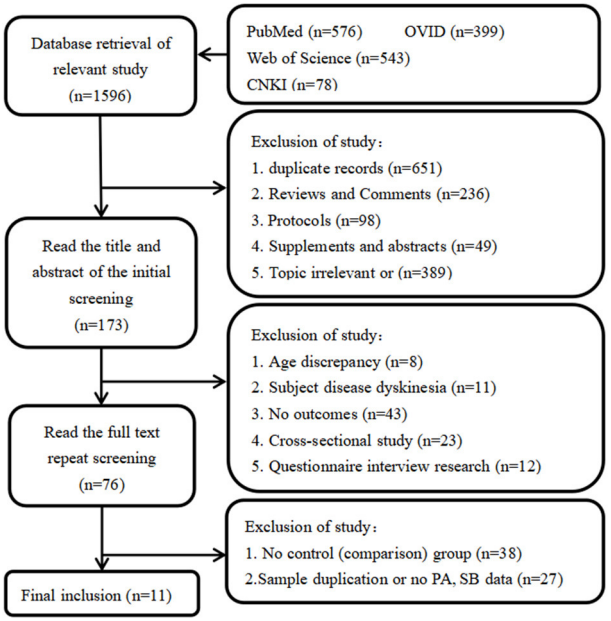

FIGURE 1 | Article selection flow chart for the meta-analysis.

Study Characteristics

All of the included studies were published in 2012 or later, among which seven were published in 2015 or later. Of them, four studies from Australia (38, 40, 45, 46), three from the United States (31, 42, 44). The United Kingdom (47), Germany (43), Finland (41), Norway, and Sweden (39) each have one study. The included studies consisted of 10 RCTs (31, 38–41, 43–47) and 1 CCT (42), with a total of 955 participants in the treatment group and 931 participants in the control group. Five of the included studies (31, 38, 39, 42, 44) only used theory interventions, including PA knowledge education, health behavior lectures, PA counseling services, interviews, and telephone return visits. One of the included studies (41) only used behavior interventions in the specific activity tasks or activity classes that parents and children participated in together. In addition, five of the included studies (40, 43, 45–47) used both theory and behavior interventions. Most interventions included in this review targeted more than one health behavior, and intervention focus was categorized as "PA only" and "included other behavior". Intervention focus, "PA only," focuses only on PA improvement during the intervention, not other health behaviors. "Included other behavior" focuses not only on PA but also on improving other health behaviors (e.g., diet, sleep, screen time) (**Table 1**).

Risk of Bias

Of the 11 articles, six articles (38, 40, 41, 43, 45, 46) were classified as low risk, two articles (31, 47) were classified as moderate risk, and three articles (39, 42, 44) were classified as high risk. All included studies were non-selective, and the integrity of the data results was described in detail. More than half of all articles described randomization, allocation concealment, and blind implementation (**Figures 2**, **3**).

Results of Meta-Analysis

The Results of PA

Meta-analysis of 11 included studies was revealed that family intervention had a significant effect on the improvement of PA in children aged 2.5–12 years (SMD = 0.10; 95% CI = 0.01–0.19). Also, no significant heterogeneity was observed across included studies ($I^2 = 0\%$, $P = 0.52$) (**Figure 4**). Publication bias was also not observed with Egger's test ($P = 0.11$, 95% CI = –0.24–2.08).

Subgroup analysis results showed that subgroups of "daily steps" (WMD = 1,006; 95% CI = 209–1,803), the "≥6 years" (SMD = 0.24; 95% CI = 0.04–0.45), intervention focus "PA only" (SMD = 0.16; 95% CI = 0.01–0.30), intervention duration "≤10 weeks" (SMD = 0.25; 95% CI = 0.09–0.41), and "low risk of bias"

TABLE 1 | Characteristics results of a meta-analysis on the family intervention on PA and SB in children aged 2.5–12 years.

Reference	Year of publication	Study location	Age Mean ± SD	BMI	Sample		Scheme[C]	Scheme[T]		Focus [T3]		Intervention duration	Outcome	Measuring methods[4]
					T	C		Theory[1]	Behavior[2]	PA	In+O			
Tucker et al. (44)	2019	USA	3.6 ± 1.0	Overweight/ Obesity	47	58	Daily PA	√			√	6 mo	MVPA	Questionnaire
Yoong et al. (38)	2019	AUT	4.3 ± 0.5 [T] 4.5 ± 0.6 [C]	Normal	37	37	Daily PA	√			√	3 mo	MVPA, TPA	Accelerometer
Morgan et al. (45)	2019	AUT	4–12	Normal	74	79	Daily PA	√	√	√		2 mo	Daily steps	Pedometer
Laukkanen et al. (39)	2017	NOR and SWE	6.09 ± 1.17 [T] 6.5 ± 1.11 [C]	Normal	44	47	Daily PA	√		√		6 mo	MVPA, SB	Accelerometer
Skouteris et al. (40)	2015	AUT	2.7 ± 0.56 [T] 2.8 ± 0.60 [C]	Normal	71	79	Daily PA	√	√		√	10 we	MVPA, SB	Questionnaire
Tuominen et al. (41)	2015	FIN	6.5 ± 0.5 [T] 6.5 ± 0.5 [C]	Normal	86	89	Daily PA		√	√		7 we	MVPA, SB	Accelerometer
Lloyd et al. (46)	2015	AUT	7.7 ± 2.5	Normal	23	22	Daily PA	√	√		√	7 we	Daily steps	Pedometer
Newton et al. (42)	2014	USA	8.7 ± 1.4	Overweight/ Obesity	13	14	MIG [5]	√		√		12 we	Daily steps, SB	Pedometer Questionnaire
De Bock et al. (43)	2013	GER	5.0 ± 0.2	Normal	433	376	Daily PA	√	√	√		12 mo	MVPA, SB	Accelerometer
Jago et al. (47)	2013	UK	6–8	Normal	25	23	Daily PA	√	√		√	8 we	MVPA	Accelerometer
Østbye et al. (31)	2012	USA	3.06 ± 1.0	Normal	102	107	Daily PA	√			√	8 mo	MVPA, SB	Accelerometer

MVPA, Moderate-to-Vigorous physical activity; TPA, total physical activity; SB, sedentary behavior; T, treatment group; C, control group; "mo"; month, "we", week.

[1]Theory interventions, including lectures on health behavior education, face to face counsel and various forms PA knowledge education; [2]Behavior intervention, including parent-child activity courses or tasks, and intervention measures to complete behavioral tasks; [3]Intervention focus were divided into intervention PA only and included other behaviors. e.g. screen time, a healthy diet (increasing the intake of vegetables, fruits, and water, avoiding the intake of junk food, etc.), promoting high-quality sleep, and supporting scientific parenting. [4]The measuring method of accelerometer and pedometer is an objective measurement, while the questionnaire is a subjective measurement. [5]"MIG" is a minimal intervention group to hand out manuals only. Accelerometers include Actigragh, Kersh Health, Triaxial, and Hookie.

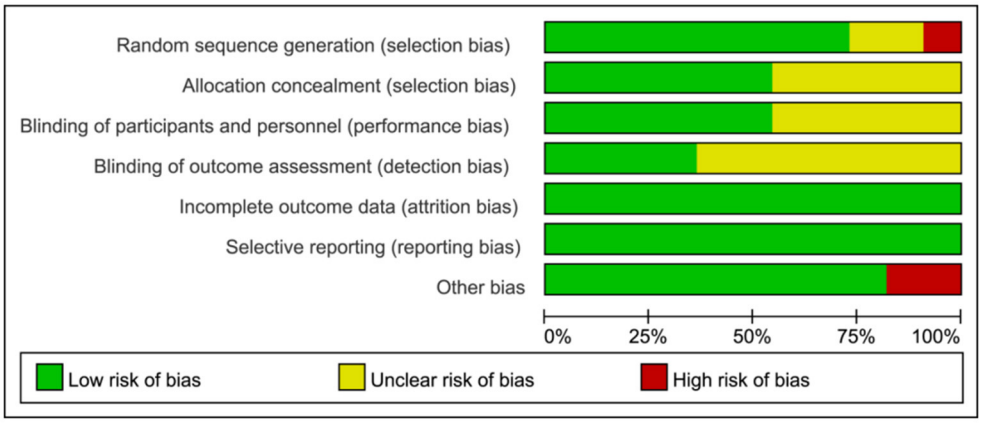

FIGURE 2 | Risk of bias graph each risk of bias item presented as percentages.

(SMD = 0.13; 95% CI = 0.02–0.23) have significant effect in PA promotion (**Table 2**).

The Results of SB

Meta-analysis of 6 included studies was revealed that family intervention had no significant effect on the improvement of SB outcome in children aged 2.5–12 years (WMD = −0.38; 95% CI = −7.21–6.46) (**Figure 5**). There was no significant difference in all subgroups. Also noteworthy was that no significant heterogeneity was observed (I^2 = 0%, P = 0.82) (**Table 3**). Publication bias was also not observed with Egger's test (P = 0.72, 95% CI = −1.36–1.80).

Sensitivity Analysis

Two sensitivity analyses were performed to test the robustness of our results: (1) the findings were consistent when the fixed-effects model was replaced by the random-effects model and (2) the results indicated no single study to be significantly modified by the overall trend by removing one study from the meta-analysis each time.

DISCUSSION

Overall Effect of Family Intervention

This study aimed to quantitatively examine the effect of family interventions on the PA and SB in children aged 2.5–12 years by synthesizing the available literature in this field of inquiry. Through the combined 11 studies included, we found that family intervention could effectively improve the PA of children aged 2.5–12 years, especially for daily steps, but there was no significant effect on SB.

Comparison With Previous Findings

Findings of this study indicated that family interventions have a positive effect on PA in children aged 2.5–12 years, and this study is, therefore, a valuable extension of two published systematic reviews and meta-analysis (48, 49). A meta-analysis provides evidence that school-based interventions can be effective in increasing PA enjoyment in children (48). Jane's (49) meta-analysis, based on school and family interventions, found that family interventions (involving children and parents) had better PA improvement than school interventions (only children). On this basis, when this study concentrates on family interventions, it still found that a significant intervention effect on PA in children. This study may provide additional information and contribute to this area of inquiry from family intervention and PA.

Indeed, a growing body of evidence has shown the benefits of intervention on children's PA (47, 48), however, which index of PA is more sensitive to family intervention remains unclear. Among children, previous reviews suggested that neither active play interventions (50) nor school-based interventions (51) affect moderate-to-vigorous PA (MVPA). In accord with previous studies, findings from this study align with the earlier points indicating that family interventions have no effects on MVPA. However, family interventions significantly improved the children's daily steps by 1,006 steps per day. Among previous reviews suggested that positive relationships between daily steps and physical fitness were observed (52). Daily steps are an excellent indicator of health-related outcomes (53, 54). Some studies suggested converting MVPA to steps because daily steps were generally easier to recognize (55). Findings from this study show that have no significant improvement in MVPA but improve daily steps may be the increased activity comes from LPA, not MVPA. Although PA guideline-recommended to engage in sufficient MVPA to obtain health benefits from PA (56), previous reviews revealed that engaging in more LPA is also suitable for children's health (57, 58). Therefore, it cannot be ignored the potential health effects from family interventions to enhance LPA.

Nevertheless, the results of this review showed that family intervention had no significant effect on SB in children aged 2.5–12 years. It is a disappointing outcome for public health practitioners and researchers who consider the family a promising intervention setting (17). Previous school-based (51) or classroom-based (59) interventions have also been ineffective

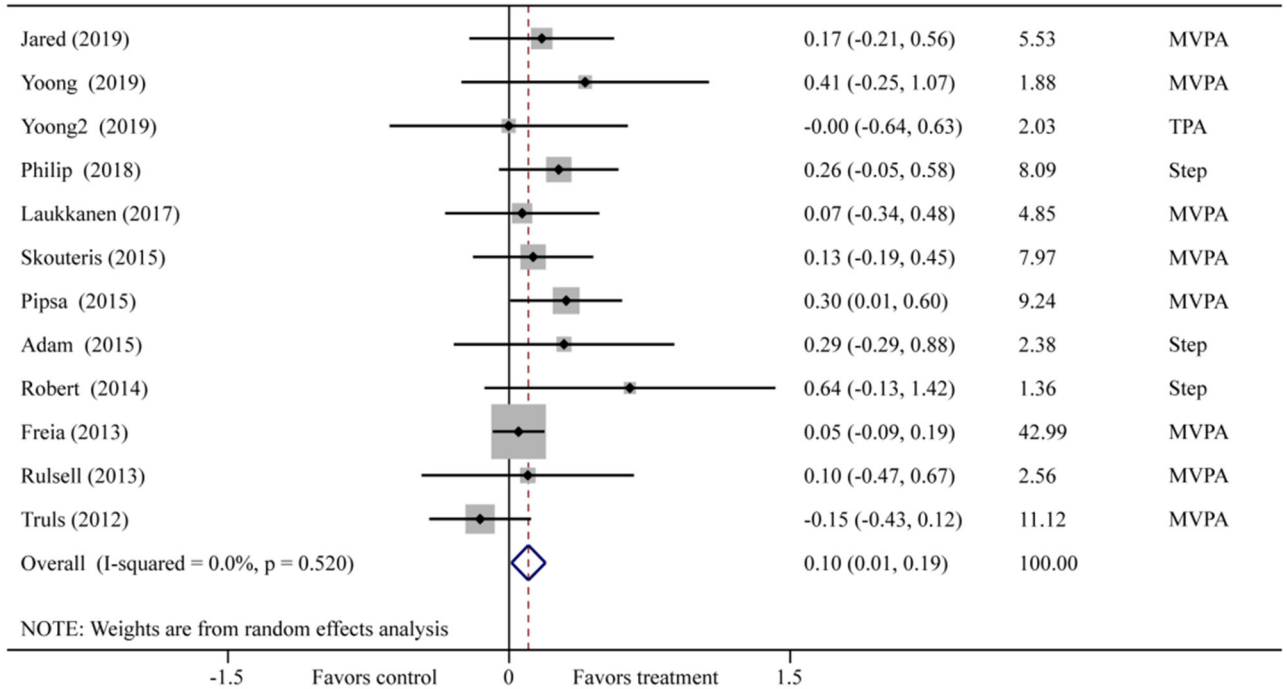

FIGURE 4 | Forest plot of family intervention on PA in children aged 2.5–12 years. (Yoong-MVPA; Yoong2-TPA).

TABLE 2 | Subgroup analysis of the effect of the family intervention on PA.

Subgroup	Potential modifiers	No. of studies	Effect size (95% CI)	Heterogeneity
All studies		11	0.10 (0.01, 0.19)	$I^2 = 0\%$, $P = 0.52$
Outcomes[a]	MVPA	8	0.43 (−1.19, 2.04)	$I^2 = 19.6\%$, $P = 0.27$
	TPA	1	–	–
	Daily steps	3	1006 (209, 1803)	$I^2 = 0\%$, $P = 0.86$
Age[b]	<6 years	5	0.05 (−0.06, 0.15)	$I^2 = 0\%$, $P = 0.56$
	≥6 years	5	0.24 (0.04, 0.46)	$I^2 = 0\%$, $P = 0.71$
BMI	Normal	9	0.09 (−0.003, 0.19)	$I^2 = 0\%$, $P = 0.53$
	Overweight/Obesity	2	0.28 (−0.11, 0.67)	$I^2 = 11.6\%$, $P = 0.29$
Types of intervention	Theory	5	0.02 (−0.13, 0.27)	$I^2 = 16.4\%$, $P = 0.31$
	Behavior	1	–	–
	Theory plus behavior	5	0.10 (−0.02, 0.21)	$I^2 = 0\%$, $P = 0.74$
Intervention focus	PA only	5	0.16 (0.01, 0.30)	$I^2 = 20.6\%$, $P = 0.28$
	PA plus others	6	0.06 (−0.10, 0.22)	$I^2 = 0\%$, $P = 0.59$
Intervention duration	>10 we	7	0.08 (−0.04, 0.19)	$I^2 = 7.5\%$, $P = 0.37$
	≤10 we	4	0.22 (0.02, 0.41)	$I^2 = 0\%$, $P = 0.84$
Measuring methods	Subjective	2	0.15 (−0.10, 0.39)	$I^2 = 0\%$, $P = 0.86$
	Objective	9	0.11 (−0.004, 0.22)	$I^2 = 9.5\%$, $P = 0.36$
Risk of bias	Low risk	6	0.13 (0.02, 0.23)	$I^2 = 0\%$, $P = 0.62$
	Moderate risk	2	−0.11 (−0.35, 0.14)	$I^2 = 0\%$, $P = 0.43$
	High risk	3	0.19 (−0.08, 0.45)	$I^2 = 0\%$, $P = 0.44$

[a]The subgroup of outcomes units were the same, and WMD statistics were used, SMD was used for all the other subgroup except the outcomes subgroup. Yoong et al. (38) contained two outcomes [MVPA and light PA(LPA)], so the total number of outcomes subgroups was 12; [b]philip (40) is not divided into age subgroup because of participants were 4-12 years old.

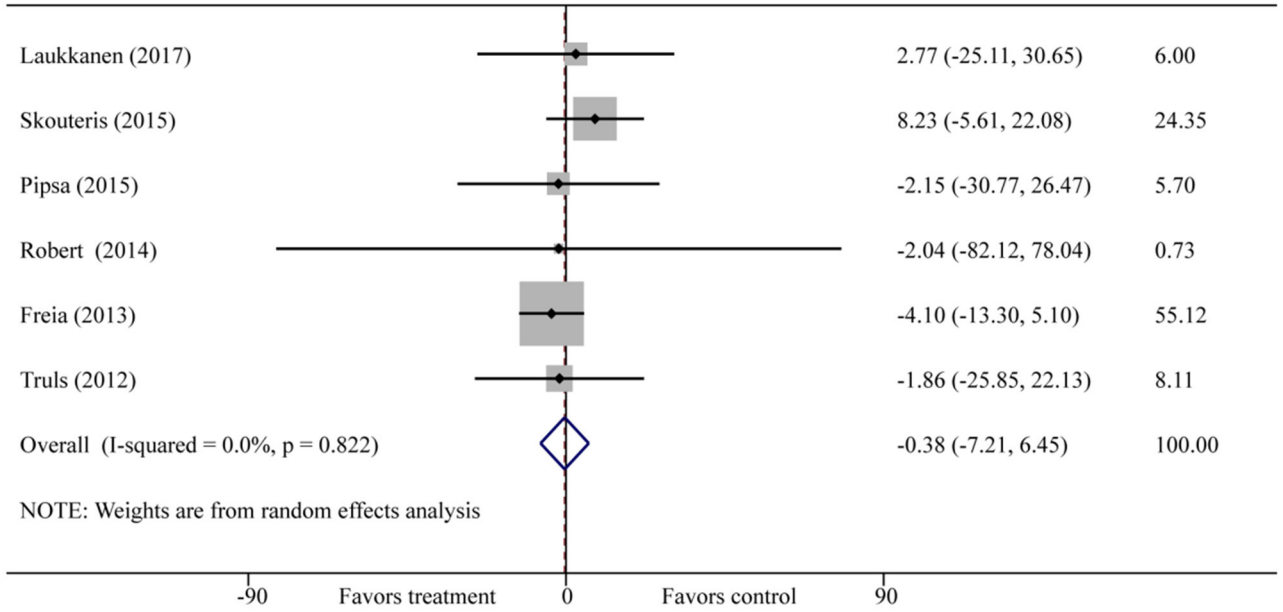

FIGURE 5 | Forest plot of family intervention on SB in children aged 2.5–12 years.

TABLE 3 | Subgroup analysis of the effect of the family intervention on SB.

Subgroup	Potential modifiers	No. of studies	WMD (min/day) (95% CI)	Heterogeneity
All studies		6	−0.38 (−7.21, 6.46)	$I^2 = 0\%$, $P = 0.82$
Age	<6 years	3	−0.46 (−7.76, 6.84)	$I^2 = 6\%$, $P = 0.35$
	≥6 years	3	0.23 (−19.15, 19.61)	$I^2 = 0\%$, $P = 0.97$
BMI	Normal	5	−0.37 (−7.22, 6.49)	$I^2 = 0\%$, $P = 0.70$
	Overweight/Obesity	1	–	–
Types of intervention	Theory	3	−0.004 (−17.73, 17.74)	$I^2 = 0\%$, $P = 0.97$
	Behavior	1	–	–
	Theory plus behavior	2	−0.32 (−7.99, 7.34)	$I^2 = 52.7\%$, $P = 0.15$
Intervention focus	PA only	4	−3.30 (−11.62, 5.01)	$I^2 = 0\%$, $P = 0.98$
	PA plus others	2	5.71 (−6.28, 17.70)	$I^2 = 0\%$, $P = 0.48$
Intervention duration	>10 weeks	4	−3.23 (−11.40, 4.94)	$I^2 = 0\%$, $P = 0.97$
	≤10 weeks	2	6.27 (−6.20, 18.73)	$I^2 = 0\%$, $P = 0.52$
Measuring methods	Subjective	2	7.94 (−5.71, 21.58)	$I^2 = 0\%$, $P = 0.80$
	Objective	4	−3.16 (−11.05, 4.73)	$I^2 = 0\%$, $P = 0.97$
Risk of bias	Low risk	3	−0.44 (−7.85, 6.96)	$I^2 = 6.1\%$, $P = 0.35$
	Moderate risk	1	–	–
	High risk	2	2.25 (−24.08, 28.58)	$I^2 = 0\%$, $P = 0.91$

for SB. In general, family interventions design may focus more on PA logically not SB. Future research should consider the differences and concerns between PA and SB in study design.

Analysis of Influencing Factors

The result of subgroup analysis expressed that family interventions were more effective in increasing PA levels in certain subgroups, for example, intervention focus "PA only," "low risk of bias". In addition, this review showed that age might be one of the factors influencing the effectiveness of family interventions. How do these findings compare to those of other published studies? A number of studies focused on preschool children found no changes in PA and SB following PA interventions (60, 61). However, in

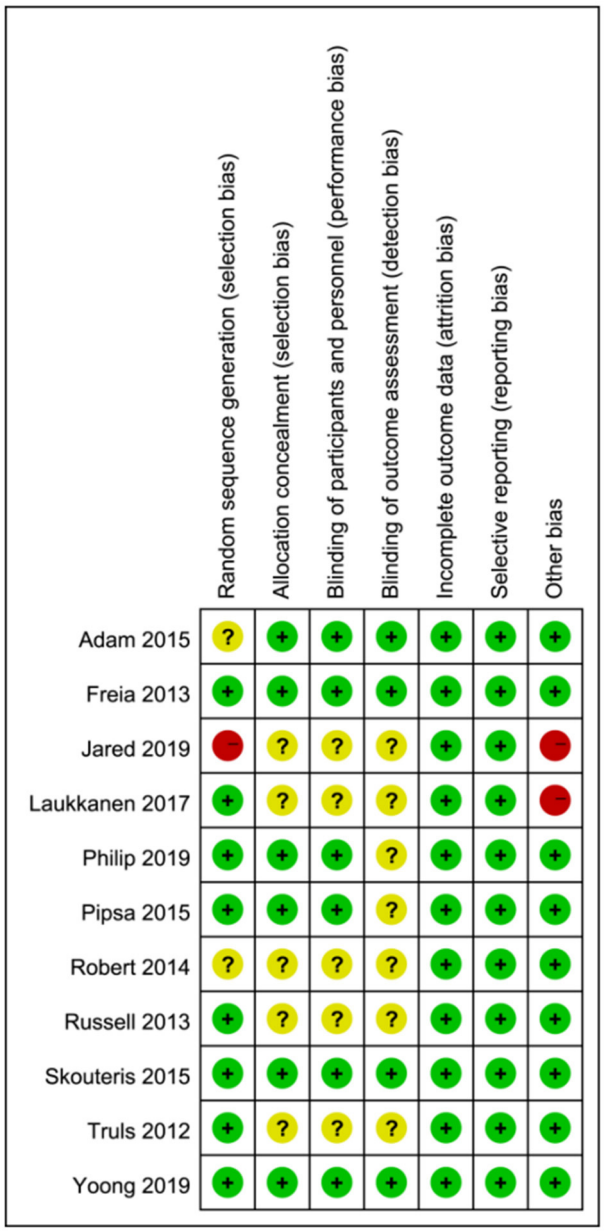

FIGURE 3 | Risk of bias of included studies. (Green = low risk of bias; yellow = unclear risk of bias; red = high risk of bias).

this study, the family intervention had a significant effect on PA in children aged 6–12 years. With the growth and cognitive development, the cognitive ability of school-age children (6–12 years old) was better than preschool children (62), and they also had a better understanding of the family intervention and PA. At this time, parents could set a good example, or they live in a PA positive family, which can have a profound effect on a child's PA. Therefore, well-designed and targeted RCTs were needed for children of other ages in the future.

The study also demonstrated that intervention duration affects the effectiveness of family interventions. Intervention duration was categorized as ">10 weeks" and "≤10 weeks" based on characteristics of included studies. It was found that interventions <10 weeks may have a more significant impact on PA improvement. The short-term (≤10 weeks) intervention effects may be attributed to the curiosity of the participants in the early stages of the intervention, and they are willing to participate in the implementation. Over time, the decline in the interest and compliance of the participants led to the intervention effect not being maintained.

Strength and Limitations

This study has demonstrated several strengths. First, this is the first meta-analysis to quantitatively examine the effect of family interventions on PA in children aged 2.5–12 years, which provides additional insight in the field of family interventions and PA. Second, the meta-analysis is based on data from controlled trials studies regarded as a study design that substantially reduces selection bias and has good comparability.

There were also some limitations in this study. First, most of the included studies were distributed in developed countries, so the research results were not widely representative. However, this study has included as much as possible the latest and most comprehensive research related to this proposition. Second, the family intervention programs (focus, means, duration) varied across included studies, leading to estimation bias of the overall effect. However, sensitivity analysis showed that the reduction of any one of the included studies did not significantly affect the combined results of this study.

CONCLUSIONS

In summary, findings from this meta-analysis that family intervention can effectively improve PA of children aged 2.5–12 years, especially daily steps, but has no noticeable effect on SB. Considering that family members engage in physical activity together is safe, meaningful, and effective for not only promoting the relationship between parents and children but also the development of good habits, we should encourage family members to take up physical exercise together. Future studies should focus on considering the different characteristics of preschoolers and school-age children, exploring the optimal combination of interventions focus, means, and duration.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Materials**, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

TH, HW, MQ, HT, and ZH designed conception and search strategy. TH, HT, MQ, and ZH designed inclusion and exclusion criteria. TH and ZH conducted the quality assessment with

arbitration by TH. Summary statistics were produced by TH and data analysis was performed by MQ and TH. TH, WL, and SS wrote the first draft. All authors made substantive contributions and approved the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fped.2021.720830/full#supplementary-material

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Interrelationship Between Age, Gender, and Weight Status on Motor Coordination in Italian Children and Early Adolescents Aged 6–13 Years Old

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Although numerous evidences reported a negative correlation between motor coordination (MC) and overweight/obesity in children and adolescents, the interrelationship between age, gender, and weight status is still debatable. Hence, the aim of this cross-sectional study was to examine the association between MC and weight status according to age and gender across childhood and early adolescence in a large sample of Italian elementary and middle school students. A number of 1961 Italian school students (1,026 boys, 935 girls) was stratified in three consecutive age groups (6–7, 8–10, and 11–13 years) and four weight status categories (underweight, normal weight, overweight, and obese) according to Cole's body mass index (BMI) cut-off points for children. MC performance was assessed measuring motor quotient (MQ) with the Körperkoordinationstest für Kinder (KTK). Results showed significantly lower MQ levels in children in overweight (OW) and with obesity (OB) in both sexes for all age groups than peers in normal weight (NW), except in 6–7-year-old boys. Girls in OW and with OB had similar MQ levels across all age groups, while younger boys in OW and with OB showed higher MQ levels than older ones ($p < 0.05$). The 6–7-year-old boys showed better MQ levels than girls peers in NW, OW, and with OB, while 8–10-year-old boys in underweight (UW), NW, and OW; and 11–13-year-old boys only in NW ($p < 0.05$). No interaction effect was found between age, gender, and weight status on MQ levels. These outcomes showed the negative impact of higher weight status on MC performance according to age and gender, pointing out the importance of planning targeted motor programs that consider these variables to improve MC performance.

Keywords: motor coordination, motor performance, motor quotient, weight status, body weight, overweight, obesity, children

INTRODUCTION

Motor coordination (MC), or motor competence, is a term that describes the ability to perform both fine and gross motor skills (1, 2). It is widely recognized that an adequate level of MC in children is fundamental to develop specialized sequences of movement for daily life tasks and for organized and non-organized physical activities. For this reason, it is crucial that a high level of MC is developed during the preschool and primary school period, to be perfected later (1, 3–6).

Furthermore, the scientific literature has highlighted the role of MC development on the consequent childhood obesity prevention and, similarly, several studies have highlighted the influence of body weight status on MC performance (7–11). The development of MC in children may be an important contributing factor to negative or positive weight trajectories (9, 12, 13). The importance of an adequate development in motor skills is also given by the fact that previous studies reported that childhood obesity involves not only locomotion and object control skills but also the ability in executing basic daily life activities (14).

Moreover, there is a body of studies in this field that have emphasized the relationship between MC and the practice of physical activity (PA) (15–17). As a matter of fact, D'Hondt et al. (9) showed that the associations between PA, MC, and body weight generally increase in childhood (9, 13).

In this perspective, the relationship between MC and weight status has been extensively studied in children and adolescents in overweight (OW) and with obesity (OB) showing impaired development of motor skills (18–21). To the best of our knowledge, an inverse relationship exists between body mass index (BMI) and MC in childhood and adolescence with similar associations between girls and boys over time (9, 12, 13, 21).

Although evidences suggest a negative correlation between MC performance and excess body mass (22–24), this relationship still remains debatable. In particular, there is a body of articles suggesting that children and adolescents in OW and with OB show lower level of MC than their peers in healthy-weight, regardless of age (21, 25–29).

Some research groups have investigated the association between children's body weight status and gross motor performances based on gender, reporting different results (29, 30). For instance, Cawley et al. (31) reported reduced MC only in boys with OB, while no differences were found among girls with OB girls and peers in normal weight (NW) (31).

The prevalence of children in OW and with OB is increasing worldwide, representing one of the most serious public health conditions nowadays and, as stated above, this weight status is related to sedentary behaviors and consequent lower MC proficiency (11, 32, 33). In detail, in Italy the prevalence of children in OW and with OB is 22.5 and 9.3%, respectively (34).

Therefore, the purpose of this study was to analyse the association between MC, assessed by the Körperkoordinationstest für Kinder (KTK), and weight status in 6– to 13-year-old Italian boys and girls. Moreover, we investigated the association between performances of KTK subtests (i.e., walking backward, jumping sideways, hopping for height, and moving sideways), and weight status according to age and gender.

Although some researches have investigated MC performance in different Italian regions during childhood and adolescence (26, 35), this study is the first to consider a large sample from all over the nation and taking into account the influence of weight status, age, and gender. The novelty of the study is not only the large sample recruited, but also the investigation of all subtest performances according to weight status, age, and gender.

We hypothesized that weight status similarly affects the levels of MC in girls and boys. In particular, children and adolescents with higher BMI (i.e., in OW and with OB) should show lower levels of MC than their peers in NW. Furthermore, we expected to find higher levels of motor competence in boys than girls, and in adolescents than children. As for the subtest performances, we expected that body weight could affect differently depending on the specificity of each subtest, that is, we hypothesized to find scores gradually decreasing with increasing body weight in motor skills that required greater effort to counteract the force of gravity (i.e., jumping sideways and hopping for height), regardless of age and gender.

MATERIALS AND METHODS

Participants

A number of 1,961 participants (boys: $n = 1{,}026$; girls: $n = 935$), between 6 and 13 years of age (**Table 1**) were recruited from elementary and middle schools in northern, central, and southern Italy, chosen as widely representative schools of the three Italian geographical areas. The measurements of this cross-sectional study were conducted in the participating schools from January 2019 to February 2020 during the regular school hours and in the respective school gyms.

This multicentre study has been led by department of Neuroscience, Biomedicine and Movement (University of Verona) and approved by the Ethical Board of Verona University (No. 2019-UNVRCLE-0298910) and Palermo University (No. 8/2019). The study complies with the criteria for the use of people in research defined in the Declaration of Helsinki. Moreover, school principals/administrators provided further authorizations for the study. After researchers explained the purpose of the investigation and the research methodology, all parents provided written informed consent prior to participating in the study.

Anthropometric Measurements

As for the anthropometric measurements, participants' body weight (kg) and height (m) were measured using an electronic scale and a standard audiometer to the nearest 0.5 kg and 0.1 cm, respectively. Body mass index (BMI) was computed as body weight divided by height squared (kg/m^2). All measures were collected by examiners who were trained in the measurement methods of height and weight.

According to the Cole's BMI percentiles for boys and girls aged 2–18 years (36), the following four categories of weight status were obtained: underweight (UW) below the 5th percentile, normal weight (NW) between 5th and 85th percentile,

TABLE 1 | Descriptive statistics for weight status categories and gender classes stratified by age groups.

			Height (m)		Weight (kg)		BMI (kg/m²)		UW		NW		OW		OB	
Age (years)	***n***	**%**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**
Boys																
6–7	242	24	1.25	0.70	26.0	5.67	16.6	2.50	26	31	157	25	38	17	21	23
8–10	522	50	1.39	0.08	36.3	9.33	18.6	3.60	40	47	293	47	129	58	60	65
11–13	262	26	1.55	0.11	46.9	11.33	19.3	3.29	19	22	175	28	57	25	11	12
Tot	**1026**	**100**	**1.40**	**0.14**	**36.6**	**11.76**	**18.3**	**3.44**	**85**	**100**	**625**	**100**	**224**	**100**	**92**	**100**
Girls																
6–7	261	28	1.23	0.07	25.6	5.23	16.8	2.60	27	33	146	26	62	31	26	29
8–10	489	52	1.38	0.09	35.3	9.87	18.5	3.73	43	53	276	49	109	55	61	67
11–13	185	20	1.54	0.08	46.1	9.17	19.2	2.84	11	14	143	25	27	14	4	4
Tot	**935**	**100**	**1.37**	**0.13**	**34.8**	**11.12**	**18.2**	**3.39**	**81**	**100**	**565**	**100**	**198**	**100**	**91**	**100**
TOT																
	1961	**100**	**1.38**	**0.14**	**35.7**	**11.50**	**18.2**	**3.42**	**166**	**8**	**1190**	**61**	**422**	**22**	**183**	**9**

n, number; %, percentage frequency; SD, standard deviation; UW, underweight; NW, normal weight; OW, overweight; OB, obesity. Total values in bold.

overweight (OW) between 85th and 95th percentile, and obesity (OB) over the 95th percentile.

Motor Coordination Assessment

Motor coordination (MC) was measured using the Körperkoordinationstest für Kinder (i.e., a body coordination test for children, referred to as KTK) by examiners who were trained in the administration of the KTK (37, 38). The KTK is a standardized, norm-referenced measure for age and gender that allows to assess MC, expressed as motor quotient (MQ), in children aged 5–14 years. The KTK was administered and scored according to the manual guidelines.

The test protocol included four subtests: (1) walking backward (WB) on a balance beam of 3 m in length of decreasing widths (6, 4.5, and 3 cm); (2) jumping sideways (JS) on two feet from side to side over a small beam (60 × 4 × 2cm) as fast as possible for 15 s; (3) hopping for height (HH) on one foot over a foam obstacle of increasing height (consecutive increments of 5 cm); (4) moving sideways (MS) on the floor in 20 s by stepping from one plate (25 × 25 × 2 cm, supported on four legs 3.7 cm high) to the next, moving onto the first plate, step ping on it, and so on.

The total MQ, standardized for age and gender, was calculated starting from the raw scores of each subtest, according to normative data tables provided by the manual. The total MQ was calculated by adding the four subtest scores. As indicated by Kiphard and Schilling (2007) KTK showed acceptable construct validity (38). In the test-retest for the raw score on the total test battery the reliability coefficient was 0.97, while corresponding coefficients for each subtest ranged from 0.80 to 0.96 (38).

Statistical Analysis

For statistical analyses, participants were divided according to the four weight status categories aforementioned, three consecutive age groups (6–7, 8–10, and 11–13 years), and gender classes.

The Shapiro-Wilk test for normality was initially used to evaluate the distribution of data. Means and Standard Deviations (SD) of weight, height, and BMI were calculated. Number and percentage frequencies were displayed to describe the weight status by age and gender. The Chi-Square test was carried out to study any significance between frequencies of weight status categories according to age groups. The scores of the KTK performance were calculated and showed as means and SDs by age groups, gender classes, and weight status categories.

The one-way Analysis of Variance (ANOVA) with Bonferroni's correction was initially performed separately between the MQ/subtest scores and weight status, age, and gender to explore the influence of each of these three variables. In order to examine any significant difference across weight status categories according to age groups and gender classes, across age groups according to weight status categories and gender classes, and across gender classes according to weight status categories and age groups, the one-way ANOVA analyses were subsequently performed. The results of the one-way ANOVA were displayed through the *F*-values and level of significance, which was set at $p < 0.05$.

The three-way ANOVA was run to examine if there was an interaction effect between the independent variables weight status, age, and gender on MQ and subtests scores. The interaction results were showed as partial sum of squares (SS) that helps express the total variation that can be attributed to the single factors and to the interaction of factors, and degrees of freedom (df), *F*-values, and level of significance were also provided. The adjusted predictions of weight status, age, and gender on MQ were plotted in a graph.

The software STATA/MP 12.1 (StataCorp LP, College Station, TX, USA) was used to perform the statistical analyses.

RESULTS

Characteristics of the Participants

Descriptive statistics of the participants are presented in **Table 1**, which shows data on the frequency of boys and girls in UW, NW, OW, and with OB categories by age groups (6–7, 8–10, 11–13 years old). The prevalence of UW, NW, OW, and with OB was

TABLE 2 | Total MQ and subtest scores of the KTK by age groups, gender classes, and weight status categories, with F-values and significance levels across the single categories.

	MQ	WB	JS	MS	HH
6–7	90.2	88.4	99.5	87.4	94.6
8–10	86.6	86.7	98.7	82.5	91.1
11–13	83.3	91.2	100.2	70.9	86.5
F (*d.f.* = 2)	25.25***	12.64***	1.18	128.41***	21.19***
Boys	89.3	86.9	105.0	81.6	93.8
Girls	83.7	89.9	93.0	79.7	87.4
F (*d.f.* = 1)	67.22***	17.47***	268.38***	5.55*	53.84***
UW	88.3	89.4	98.5	83.6	92.7
NW	88.7	91.3	101.2	81.2	91.8
OW	82.5	84.3	95.9	78.5	87.4
OB	77.4	78.6	93.2	77.2	81.6
F (*d.f.* = 3)	37.66***	40.38***	15.82***	5.71***	15.98***

*MQ, motor quotient; WB, walking backward; JS, jumping sideways; MS, moving sideways; HH, hopping for height; UW, underweight; NW, normal weight; OW, overweight; OB, obesity; d.f., degrees of freedom; *p < 0.05; **p < 0.01; ***p < 0.001. F-values were estimated through the one-way ANOVA.*

8, 61, 22, and 9%, respectively. In particular, the prevalence of participants in OW was significantly higher ($p < 0.05$) in 6–7-year-old girls than boys of the same age range (31 vs. 17%), while it was significantly lower ($p < 0.05$) in 11–13-year-old boys than girls' peers (14 vs. 25%). Higher prevalence of participants with OB was found out in boys aged 11–13-year-old than girls in the same age range (12 vs. 4%), but this difference was not significant.

Analyses of Motor Coordination Levels by Weight Status, Age, and Gender

The one-way ANOVA between MQ and weight status, age, and gender revealed that these three variables were strongly associated with MQ. In detail, MQ level was progressively reduced ($p < 0.001$) in: (1) weight status categories from UW/NW (in these two categories performances were not different) to OW and OB ($F = 37.66$); (2) older than younger ones ($F = 25.25$); (3) girls than boys ($F = 67.22$) (**Table 2**). The same trend was evidenced for the MS and HH subtests, with MS showing a very high significance ($F = 128.41$) across age groups, and HH across gender categories ($F = 53.84$). A significant ($p < 0.001$) inverse trend was revealed for the WB subtest, with performance significantly increasing in older participants ($F = 12.64$) and in girls ($F = 17.47$), while scores were decreasing in OW and OB categories ($F = 40.38$). No differences were found for the JS subtest across age groups, while decreasing performance was found out for girls ($F = 268.38$) and higher weight status categories ($F = 15.82$) (**Table 2**).

Analyses of Motor Coordination Levels Across Weight Status Categories by Age and Gender

Significant differences were found out across weight status categories (decreasing performances from participants in OW to participants with OB), both in boys and girls and in all the age groups except for 6–7-year-old boys (**Table 3**). The strongest significant differences ($p < 0.001$) were evinced across the age groups 8–10 and 11–13 in boys ($F = 13.45$ and $F = 10.61$, respectively), and across the age group 8–10 in girls ($F = 14.17$); while the weakest changes in performance were revealed in age groups 6–7 and 11–13 in girls ($F = 4.86$, $p < 0.01$, and $F = 2.81$, $p < 0.05$, respectively). In most cases, performances in participants in UW were very close to those in NW, while in few cases they were different but non-statistically significant: in 11–13-year-old boys they were higher (mean 92.9 vs. 87.5, $p > 0.05$), and in 8–10 and 11–13-year-old girls they were lower (mean 82.5 vs. 87.0, and 73.8 vs. 81.3, $p > 0.05$, respectively). Subgroups analyses for subtests' scores (**Table 3**) revealed that the trend was similar to the MQ results, except for the WB and JS subtests that were not significantly different across girls in age groups 11–13 and 6–7, respectively. With regard to the MS subtest, no difference was evidenced across age groups 6–7 and 11–13 years in girls. Contrarily, a significant decreasing performance in the HH subtest was evidenced in boys within the age group 6–7 ($F = 4.56$, $p < 0.01$); while no difference was revealed in boys and in girls in the age group 11–13.

Analyses of Motor Coordination Levels Across Age Groups by Gender and Weight Status

The one-way ANOVA performed to assess the significance level of the differences in MQ across age groups by gender and weight status (**Table 4**) showed that there was no difference across age groups in boys in UW, while this difference was found out in girls. Girls in OW and with OB had not significantly different MQ across age groups. In participants in NW, for both boys and girls, significantly higher performances were observed in 6–7-year-old children than 8–10 and 11–13 ($F = 12.65$, $p < 0.001$ and $F = 8.55$, $p < 0.001$, respectively). The same trend was found out in participants in OW and with OB, whose performances were better in younger groups ($F = 8.81$, $p < 0.001$ in OW category, and $F = 5.29$, $p < 0.01$ in OB category). With regard to the subtest scores, mostly the same trends with the highest significant differences were found out in the NW categories for all the subtests (except for the JS in girls), and in particular for the MS subtest ($F = 64.97$, $p < 0.001$ in boys in NW, and $F = 57.07$, $p < 0.001$ in girls in NW).

Analyses of Motor Coordination Levels Across Gender Classes by Age and Weight Status

The one-way ANOVA carried out to assess the significance level of the differences in MQ across gender classes by age and weight status (**Table 5**), highlighted that 6–7-year-old boys had better performances than girls' peers in NW, OW, and OB categories ($F = 18.10$, $p < 0.001$; $F = 14.50$, $p < 0.001$; $F = 4.63$, $p < 0.05$, respectively). This trend was similar in 8–10-year-old children in NW and OW, but not in the OB category, while it was observed only for the NW category in the 11–13 years-old group (**Table 5**). No differences were found out across gender categories for the

TABLE 3 | Total MQ and subtest scores of the KTK by age groups, gender classes, and weight status categories, with *F*-values and significance levels across the weight status categories.

			Boys										Girls									
				MQ		WB		JS		MS		HH		MQ		WB		JS		MS		HH	
Age groups	**Weight status categories**	**N TOT**	**N Boys**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**N Girls**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
6–7	UW	53	26	95.4	15.11	87.0	15.60	102.9	15.26	91.6	17.49	104.5	14.28	27	87.6	14.76	93.7	14.75	91.6	15.34	88.0	14.54	88.5	19.84
	NW	303	157	95.8	14.39	88.9	16.38	104.8	16.00	91.1	15.35	102.5	14.12	146	88.3	16.34	90.5	15.43	96.3	18.83	87.9	15.66	89.3	18.37
	OW	100	38	91.8	13.59	83.1	17.35	106.8	17.63	86.5	13.74	98.6	12.74	62	81.3	13.33	87.0	13.79	90.4	15.42	83.6	14.96	81.5	16.29
	OB	47	21	88.0	14.19	84.0	16.14	104.1	14.59	83.4	12.90	91.7	15.83	26	78.9	14.41	81.9	13.39	89.4	16.44	84.5	15.75	79.5	15.75
	F (*d.f.* = 3)			2.33		1.63		0.34		2.37		4.56**			4.86**		3.76*		2.45		1.35		4.29**	
8–10	UW	83	40	92.1	14.90	88.1	17.96	109.3	12.56	84.8	19.12	93.8	18.56	43	82.5	13.45	90.1	14.94	90.4	17.99	77.9	13.93	87.9	18.43
	NW	569	293	91.1	15.68	86.6	16.04	105.6	16.90	85.5	17.67	95.1	20.4	276	87.0	15.54	92.3	17.37	94.0	17.52	82.0	15.54	91.8	20.09
	OW	238	129	85.9	16.78	83.5	15.57	102.3	18.19	80.8	17.16	90.4	20.73	109	80.3	14.56	82.6	15.32	89.27	16.96	79.7	15.46	87.5	21.01
	OB	121	60	77.9	14.83	75.3	14.78	99.2	17.98	77.3	15.63	80.1	18.60	61	74.1	16.41	78.9	16.54	84.7	17.50	75.6	16.24	81.2	23.40
	F (*d.f.* = 3)			13.45***		9.32***		4.10**		4.83**		9.57***			14.17***		16.39***		5.66***		3.39*		4.83**	
11–13	UW	30	19	92.9	16.51	89.5	15.11	105.5	20.63	88.3	19.47	95.6	16.65	11	73.8	16.42	85.8	20.61	85.3	10.35	64.6	16.01	84.4	25.53
	NW	318	175	87.5	14.06	95.3	17.74	109.9	17.30	69.4	22.06	87.3	22.76	143	81.3	14.67	97.4	18.38	96.3	16.92	67.8	19.21	81.1	24.12
	OW	84	57	78.0	18.58	84.0	20.38	96.9	19.88	66.9	19.74	84.5	23.29	27	73.7	16.41	91.7	22.66	87.1	20.39	63.8	17.26	76.6	26.06
	OB	15	11	71.1	18.58	72.5	17.76	97.6	11.00	63.2	18.4	78.0	25.78	4	72.8	18.03	91.5	31.10	88.5	6.25	59.0	8.37	77.5	27.8
	F (*d.f.* = 3)			10.61***		9.88***		8.33***		5.50**		1.73			2.81*		1.76		3.46*		0.67		0.37	

*MQ, motor quotient; WB, walking backward; JS, jumping sideways; MS, moving sideways; HH, hopping for height; UW, underweight; NW, normal weight; OW, overweight; OB, obesity; d.f., degrees of freedom; *p < 0.05; **p < 0.01; ***p < 0.001. F-values were estimated through the one-way ANOVA.*

TABLE 4 | F-values and significance levels of differences in the total MQ and subtest scores of the KTK across age groups by gender classes and weight status categories.

	Across age groups									
	Boys					Girls				
Weight status categories	MQ	WB	JS	MS	HH	MQ	WB	JS	MS	HH
UW	0.37	0.12	1.38	1.05	3.32*	3.67*	1.04	0.61	10.93***	0.18
NW	12.65***	15.13***	4.70**	64.97***	24.55***	8.55***	6.51**	1.19	57.07***	12.77***
OW	8.81***	0.04	3.39*	17.81***	5.46**	2.79	3.98*	0.35	15.77***	3.89*
OB	5.29**	3.01	0.81	6.25**	3.25*	0.88	1.29	0.74	5.67**	0.10

*MQ, motor quotient; WB, walking backward; JS, jumping sideways; MS, moving sideways; HH, hopping for height; UW, underweight; NW, normal weight; OW, overweight; OB, obesity; *p<0.05; **p<0.01; ***p<0.001. F-values were estimated through the one-way ANOVA.*

WB subtest, except for the age group 8–10 ($F = 16.60$, $p < 0.001$). For the JS subtest, there were strong differences in all weight status categories and age groups, with the only exception of 11–13-year-old adolescents with OB, who did not differ in their performance between boys and girls ($F = 2.40$, $p > 0.05$). The MS subtest did not reveal any significance in all classes, except for 8–10-year-old children in NW and 11–13-year-old adolescents in UW. The HH subtest showed strong differences only in the age group 6–7, and small significant difference in 11–13-year-old adolescents in NW.

Interaction Effect Analysis of Weight Status, Age, and Gender on Motor Coordination

The three-way ANOVA evidenced no interaction effect of weight status, age, and gender on MQ scores (**Table 6** and **Figure 1**). Thus, it means that the joint effect of weight status, age, and gender on MQ is not statistically higher compared to the sum of the three effects individually.

DISCUSSION

The aim of the present study was to investigate the association between motor coordination (MC), expressed as motor quotient (MQ), and body weight status in Italian children and early adolescents aged 6–13 years according to age and gender. Similarly, we analyzed the associations between the four motor skills included in the test protocol for the MC assessment and weight status categories across age groups and gender classes.

First of all, it should be noted that the prevalence of participants in UW, NW, OW, and with OB was 8, 61, 22, and 9%, respectively, that is a proportion which is consistent with recent data on Italian children of the same age (39). Based on this premise, our hypothesis was mostly confirmed because the findings showed that weight status, age, and gender were strongly associated with MC. In fact, MQ level decreased ($p < 0.001$) from participants in OW to participants with OB ($F = 37.66$), in older than younger ($F = 25.25$), and in girls than boys ($F = 67.22$). Lower levels of MQ, HH, JS, WB, and MS ($F = 128.41$) were found in participants in OW and with OB than peers in NW, both in boys and girls, and in all the age groups except for the age group 6–7-year-old boys.

This latter result is consistent with outcomes obtained in our previous study, in which gross motor quotient, locomotor, and object control skills were not significantly different throughout the classes of underweight, normal overweight, and obesity in preschool children aged 3–5 years old (40). Therefore, MC performances appears to not be significantly affected by weight status in early childhood as also demonstrated in the present study by the highest levels of MQ scores in 6–7-year-old children. These findings could be explained with the relevant range of interindividual variation in early motor development. Indeed, development process can be continuous but also intermittent when periods of instability or negligible changes are followed by significant progresses, or when regression stages precede a more advanced stage (41). As a matter of the fact, according to the "reciprocal interweaving" model, during childhood and adolescence the development of motor competence can alternate periods of maturity followed by subsequent periods of immaturity, and so on (42).

Our findings relating to the negative influence of higher BMI levels on MC are in agreement with previous studies in which it was detected that children and adolescents in overweight or with obesity were more likely to possess lower MC than peers in healthy weight (3, 12, 21).

The lower MQ levels in older than younger ones ($F = 25.25$) could be also associated with the high prevalence of participants in OW and with OB in 8–10 and 11–13 age groups. In agreement with previous studies (9, 21), the reported deficiencies in MC associated with OW and OB do not seem to be temporary, and we found that, increasing age, MC even appeared to deteriorate. This could be related to a disadvantageous effect of an excessive body mass on MC. In fact, it increases as a greater body mass is involved in the action and when the body needs to be moved under time constraints or against gravity (8).

Our results showed significant differences in MQ ($F = 67.22$) and JS scores ($F = 268.38$) between girls and boys. These results are similar to those reported in other studies that exhibited significant differences in motor skills between boys and girls (9, 43). Gender differences in motor performance, in which boys performing better than girls, could be related to the difference both in the usual PA level and the sport practice, regardless

TABLE 5 | *F*-values and significance levels of differences in the total MQ and subtest scores of the KTK across gender classes by age groups, and weight status categories.

	Across gender classes														
	6–7					8–10					11–13				
Weight status categories	**MQ**	**WB**	**JS**	**MS**	**HH**	**MQ**	**WB**	**JS**	**MS**	**HH**	**MQ**	**WB**	**JS**	**MS**	**HH**
UW	3.64	2.53	7.17*	0.64	11.30**	9.53**	0.31	30.30***	3.58	2.05	9.34**	0.31	9.12**	11.69**	2.13
NW	18.10***	0.74	18.10***	3.26	49.71***	9.83**	16.60***	65.08***	6.14*	3.71	14.70***	1.09	49.17***	0.42	5.64*
OW	14.50***	1.54	24.06***	0.91	30.41***	7.59**	0.18	32.35***	0.25	1.14	1.25	2.42	4.45*	0.50	1.98
OB	4.63*	0.23	10.21**	0.07	6.91*	1.76	1.59	20.25***	0.36	0.08	0.02	2.28	2.40	0.19	0.00

*MQ, motor quotient; WB, walking backward; JS, jumping sideways; MS, moving sideways; HH, hopping for height; UW, underweight; NW, normal weight; OW, overweight; OB, obesity; *p < 0.05; **p < 0.01; ***p < 0.001. F-values were estimated through the one-way ANOVA.*

TABLE 6 | Interaction effect of weight status, age, and gender on MQ.

$N = 1961$	$R^2 = 0.1257$			
MQ	**Partial SS**	**d.f.**	**F**	***p*-value**
Weight status	18145.61	3	25.96	0.0000
Gender	8460.35	1	36.32	0.0000
Age	8306.30	2	17.83	0.0000
Weight status × gender	1330.26	3	1.90	0.1270
Weight status × age	969.75	6	0.69	0.6547
Gender × age	429.91	2	0.92	0.3976
Weight status × gender × age	1182.53	6	0.85	0.5343

MQ, motor quotient; SS, sum of squares; d.f., degrees of freedom. F-values were estimated through the three-way ANOVA.

of body weight status (9, 44, 45). Indeed, in a cohort of 2,815 children and adolescents of both sexes aged 3–15 years, in which ∼ 90% of the participants had a healthy body weight status, Ishii et al. (45) reported that boys were more physically active than girls (45). Similar results were also found by Ridley et al. (46) in the practice of organized sports in which authors, among the findings, detected that between girls' and boys' soccer teams, the latter spent significantly higher time in moderate to vigorous physical activity (MVPA) (46). In a similar way, previous studies reported lower time spent in MVPA among children with obesity than peers without obesity (47).

The significant ($p < 0.001$) inverse trend revealed for the WB subtest, with a significant increasing performance in older participants ($F = 12.64$) and in girls ($F = 17.47$), is in agreement with seminal studies on this topic. For instance, D'Hondt et al. (9) detected increasingly higher scores in this motor skill with rising age in children, as well as in girls than boys of the same age in all weight categories (9). This outcome could be related to the better balance performance of adolescents than children (48), and that of girls than same-aged boys, regardless of body weight status (49–51). According to Woollacott and Shumway-Cook (48), we speculate that older participants exhibit better dynamic balance in WB subtest than younger ones because the maturation of balance control does not complete in childhood, but, possibly, continues throughout adolescence (52). However, the literature reports contrasting results on the impact of body weight on balance control in children and adolescents (53, 54).

No interaction effect was found between weight status, age, and gender on MQ. Thus, it means that the joint effect of weight status, age, and gender on MQ is not statistically higher compared to the sum of the three effects individually. For example, a girl in OW, who is also in the higher age group, has a lower performance, but, since there is not any interaction between being girls, OW, and belonging to the higher age groups, the effect on decreasing performance is not enhanced compared to the sum of the single aspects.

In conclusion, these data showed that weight status affects the development of MC throughout childhood and early adolescence.

Perspective

It is known that children's and adolescents' general behavior, including daily activities and the practice of PA, is determined by MC (7). Furthermore, higher levels of MC during childhood and adolescence influence children's ability to successfully participate in movement situations and, moreover, to engage in lifelong PA (15–17). Since sedentary behaviors and a low level of PA negatively affect body weight across childhood and adolescence (25, 40, 55, 56), it is important to take into account MC in children and adolescents with excessive BMI.

Therefore, the adoption of a health-related educational strategy, such as motor plans that include the development of motor coordination, is crucial in school in order to promote an active and healthy lifestyle in children and adolescents (57–60).

Strengths and Limitations

The main strength of the study is the large Italian sample recruited. Furthermore, among the strengths it should be noted that not only the general level of MC was taken into consideration but also the score of each subtest.

Growth and maturity characteristics of children (morphological, physiological, and neuromuscular) might contribute to influence the development of MC during childhood and adolescence, therefore, the absence of data concerning these aspects represents a limitation of this study. Additionally, it is important to highlight among the limitations of the study

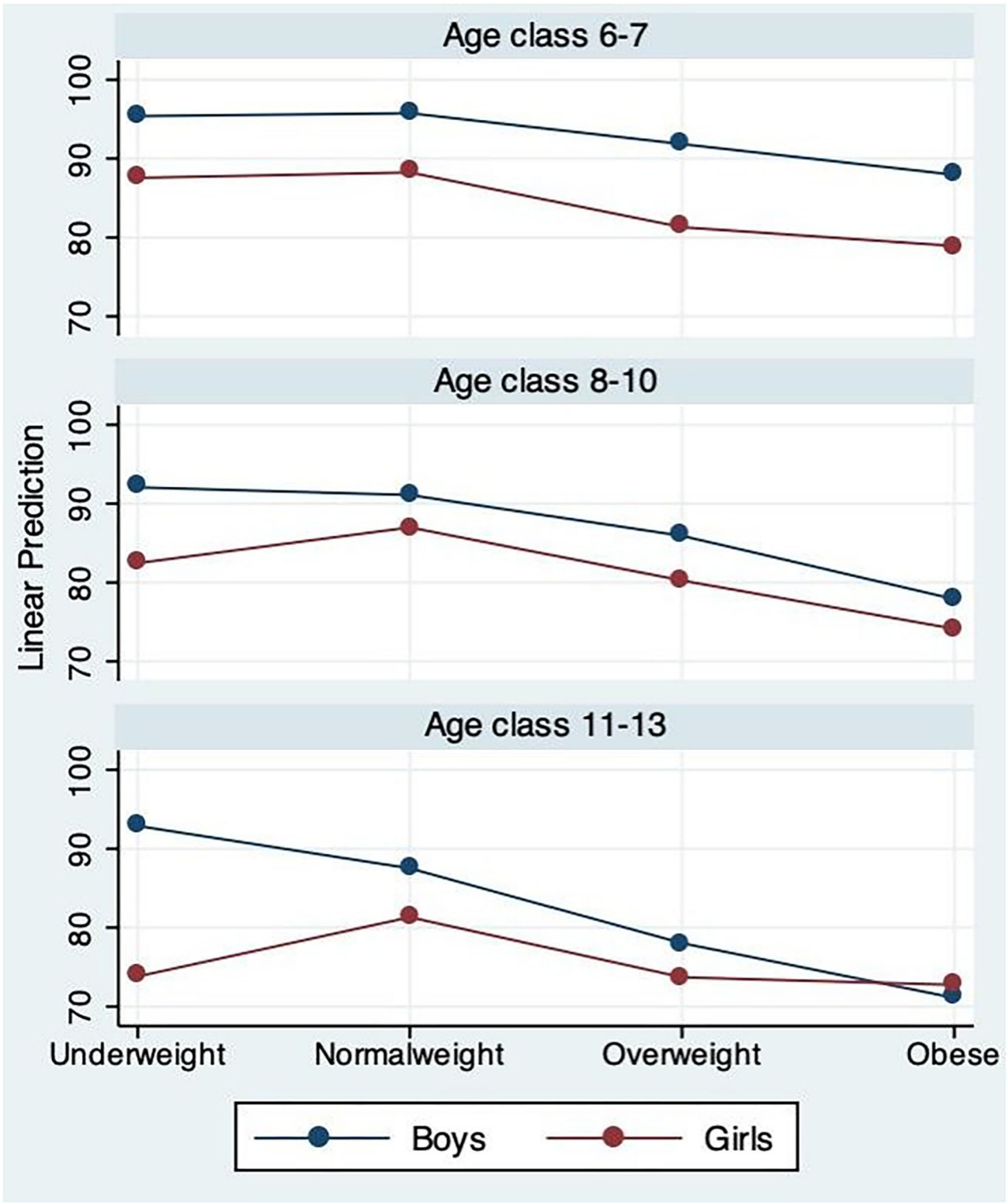

FIGURE 1 | Adjusted predictions of weight status-age-gender on MQ.

that, although KTK is a reliable protocol test commonly used to measure MC performance in children and adolescents, it does not include the assessment of fine motor coordination.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethical Board of Verona University (No. 2019-UNVRCLE-0298910) and Palermo University (No. 8/2019). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

ML, MB, LG, and CB conceptualization and methodology. VB, MG, MCG, and AG Data collection. GT, GB, and MB data analysis. VG, ML, FS, and AP data interpretation. GB and VG writing—original draft preparation. MB writing—review & editing. MB and AP supervision. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

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SYSTEMATIC REVIEW
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A Systematic Review and Meta-Analysis of Moderate-to-Vigorous Physical Activity Levels in Children and Adolescents With and Without ASD in Inclusive Schools

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Background: The health benefits of physical activity (PA) participation are well-documented. Little was known about the PA levels of students with autism spectrum disorder (ASD) and their typically developing (TD) peers in inclusive schools. This study aimed to synthesize available studies examining PA levels of children and adolescents with and without ASD and its associated factors that affected their PA participation during inclusive schools applying the social–relational model of disability (SRMD).

Methods: Eight databases were searched including CINAHL Complete, SPORTDiscus with Full Text, PubMed, Embase, Web of Science, Eric, APA PsycINFO, and Scopus from inception through May 2021 to identify related studies. Two researchers independently screened studies, assessed methodological quality, and summarized relevant data. The McMaster Critical Reviewer Form for quantitative studies was used to evaluate the methodological quality of the included articles.

Results: A total of seven articles were included in this systematic review. Overall, meta-analysis results indicated that children and adolescents with ASD had a moderately decreased PA levels compared with their TD peers [SMD = −0.585, 95% CI (−0.774, −0.425), $p < 0.01$]. Individual-, social-, and environmental-level factors that influence PA levels in children and adolescents with ASD were identified from the perspective of SRMD.

Conclusion: This review indicates that children and adolescents with ASD have lower PA levels than their TD peers in inclusive schools and multilevel factors affect their PA.

Keywords: physical activity, autism spectrum disorders, inclusive school, social-relational model of disability model, children

INTRODUCTION

Individuals with autism spectrum disorders (ASD) are dramatically characterized by deficient social communication, stereotyped behaviors, and intelligence development (1). The current prevalence of ASD in the global population is around 0.7–1.1% (2). Children and adolescents with ASD are of great sensitivity to changes in their environment and are prone to depend on routines (1). This may expose them to the limited opportunities to participate in exercise and physical activities (3). Additionally, a wide range of precipitating factors, including increased screen-based time, social skill impairments, and motor skill deficiencies, are likely to result in physical inactivity and sedentary behavior (4–6). Previous studies have indicated that children with ASD exhibit high rates of overweight and obesity (7). The consequences of physical inactivity could lead to a diversity of chronic diseases, such as obesity, diabetes, hypertension, cardiovascular disease, and mental disabilities (8).

Schools are valuable setting to engage students with and without disabilities to increase PA and shape their PA behaviors (9, 10). In light of this, examining the time slots contributing to the most PA participation during a school day is essential to better understand their PA patterns and to promote PA behaviors among students with ASD. Schools are identified as the best place to promote PA opportunities for all students according to the latest *WHO Guidelines on physical activity and sedentary behavior* (11); it recommends that children and adolescents with living disabilities aged 5–17 years should engage in at least 60-min moderate-to-vigorous physical activity (MVPA) daily to achieve health benefits. Achieving the recommended amounts of PA plays a crucial role to promote and maintain a life-long healthy active lifestyle for people of all ages and abilities. However, only 42% of children and adolescents aged 5–17 years with ASD met the WHO Guidelines (12). Schools are recommended to offer physical education (PE) class and recess period to enable students to gain MVPA opportunities. Especially, an increasing number of students with ASD have received their education in inclusive schools with their typically developing (TD) peers, with the implementation of legislation and policies regarding inclusive education (e.g., the Salamanca Statement). Inclusive education is an approach that aims to eliminate social exclusion on the premise that education is a foundation for society, and this concept has been accepted as a core education policy worldwide (13). A PA guideline (PAG) stated that children and adolescents should spend at least 50% of the PE class time and 40% of the recess period engaging in MVPA (14). The availability of PE classes and recess periods has been found to be effective in increasing PA in students with ASD (11, 12). Studies over the past two decades have provided important information on PA levels in children with ASD during school time in inclusive settings (e.g., inclusive PE class or inclusive recess). To date, limited attention has been emphasized to compare the PA levels of children and adolescents with and without ASD during a school day and take school PAG into consideration, especially for those who enrolled in the inclusive schools.

One previous systematic review summarized the objectively measured MVPA level on weekdays and weekends among children and adolescents with ASD (12). However, this review conducted an overview of MVPA of children and adolescents with ASD in diverse settings (e.g., special schools, home schools, and inclusive schools) as a whole, without a comparison with their TD peers. Therefore, it is difficult to identify the PA levels of students with and without ASD in inclusive schools, which cause barriers to design and implement effective interventions targeting inclusive school settings. In addition, the reasons for low PA levels in children and adolescents with ASD at school are complex. In the light of the nature of the ASD symptoms, students with ASD may meet various obstacles in PA engagement with their TD peers. Different factors ranging from personal, social, cultural, and environmental perspectives act as either facilitators or inhibitors for their PA participation (15). Therefore, there is a pressing need to develop a comprehensive review to determine the PA levels of children and adolescents with ASD compared with their TD peers, and to identify the factors that affect their PA participation in the setting of inclusive schools.

Because of the complexity of diverse factors affecting PA engagement, it is necessary to summarize multiple factors through a conceptual framework. The social-relational model of disability (SMRD) has been applied in previous studies to examine the individual, social, and environmental level of barriers to PA for individuals with disabilities (16). SMRD emphasized the social influence imposed on impairment by individuals without disabilities either through "barriers to doing" or "barriers to being" (17). Considering that the present study was based on inclusive setting, SMRD is a more appropriate theoretical framework than other models (e.g., social-ecological model) due to its underlying alignment to the morality of inclusion, in which personal impairment interacts with the social environments (18, 19). Therefore, this model was adopted to address the factors that inhibit or promote PA participation among children and adolescents with ASD in inclusive schools.

To the best of our understanding, no systematic reviews have yet examined the accelerometer-measured PA levels of children and adolescents with and without ASD in inclusive schools, and the associated factors that affect their PA levels applying a theoretical framework. The aim of this systematic review was two-fold. The first was to systematically review and quantitatively synthesize the published literature to determine the PA levels in ASD compared with TD children and adolescents in inclusive schools. The second was to identify the factors that affected the PA levels in children and adolescents with and without ASD at different levels using the SMRD as a theoretical framework.

METHODS

This study complied with the Preferred Reporting Items for Systematic Review and Meta-analyses Statement (PRISMA) (20).

Abbreviations: PA, physical activity; ASD, autism spectrum disorder; TD, typically developing; SRMD, social–relational model of disability; MVPA, moderate to vigorous physical activity; PE, physical education; PAG, physical activity guideline; SEN, special education needs.

Search Strategy

Electronic searches were conducted in CINAHL Complete (via EBSCOhost), SPORTDiscus with Full Text (via EBSCOhost), PubMed, Embase (via Ovid), Web of Science, Eric (via EBSCOhost), APA PsycINFO (via Ovid), and Scopus from inception through May 2021 to identify all relevant published articles regarding the objectively measured PA levels and correlates in children and adolescents with and without ASD. The search was limited to "English," "human-related," and "peer-reviewed" articles if applicable to that database. The initial search was undertaken using the following key terms: physical activity, physical activity levels, ASD, children, or adolescents. The search keywords for each main term were developed from the search strategies of previous reviews related to PA and children or adolescents with ASD and expert opinions in the fields of PA and special education. To expand our search, a manual search in reference lists of retrieved articles and Google Scholar was also screened to identify relevant articles.

Inclusion and Exclusion Criteria

Inclusion criteria were as follows: (a) objectively measured the PA levels (e.g., MVPA) of children and adolescents with ASD and compared with their TD peers; (b) observational research (i.e., cross-sectional, case-control, and cohort); (c) reported the PA levels in the form of duration in minutes in different inclusive school settings (e.g., inclusive physical education class, recess, lunchtime, and after-school time); (d) peer-reviewed articles with full-text available written in English; (e) included participants who are aged 5–17 years old; (f) provided complete research data where the length of MVPA could be computed. Exclusion criteria were as follows: (a) did not collect data from inclusive school settings; (b) only included participants with ASD without their TD peers; (c) written in a language other than English; (d) intervention research (e.g., clinical and field trials); (e) review studies, case/government reports, conference papers, book chapters, and policy documents; and (f) included preschool children (aged 0–5 years) and adult people up to 18 years old as subjects.

Data Selection and Data Extraction

Two independent reviewers examined each article obtained from the databases to ensure the accuracy of the systematic search process. If two independent reviewers had any disagreement, the third reviewer would discuss dubious papers with the two reviewers and made a final call. The consistency of the title/abstract and full-text screening between the two reviewers was measured using the kappa value (21). A standardized data extraction form was developed to extract characteristics from each study, including the relevant data about bibliographic details (author and year), participant characteristics (sample size, age range, gender, school placement, location, and classification of ASD severity), outcome measures (measurement tools of PA), PAG cited in the study, study purpose, major findings, and PA-related factors applying in SMRD.

Quality Assessment

The McMaster Critical Reviewer Form for quantitative studies (16) was used to evaluate the methodological quality of the included articles on the basis of the Guidelines for Critical Review Form-Quantitative Studies (22). The numerical rating criteria for non-experimental quantitative study developed by Imms (23) was also employed to interpret the methodological quality. These scoring criteria have been widely used in previous systematic reviews related to disability and PA research (12, 24, 25). The three key criteria in the included studies were evaluated in the present study: sample, measurement, and analyses (23). The sample was evaluated whether the selection bias was reduced (e.g., representative of selected population or convenience sample), whether the sample size was suitable for the research design and questions, and whether the characteristics of the subjects were clearly described by the authors. The measurement examined whether the measurement bias was reduced (e.g., reliability and validity of the measurement tool, recall/memory). The analyses examined whether reported analyses were appropriate for the research questions and outcome measures (e.g., reported statistical significance, point estimates, provided variability, and discussed clinical importance) (12, 24, 25). Each criterion was scored with one star, which means no evidence shows that the study can meet any criterion. Two stars indicate that certain pieces of evidence in the study can meet the criteria, or the report is unclear. Finally, three stars indicate that the evidence in the study can totally meet the criteria (23, 24). Two reviewers independently evaluated the methodological quality assessment for the included studies. Discrepancies between the two reviewers were discussed until consensus was finally reached. If an agreement could not be obtained from the two reviewers, then a third research could make the final call after discussing with two reviewers.

Data Analysis

A meta-analysis was developed by the Comprehensive Meta-Analysis (v.2). The MVPA of children and adolescents with ASD and their TD peers was calculated to actual minutes during an inclusive school day including five settings (e.g., overall, PE class, recess, lunch time, and after-school time) to determine PA levels and calculate the effect size. Hedges' g was chosen as the effect size index as it was suitable for the included smaller number of studies ($k < 20$) (26). Data for each study were expressed as the standardized mean differences (g) using the random effects model and given weighted by the study inverse variance. The magnitude of Hedges' g values was interpreted as small (<0.2), moderate (0.5), and large (>0.8) effect size, respectively (27). To check for the existence of publication bias, funnel plots was presented. The I^2 value was used to assess the heterogeneity of the effect sizes, indicating small ($\leq$25%), medium (50%), and large ($\geq$75%) amount of heterogeneity, respectively (28). Fifty percent of I^2 value was set as a cutoff point to evaluate the heterogeneity of the included studies. If the value of I^2 statistics was >50%, indicating an existence of the heterogeneity. In order to address heterogeneity, a sensitivity analysis was used to estimate potential outliers. Since <10 studies were included

in each analysis, publication bias was not investigated. Statistical significance ($p < 0.05$) was set for all tests.

To identify factors as being "related" or "not related" to PA participation of students with ASD in inclusive schools, those potential factors showing significant association with PA participation were summarized.

RESULTS

Study Identification

A total of 1,457 articles were found in the initial search of the eight databases described. **Figure 1** illustrates the procedure of screening and the number of articles that met the inclusion criteria. After removing the duplicates, 604 articles were further screened through title/abstract. Twenty of them potentially met the inclusion criteria with an inter-rater reliability kappa value = 0.84 between the two reviewers. Subsequently, full-text screening was conducted to identify eligible studies. Finally, seven articles were included in this systematic review and meta-analysis, with an inter-rater reliability of kappa value = 0.94.

Descriptive Characteristics of Included Studies

The characteristics of included studies are summarized in **Table 1**. All included studies used a cross-sectional design, and only one study was conducted in the USA (14%) (29), whereas 86% of the included studies were from Taiwan (3, 30, 31, 33–35). The total sample included 172 children and adolescents with ASD and 277 of their TD peers aged from 9 to 15 years, and 97% of the participants were male students. The school placement of participants in the included studies ranged from primary school to high school: primary school (43%) (29–31), secondary schools (43%) (33–35), and high school (14%) (3). Six included studies (86%) provided a clear classification of ASD severity (29–31, 33–35). All included studies used accelerometers as an objective measuring instrument to assess the PA levels of children and adolescents with ASD and their TD peers. Only Sandt and Frey (29) adopted both accelerometer and direct observation using BEACHAES observation form to measure PA levels of students with and without ASD. The included studies cited different PAG as outcome measures to evaluate the number of participants and amount of time that meet the standard PAG.

Meta-Analysis of Time Spent in Moderate-to-Vigorous Physical Activity at Different Settings

Finally, seven studies including data of 172 ASD populations and 277 of their PD peers were included in the meta-analysis. The results of the meta-analysis are shown in the **Figure 2.** It indicated the overall effect size for overall PA levels and separated by specific school settings. Overall, the meta-analysis indicates that children with ASD had moderately decreased PA levels compared with TD [SMD = −0.585, 95% CI (−0.774, −0.425), $p < 0.01$], with small-to-medium heterogeneity ($Q = 23.614$, $I^2 = 32\%$, $p = 0.099$). Specifically, two studies focusing on after-school time (see **Figure 2A**, after school) and reported that children with ASD (mean = 38.07 min) had non-significant small decreased PA levels compared with TD (mean = 41.42) [SMD = −0.069, 95% CI (−0.709, 0.570), $p = 0.832$], with a medium heterogeneity ($Q = 2.145$, $I^2 = 53\%$, $p = 0.143$). For the lunch break (see **Figure 2B**, lunch break), two studies focused on this time periods and reported that children with ASD (mean = 7.49 min) had a moderate to large significant decreased PA levels compared with TD (mean = 10.57 min) [SMD = −0.703, 95% CI (−1.153, −0.254), $p = 0.002$], with a small to moderate heterogeneity ($Q = 1.352$, $I^2 = 26\%$, $p = 0.245$). The meta-analysis of MVPA during PE class (see **Figure 2C**, PE class) showed a significant and moderate decrease in ASD (mean = 14.90 min) compared with TD (mean = 19.07 min) children [SMD = −0.627, 95% CI (−1.004, −0.250), $p = 0.001$], with a medium heterogeneity ($Q = 9.406$, $I^2 = 57\%$, $p = 0.052$). The MVPA during recess time (see **Figure 2D**, recess) also indicated a moderate effect with a lower score in ASD (mean = 24.72 min) compared with TD (32.68 min) children [SMD = −0.663, 95% CI (−0.956, −0.371), $p < 0.00$], with a small heterogeneity ($Q = 1.182$, $I^2 = 0\%$, $p = 0.757$). Last, for overall MVPA during a school day (see **Figure 2E**, school day), four studies reported that children and adolescents with ASD (mean = 69.51 min) had a significant and moderate decrease in PA levels compared with TD (mean = 93.97 min) [SMD = −0.544, 95% CI (−0.819, −0.270), $p < 0.00$], with a small heterogeneity ($Q = 1.306$, $I^2 = 0\%$, $p = 0.728$).

Factors Affecting the Physical Activity Levels of Children and Adolescents With Autism Spectrum Disorder

Three-level factors that affect the PA levels of children and adolescents with ASD in inclusive school settings have been identified by previous researchers and summarized from included studies in **Table 2**. At the individual level, age is a crucial factor that affect the PA levels of children and adolescents with ASD (30). In addition, the sedentary pursuits, physical fitness level, self-determined motivation, and social impairment play a key role in determining the PA levels of children and adolescents with ASD (3, 29–31, 33, 34). At the social level, PE class should be the focus. PE content, behaviors and social interactions of PE teachers with TD peers during PE class affected the PA levels of students with ASD during their inclusive PE (3, 29–31, 33). Last, at the environmental level, in-school PA opportunities (e.g., PE, recess, lunch time, and after-school PA programs) and school environment (playground, PA equipment, and facilities) have great influences on PA levels of children and adolescents with ASD during school days.

Quality Assessment

Assessment of the methodological quality of included studies according to the McMaster Critical Reviewer Form is reported in **Table 1**. None of the studies met all the three criteria. For the *Sample* component, all studies used a convenience sample, and male participants dominated the sample selection. Six studies gave detailed classification of ASD diagnosis. For the *Measurement* component, only one study was given three stars as adopting both objective tool and observation form to record PA levels. For the *Analyses* component, four studies were given

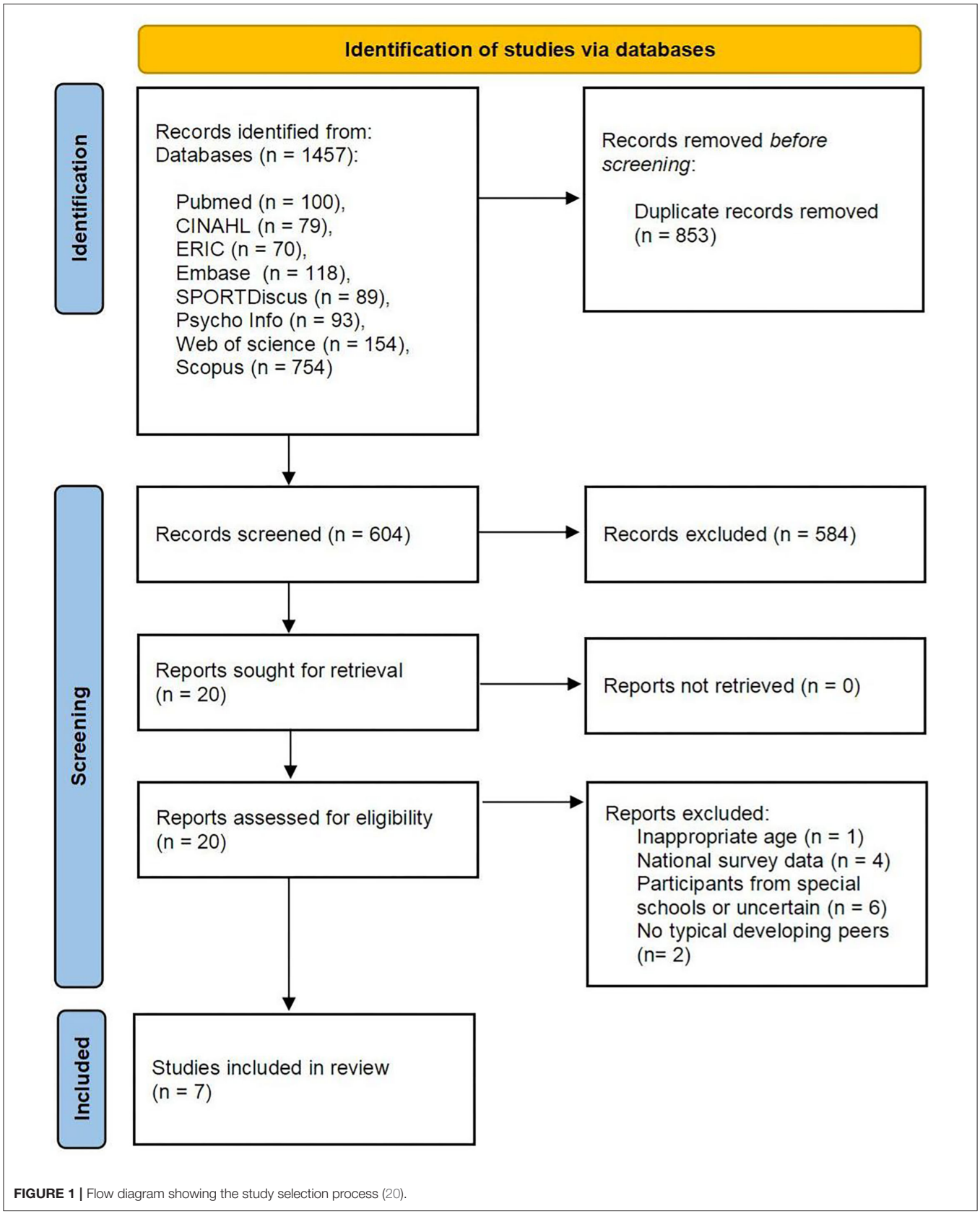

FIGURE 1 | Flow diagram showing the study selection process (20).

TABLE 1 | Summary of the participants' characteristics of included studies.

	Sample size	Gender (ASD; TD)	Age range (mean, SD)	School level	Location	Classification of ASD severity	Measures of PA	PAG	Quality criteria		
									Sample	Methods	Analysis
Sandt and Frey (29)	15 ASD; 13 TD	10M, 5F; 8M, 5F	5–12 (9.5, 1.9); 5–12 (8.9, 2.0)	PS	USA	Autism (9), Asperger syndrome (2), PDDNOS (4)	Accelerometer & Observation (BEACHES)	a	**	***	***
Pan (30)	24 ASD; 24 TD	23M, 1F; ?, ?	7–12 (?, ?); 7–12 (9.2, 1.4)	PS	Taiwan	Autism (21), Asperger syndrome (3)	Accelerometer	b, c	**	**	***
Pan (31)	24 ASD; 24 TD	23M, 1F; 23M, 1F	7–12 (9.3, 0.87); 7–12 (9.13, 0.68)	PS	Taiwan	Mild or high-functioning autism (12), moderate autism (9); Asperger syndrome (3)	Accelerometer	c	**	**	***
Pan et al. (3)	19 ASD; 76 TD	19M; ?, ?	? (14.19, 0.82); ? (14.1, 0.80)	HS	Taiwan	NR	Accelerometer	b	*	**	*
Pan et al. (32)	25 ASD; 75 TD	25M; 75M	? (14.26, 0.89); ? (14.08, 0.80)	SS	Taiwan	Mild autism (15), Asperger syndrome (10)	Accelerometer	b	**	**	**
Pan et al. (33)	30 ASD; 30 TD	30M; 30M	12–17 (14.51, 1.54); 12–17 (14.72, 1.54)	SS	Taiwan	Mild autism (23), Asperger syndrome (7)	Accelerometer	a, b, c	**	**	**
Pan et al. (34)	35 ASD; 35 TD	35M; 35M	12–17 (14.55, 1.54); 12–17 (14.81, 1.55)	SS	Taiwan	Mild autism (25), Asperger syndrome (10)	Accelerometer	a	**	*	***

M, male; F, female; TD, typical development; SS, secondary school; HS, high school; PS, primary school; SD, standard deviation; NR, not reported; PDDNOS, Pervasive Developmental Disorder—Not Otherwise Specified; ?, no data provided; PAG, physical activity guideline; BEACHES, Behaviors of Eating and Activity for Children's Health: Evaluation System; a, children and adolescents should spend at least 60 min in MVPA daily; b, children and adolescents should have 50% of PE class time in MVPA; c, children and adolescents should have 40% of recess time in MVPA.

**No criteria was met within that component.*

***Only some criteria were met within component.*

****All criteria were met within that component.*

three stars because they fully addressed the research questions and clearly explained the limitations.

DISCUSSION

The aim of this systematic review and meta-analysis was to determine the PA levels of children and adolescents with and without ASD in inclusive schools and identify the PA-related factors at three levels that affect PA engagement of children and adolescents with ASD in inclusive schools. In general, the results showed evidence for lower PA levels in ASD compared with TD children. A previous systematic review (36) found that individuals with ASD (aged 0–18 years old) engaged in approximately 86 min in of MVPA daily (ranging from 34 to 188 min/day). Our synchronized results of time in MVPA in inclusive schools was 69.51 min/day, which fell within this range. Comparatively, a recent study indicated that TD students spent around 135 min in MVPA daily (37), and our calculated results (101.96 min/day) for TD peers in inclusive schools is greatly lower than their results. A recent study in children with ASD in special schools in Spanish found that children with ASD recorded approximately 70 min of MVPA during weekdays (38), and their measured results in special schools were slightly lower than our calculated results in inclusive schools. In addition, a previous study in 13 special schools in Hong Kong recruiting 259 children with five types of disabilities including children with ASD found that children spent 70% of their school time being sedentary and only acquired 17 min in MVPA (10). Therefore, the results may suggest that children and adolescents with ASD who attended inclusive schools were more likely to have opportunities to accrue more MVPA daily than those with ASD attending special schools. Specifically, students with ASD spent less time in MVPA than non-ASD peers during PE lessons (37.3 vs. 47.3%, SMD = −0.627). Although students without ASD cannot meet the PE lessons criteria in inclusive schools, they acquired more MVPA than elementary school-aged TD students (44.8%) (39) and students in secondary school PE lessons (40.5%) (40). In addition, students with ASD consumed less time in MVPA than their TD peers (31 vs. 40.1%, SMD = −0.663). The PA intensity achieved by students with ASD during inclusive recess is higher than students with physical disabilities in special schools in Hong Kong (17%) (41), 22% of special school population in Hong Kong (9.4%) (10), and adolescents with intellectual disabilities in inclusive recess in Taiwan (17.89%) (42), but they are less active

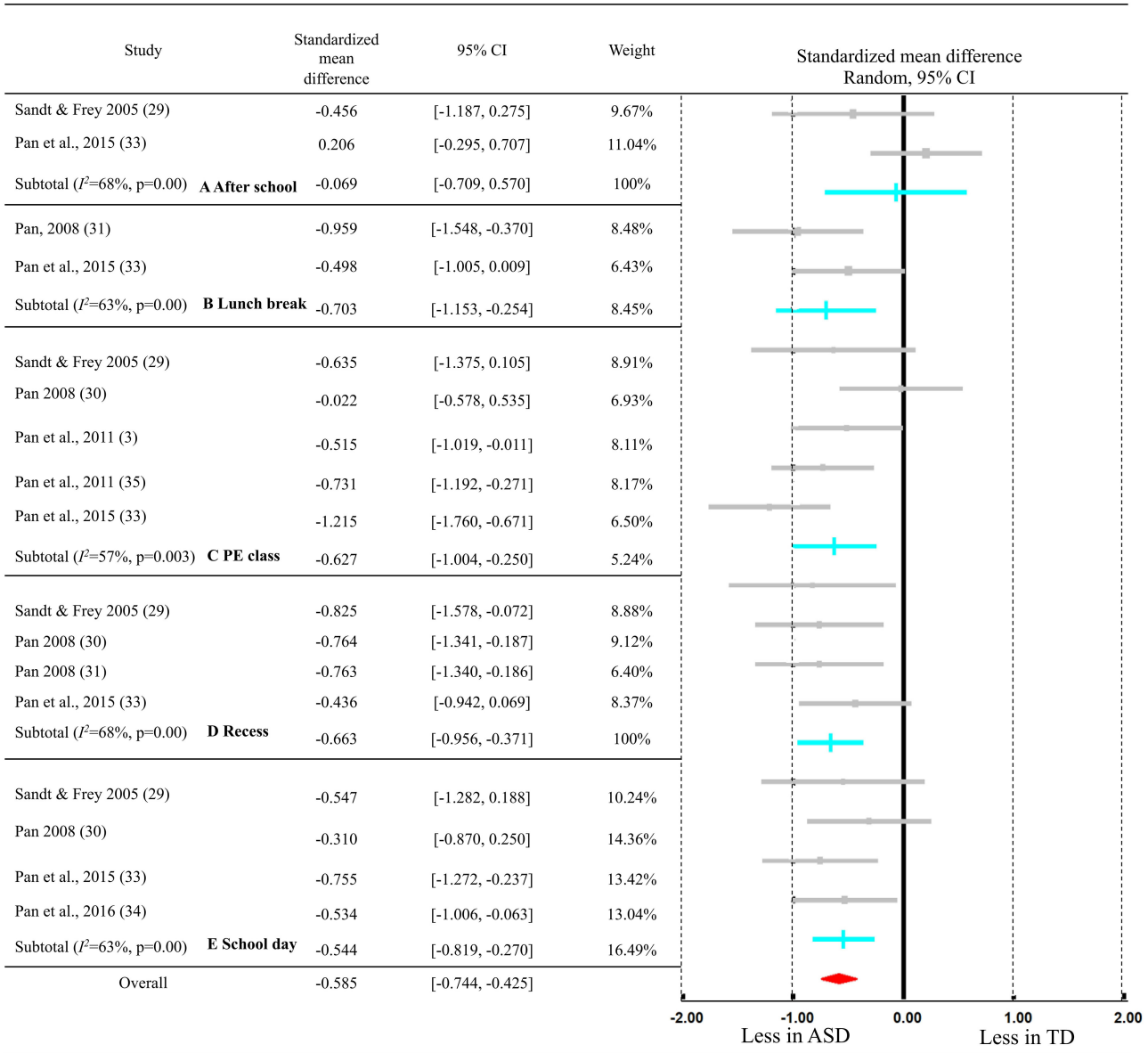

FIGURE 2 | Meta-analysis of difference of the time spent in MVPA between children with ASD and TD after school **(A)**, during lunch break **(B)**, at PE class **(C)**, at recess **(D)**, and during the school day **(E)**.

than primary school students with intellectual disabilities in the USA (78.3%) (43). Furthermore, during lunch break, students with ASD achieved lower levels of PA than their TD peers (16.3 vs. 22.2%, SMD = −0.703), but the PA levels of students with ASD during lunch time in inclusive schools is greatly higher than students with special education needs (SEN) in special schools in Hong Kong (4.5%) (10), and students with physical disabilities in Hong Kong (14.1%) (41). Based on the latest *WHO Guidelines on physical activity and sedentary behavior* (11), schools should provide tailor-made programs in specific settings (e.g., PE and recess) to promote MVPA for children and adolescents with ASD to meet the daily 60 min of MPVA guidelines.

The accelerometer has been widely used to measure PA for children and adolescents with and without ASD as an objective measuring tool in inclusive school. In addition, only one study (29) adopted the accelerometer and the Behaviors of Eating and Activity for Children's Health: Evaluation System (BEACHES) to collect PA data. It is better to utilize two different types of PA measuring tools to collect PA data for children and adolescents with disabilities (44). It is still necessary to notice that none included studies using questionnaires or interviews to gather richer data from educational stakeholders such as parents, teachers, TD peers, and students with ASD. Using the accelerometer alone can only get the quantified data. As

TABLE 2 | Summary of included studies on physical activity (PA)-related findings in inclusive schools.

References	Study design	Study purpose	Major findings	PA-related factors of students with ASD in SRMD		
				Individual	Social	Environment
Sandt and Frey (29)	Cross-sectional	Compare PA levels and patterns between children with and without ASD	Children with ASD were similarly active in recess and PE than children without ASD	Sedentary pursuits (technology-based activities)↓	Unstructured after-school activities↑; excessive class management and unmodified instructions by PE teachers↓; lack of APE specialists↓	Limited recess time↓
Pan (30)	Cross-sectional	Compare MVPA of students with ASD and TD students during inclusive PE and recess	Students with and without ASD spent a larger percentage of time in MVPA during PE compared with recess period	Social impairment (lack of verbal or physical prompts during inclusive recess)↑	PE teacher support (demonstration and physical assistance)↑; PE content adjustment (isolated context)↑; PE content and location (fitness and outdoor)↑	School environment (limited spaces, equipment, and playground facilities)↓
Pan (31)	Cross-sectional	Compare the PA levels of children with ASD and TD children during inclusive recess settings	Children with ASD were less active during overall recess compared with their TD peers	Age (old children to be active in recess)↑; sedentary pursuits (directly go home after school)↓	Lack of support and instruction during recess↓; teachers' behaviors (curricula accommodation and assignments)↓	NR
Pan et al. (3)	Cross-sectional	Examine PA behaviors and correlates that may affect the PA of adolescents with and without ASD during inclusive PE	Adolescents with ASD were less physically active than their TD peers, their PA was related positively to their social interaction with TD peers	NR	PE content and location (fitness test, free-play, and outdoor)↑; teacher-related characteristics (female teachers and non-certified teachers)↑; social initiations and interactions with TD peers↑	NR
Pan et al. (35)	Cross-sectional	Examine PA and motivation between adolescents with and without ASD during inclusive PE	Adolescents with ASD had less PA levels in PE and lower motivations toward PE than adolescents without ASD	Motivation (external regulation)↑; age↓; social impairment (less self-motivated)↓	Teacher support (providing feedback and encouragement)↑	NR
Pan et al. (33)	Cross-sectional	Compare the PA intensity of secondary school-aged students with and without ASD during a school day	Students with ASD had significantly lower daily PA than TD students during a school day	Age (PA declines with age)↓	PE teachers lack APE training↓;	In-school PA opportunities (PE, recess, and lunchtime)↑
Pan et al. (34)	Cross-sectional	Compare PA and physical fitness between secondary school-aged male students with and without ASD	Students with ASD were less physically active overall and had significantly lower scores on physical fitness measures than their TD peers	Fitness level (cardiovascular endurance, muscular strength, and endurance)↑	Lack of extracurricular PA programs↓	NR

NR, not reported; MVPA, moderate to vigorous physical activity; ↑, positive association; ↓, negative association; ASD, autism spectrum disorder; TD, typically developing.

to why students with ASD cannot fully participate in PA, further observations, questionnaires, and interviews for diverse educational stakeholders can help researchers know more details.

The reasons for low PA levels in children and adolescents with ASD are complex. In compliance with the SRMD, the factors affecting PA levels and PA participation can be divided into three levels ranging from individual to environmental level.

At the individual level, in general, a decline in PA with age is recorded, especially in recess time. Primary-school-aged students

with ASD spent 31.38% of recess time in MVPA, whereas secondary-school-aged students with ASD only spent 21.24% of recess time in MVPA. A previous review also echoed this finding that age was consistently inversely related to PA in children with ASD (36). One possible explanation is that as children become older, game rules and required motor skills become more complex. Students with ASD cannot adopt in competitive group games with TD peers and always selected low intensity and solo games during recess time (45). Sedentary pursuits, such as playing with technology-based activities during after-school time, have negative effects on children and adolescents with ASD to shape active behaviors. One systematic review calculated that children with ASD spent an average of 479 min/day in sedentary behaviors including an average of 271 min/day in screen time (36). Another study also reported that children with ASD spent over 62% more time on screen-based activities (e.g., TV viewing and video games) (46). Long engagement with electronic screen activities during after-school time at home has been reported by parents of children with ASD and children with ASD themselves as the most common reason for decreased PA levels (15, 47). Only one study focused on the associations between motivation and PA levels in adolescents with ASD and found that external regulation was positively and significantly related to the time spent in MVPA during the inclusive PE class (35). One possible explanation is that adolescents with ASD were afraid of being isolated by their friends and TD peers (external regulation) during the inclusive PE class. However, it is noticed that PA participation can be regarded as an external award for children with ASD, and fear of isolation by TD peers (introjected regulation) as their motivation to be active during inclusive PE may be not beneficial for their mental health. Therefore, there is a need to develop their intrinsic motivation to actively participate in inclusive PE with their TD peers. Social impairment of students with ASD also decreased their PA levels especially in inclusive recess. One previous review also reported that higher levels of encouragement from friends were related to higher PA levels during recess time (48). However, for adolescents with ASD, they frequently reported that they were socially isolated and preferred solitary activities (49). Therefore, students with ASD hardly participate in PA programs with TD peers during unstructured time.

At the social level, PE lessons were reported to be the focus. PE teachers reported several barriers to implement inclusive PE, such as lack of APE specialists, professional knowledge, and training regarding teaching students with ASD in general PE lessons and modification of PE content and instruction (29, 30, 33). These barriers are commonly reported by inclusive PE teachers and need support by the school (50, 51). In addition, tailored PE content and appropriate equipment and facility location are positively associated with MVPA of students with ASD (12). Well-designed PE lessons not only can help students with disabilities grasp opportunities to accumulate MVPA daily but also shape their PA behaviors as a primary institution (9, 10, 52). Last, schools cannot organize enough after-school PA programs to promote PA participation for all students. Organized extracurriculum PA programs in schools can accept children with ASD to accumulate MVPA daily, decrease sedentary time, and improve social interaction skills with TD peers.

At the environmental level, very little research recorded school environment and examined the effects of school environment on the PA levels of students with ASD during inclusive schools. Only one study found that limited space, equipment, and playground restricted students with ASD from acquiring enough MVPA (31). Previous studies have reported that teachers lacked equipment and facilities to include students with SEN in general PE (53, 54). In addition, it is worth noting that in-school PA opportunities are very different. Some schools provided limited recess and lunch time and moved students with ASD quickly to the classroom to prepare for the next course after lunch (29–31). Thus, schools are much needed to formulate written policies to regulate recess and lunch time at school level because a clear and mandatory policy for recess and lunch time cannot only promote PA engagement of students with and without SEN but also help them maintain health and improve the quality of life into adulthood.

The limitations of this review are noteworthy. First, the total number of included studies are limited, which caused bias in summarizing the results. Second, all included papers have utilized convenience sampling method to recruit participants, which can cause a high level of sampling bias and reflect the pointed PA levels of individuals with ASD. We also noticed a heavy gender difference; only 3% of the participants are females so that we cannot examine whether gender was associated with PA levels in this population. Third, only the studies that indicated detailed minutes spent for MVPA in inclusive schools and compared PA levels with TD students are included. This inclusion criterion may miss some studies and cause bias in determining the PA levels of children and adolescents with ASD. Fourth, the majority of included studies only used objective measurement to calculate PA levels of children with ASD so that there is lack of details to understand PA acquisition from the subjective perspectives. Last, external validity may be low. This review is limited by insufficient participants and geographic differences (six studies in Taiwan and one study in the USA), indicating that the results cannot be widely applied.

CONCLUSION

In sum, the PA levels of children and adolescents with ASD are relatively lower than those of their TD peers in an inclusive school. Limited studies have been developed to focus on children and adolescents with ASD, especially those who attended inclusive schools. Based on this review, in-school PA intervention programs are much needed to design the promotion of PA levels of children and adolescents with ASD during school days. Future studies also are encouraged to explore more diverse variables (e.g., gender, educational stakeholders, school environment, policies, etc.) to identify the effects of those variables on the PA levels in children and adolescents with ASD in inclusive schools.

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.

AUTHOR CONTRIBUTIONS

XL and ZR contributed to the design of this study. RL and XL acquired the data and drafted the manuscript. RL, XL, and YZ interpreted the data and performed the statistical analysis. All authors contributed to the revision and approval of the submitted and final version of this manuscript.

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Effects of a 12-Weeks Yoga Intervention on Motor and Cognitive Abilities of Preschool Children

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Since early childhood is regarded as an important period of motor and cognitive development, understanding the effects of physical activity on motor abilites and cognitive development in preschool children has major public health implications. This study investigates the effects of a 12 weeks' yoga intervention program on motor and cognitive abilities in preschool children. Preschool children (n = 45; age 5–6 years) attending regular preschool programs were non-randomly assigned to yoga intervention (n = 23; 30 min sessions three times per week) or a control group (n = 22; no additional organized physical activity program). Exercise training for the intervention group included yoga program. Motor abilities (BOT-2 subtests: fine motor integration, manual dexterity, balance and bilateral coordination), and cognitive abilities (School Maturity Test subtests: visual memory, stacking cubes and codes) were assessed before and after the intervention period in both groups. Data were analyzed using repeated-measures ANOVA. Participants in the intervention group improved fine motor integration (p = 0.022), fine motor skills in general (0.029), bilateral coordination (0.000), balance (0.000), and body coordination (0.000). Preschool children's participation in the preschool yoga intervention significantly improved their motor abilities, but not their cognitive abilities.

Keywords: motor skills, cognitive function, physical development, physical activity, coordination

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INTRODUCTION

Since early childhood is regarded as an important period of motor and cognitive development, understanding the effects of physical activity on motor abilities and skills, and cognitive development in preschool children has major public health implications (1). Regular participation in physical activities prevents obesity in children and provides numerous health benefits, both physical psychological (2). Along with prevention and reduction of obesity in children, physical activity is also connected with health and good condition of vascular system, muscle strength and endurance, reduction of depression and anxiety, as well as with the academic achievement (3). The results of the research indicate that physical activity is the basis for the early development of each child and it influences many aspects of the child's health (4). Leading health organizations emphasize that higher level of physical activity in children correlates with the important short-term

and long-term health benefits in the physical, emotional, social, and cognitive domains through their whole life. However, it is very important to examine how different programs contribute to the development of different abilities and skills which are necessary for both participation in different sports activities during lifetime and the normal functioning of an individual. One of these programs is yoga for children.

Yoga is a specific form of exercise which is defined as a system of physical positions (asana), breathing techniques (pranayama), and meditations (shavasana), which are practiced with the aim to improve one's physical and emotional well-being. In the pediatrics population, yoga has been used to improve physical fitness, motor skills, strength, negative behavior, attention to task, mindfulness and to reduce stress in older children with typical development and those with physiological disorders and behavioral and developmental conditions (5–7). Areas for which yoga has been studied include physical fitness, cardiorespiratory effects, mental health, behavior and development, irritable bowel syndrome, eating disorders, and prenatal effects on birth outcomes (5). Yoga training became more and more attractive, because it influences the improvement of the health condition in all ages, but the authors state the need for the additional researches on the children population (5).

When it comes to the effects of physical exercises on children's cognitive abilities some research show that yoga practice improves several aspects of cognition and executive functions (8), which can be good predictors of math and reading competence throughout the school years. It is possible that yoga might help improve executive functions, spatial memory scores, strategic planning and the ability to concentrate. It is shown that regular yoga practice is coupled with the improved impulse control, sustained attention, attenuated antisocial and self-harm behaviors, reduced stress, and psychological distress (9), as well as with the positive impact to concentration, attention and behavior (10). These improvements may reflect underlying improvements in motor planning, motor speed, and hand steadiness. In terms of behavior, fine and gross motor skills and the academic achievement, there is an insignificant or no change (8). One of the studies that was conducted exclusively examined the influence of Hatha yoga on the motor abilities, such as strength, flexibility, coordination and balance. When it comes to motor performances, Telles et al. concluded that after the yoga training there is an improvement of statistical performances in children (11), but most of the authors recommended additional research to address methodological shortcomings.

Numerous researches have confirmed that during the physical activity, the level of motor abilities increases, along with development of cognitive abilities. Findings favor causal evidence of relations between physical activity with both motor and cognitive development in preschool children, with increased physical activity having significant beneficial effects on motor abilities and cognitive functioning, but given the small number of studies available in the literature, future research with large representative samples is needed to explore other cognitive domains and to strengthen and confirm the dose-response evidence (1). Regarding that the aim of the study was to examine the effects of yoga on motor and cognitive ablities in preschool children.

TABLE 1 | Decriptive statistics (Mean ± SD).

Variable	Yoga group	Control group
Number	23	22
Gender	Boys: 9 Girls: 14	Boys: 9 Girls: 13
Age	Initial: 5.82 ± 0.23 Final: 6.06 ± 0.23	Initial: 5.90 ± 0.27 Final: 6.14 ± 0.27
Body weight (kg)	21.43 ± 4.55	22.60 ± 3.60
Body height (m)	1.15 ± 0.05	1.17 ± 0.05
BMI (kg/m^2)	16.07 ± 2.45	16.42 ± 1.65

METHODS

Subjects

A total of 45 children (age range 5–6 years) participated in this study for a 12-week period. The sample was divided into two groups: experimental group ($n = 23$) aged 5.82 ± 0.23 years, with a mean height of 115 ± 0.05 cm and a mean weight of 21.45 ± 4.55 kg, and control group ($n = 22$) aged 5.90 ± 0.27 years, with mean height 117 ± 0.05 cm, 22.60 ± 3.60 kg (**Table 1**).

All children attended a standard preschool program during the day at one of the preschool institutions in PoŽarevac, Serbia. The experimental group consisted of 23 children who attended the preschool yoga program (three 30-min sessions per week) in addition to their participation in a standard preschool institution program. The control group consisted of 22 healthy children from a single preschool institution who did not engage in any additional organized PA outside of the standard preschool program. It should be noted that the authors point out that in children at this age, weight, height and endurance and development of physical abilities are very similar in girls and boys and that joint participation in the same programs is not contraindicated (12).

All participants' parents gave written consent for their children to participate in the study. This study was approved by the Institutional Review Committee of the University of Niš (Ref. No. 04-1186/2) and was conducted under the Declaration of Helsinki.

Motor Abilities Assessment

Subtests from the BOT-2test battery were used to evaluate motor abilities (Bruininks-Oseretsky Test of Motor Proficiency). BOT-2 is used as a standardized measure of the level of motor ability in children and adolescents aged 4 to 21 (13). Previous researches in this area have proved that BOT-2 test is valid (14). For the purposes of this research 4 subtests were used: fine motor integration (8 tasks), manual dexterity (5 tasks), balance (9 tasks) and bilateral coordination (7 tasks). The mentioned four subtests

include a total of 29 motor tasks, and the last two subtests—balance and bilateral coordination, together give a composite of body coordination, which additionally indicates this ability of the examinee.

Cognitive Assessment

To evaluate the cognitive abilities of preschool children three subtests of the School Maturity Test (Serbian TZŠ+) were used: visual memory, stacking cubes and codes. The results of the study showed high reliability and validity of this test and they suggest that TZŠ+ has high correlation with the cognitive tests of TYPE1 and with Raven's Colored Matrices (15). *Visual memory* is a test designed to evaluate the ability of memorization and attention span, and it consists of 15 tasks. *Stacking cubes* is a test meant to evaluate the ability of visual-motor coordination, perceptive organization and the ability of planning, and it consists of eight tasks. *Codes* is a test which evaluates the ability of learning from experience, concentration and visual-motor coordination, and it consists of 25 tasks.

For the purposes of this research the school maturity test was ordered and purchased from the "Association of Psychologists of Serbia" from Belgrade. When using this test two psychologists were hired at the Faculty of Sports and Physical Education in Niš and in the "Ljubica Vrebalov" preschool in Požarevac. The hired psychologists conducted the cognitive tests and interpreted the results, which is in accordance with the article 10 of the Rulebook on the Standards and Procedures for the Development and Use of Psychological Measuring Instruments. Testing of all the participants in this experimental study was performed immediatelyy before (the initial measurement) and later again, after the applied experimental exercise programs (the final measurement). All the testings, as well as the implementation of the experimental program was conducted in the gymnasium of "Ljubica Vrebalov" preschool in Požarevac.

Experimental Program of Yoga Exercises

The duration of the program of exercises is defined on the bases of the recommendations of previous research. In this regard, it was found that the duration of program in most studies ranged between 2 and 4 months, and the treatments ranged most frequently between 1 and 2 h per week, distributed between 2 and 5 h per week. The yoga program was a modified version of standardized yoga curricula for preschool children (16–20). In these curricula most represented kinds of asana are the animal positions (e.g., cat, cow, dog downward) and the positions of the nature (e.g., mountain, tree, moon), because they are relatively simple and interesting to the small children. In accordance with the guidelines that for children under the age of six the total time for yoga session should be up to 20 min, the class was divided into three parts. The introductory part of the class lasted for 5 min and was aimed to prepare the children for the activities in the main part through light breathing exercises. The main part of the class lasted up to 20 min. In this part yoga positions are performed and the children stay in the final position of any yoga asana/exercise for up to 10 sec. This modified form of yoga combines different physical positions, visual images, but it doesn't include extremely deep breathing, because it is considered difficult for small children to include distinct breathing along with holding an appropriate position (8, 21). Final part of the class lasted for up to 5 min and was intended for relaxation.

The 2 × 2 repeated-measures ANOVA was used to compare differences in outcome measures after the intervention period between the two study groups. Moreover, p-values of <0.05 were considered statistically significant. No corrections were applied for multiple comparisons. The data are reported as mean ± SD or frequency (percentage). The data were analyzed using the statistical package SPSS version 20.0 (SPSS Inc., Armonk, NY, USA).

RESULTS

The results of motor abilities tests indicate certain changes among participants. Improvement in the fine motor integration test results has been noted in favor of the intervention group ($p = 0.022$). A significant differences were detected in the fine motor skills test results ($p = 0.029$), bilateral coordination ($p = 0.005$), balance ($p = 0.000$), and body coordination total score ($p = 0.000$) (**Table 2**).

DISCUSSION

This study evaluated the effectiveness of a 12-weeks yoga intervention in preschool children and the results showed that the program had higher influence on motor than on the cognitive abilities. Significant improvements were observed in 5 of total 6 subtests for motor abilities assessment, in fine motor integration, manual dexterity, coordination, and balance, in the intervention group compared to the control group. On the contrary, no progress is observed in 3 subtests for cognitive assessment.

The significant contribution of the experimental program which was recorded on the tests of motor coordination in the variables bilateral coordination, balance and overall body coordination, is in line with previous research (22–25). When it comes to fine motor abilities test, a significant contribution of yoga practice to fine motor integration and overall fine motor abilities has been noted, which is also in line with previous research (8). It is important to point out that motor coordination affects the child's quality of life and different bio-psycho-social aspects (26), and that fine motor abilities have a positive impact on the sensorimotor development of the nervous system (27). Therefore, special attention should be paid to their development in children.

A great improvement noted in the balance subtest is also in line with the results in a large number of previous studies showing that great improvement has been achieved in the static balance of preschool children (28) and school-age children (2, 5, 6, 29). All these findings confirm the theory of motor development in children which says that preschool children, aged 3–6 are in a period of rapid development of balance skills (30). Statistically significant improvement in balance abilities can be attributed to the specific yoga positions. During yoga practice, taking many positions or asanas stimulates the work of the torso

TABLE 2 | SPANOVA (ANOVA goup × time).

Variables	Yoga		Control		F	*p*	ηp^2
	Inicial	Final	Inicial	Final			
Fine motor integration	12.22 ± 4.56	12.87 ± 3.09	13.41 ± 3.83	11.82 ± 2.26	5.68	0.022*	0.117
Manual dexterity	13.70 ± 4.17	16.09 ± 5.51	12.91 ± 4.26	14.00 ± 4.69	0.60	0.445	0.014
Fine motor skills	25.91 ± 7.70	28.96 ± 7.78	26.32 ± 6.16	25.82 ± 5.48	5.10	0.029*	0.106
Bilateral Coordination	14.65 ± 2.06	17.22 ± 2.61	16.55 ± 1.99	16.68 ± 2.77	8.69	0.005*	0.168
Balance	15.74 ± 4.91	18.17 ± 5.06	15.27 ± 3.01	13.27 ± 3.65	15.60	0.000*	0.266
Body Coordination	30.39 ± 5.73	35.39 ± 6.35	31.82 ± 3.32	29.95 ± 5.43	20.44	0.000*	0.322
Visual memory	3.22 ± 0.67	3.35 ± 0.49	3.14 ± 0.35	3.27 ± 0.46	0.00	0.975	0.000
Stacking cubes	4.35 ± 0.88	4.48 ± 0.73	4.41 ± 0.67	4.18 ± 0.80	3.02	0.089	0.066
Code	3.43 ± 1.04	4.00 ± 0.85	3.23 ± 0.61	3.41 ± 0.67	2.30	0.137	0.051
Total cognitive Abilities	3.67 ± 0.67	3.94 ± 0.58	3.59 ± 0.40	3.62 ± 0.46	3.56	0.066	0.076

*F-coefficient of the F-test; p—coefficient of significance of the differences, * at the $p < 0.05$ level; ηp^2-partial Eta squared.*

stabilizer muscles. This improves the interaction between the upper and lower extremities in the kinetic chain, which facilitates the maintenance of static balance during exercise (31). If this ability isn't developed properly and on time, it will negatively affect other related abilities (30). About 73–87% of children with poor motor development have problems with balance, and these problems have an impact on their further learning of complex motor skills such as climbing, running, cycling etc. (32). These results are consistent with research by Bubel and Gaylord (28), where no progress was made in dynamic balance after a six-month yoga program in preschool children. However, the author emphasizes his assumption that the cause of poor progress in dynamic balance is the weak discriminativeness of BOT-2 items which represent the dynamic balance (items 2 and 5), where the respondents generally achieve high or maximum results, so there is not enough space to quantify progress.

When it comes to cognitive assessment, the contribution of experimental program is not noticed in any of 3 subtests, which is unexpected because the vast majority of previous research suggest slightly different results. A large number of authors claim that the implementation of physical exercise programs for preschool children can significantly contribute to the improvement of their overall psycho-physical development. It can influence the improvement of both their motor abilities and skills and their cognitive abilities, which will enable them to reach their full potential more easily (2, 33–35). We will list the claims of several other significant authors: Lawson et al. (8) suggest that yoga may have positive effects for preschool-age children, particularly in the areas of fine motor and academic performance; Preschool children's fine motor improvement with yoga is consistent, with literature showing fine-motor improvement in school-age children participating in yoga (36, 37); the yoga program helped students feel focused and gave them strategies to control their behavior in stressful situations (38); the significant improvement was observed in measures of mental ability and memory in experimental group of yoga practices in residential school children (39); a positive influence of yoga practice in children on the parameters of visual attention (40); Hillman et al. (41) suggest that the exercise can increase the children's brain volume, improve their cognitive abilities and their academic achievement (41).

Although numerous studies have confirmed that during the physical activity the level of cognitive abilities increases, the result of this study suggest the opposite and indicates that yoga exercise didn't have a significant influence on any variable of cognitive abilities in preschool children. Some studies which agree with the results of this study, although few in number, can still be found, so Songul et al. (42) argue that after 1 h a week of yoga education, significant difference was no found between the pretest and post-test score in averages, which suggests that this topic should be approached with a dose of caution, and that it should be further examined. The tests of coordination are largely related to intelligence, i.e., their adequate performance largely depends on it, and due to this fact it cannot be literally said that there is no progress in cognitive abilities.

Failure to achieve the expected results in our study can be reflected in a small sample, in the insufficient duration of the experimental exercise program itself, which may be the limit of this study, so in future research, it is recommended to use different cognitive tests which will more completely measure a wider range of cognitive abilities. Certainly, we should also keep in mind the analysis of Stojiljković et al. (43), who found that exercise should be added to the simultaneous performance of certain tasks which require cognitive thinking and higher levels of attention. This suggestion should be a guideline for some further research in this field, i.e., for designing a program of yoga exercises that would include solving certain cognitive tasks at the same time.

CONCLUSION

This study provides evidence that a 12-week yoga program has beneficial effects on typically developed preschool children, demonstrating a positive influence on their motor abilities. Such research is extremely important, because the preschool period is a critical period for the development of these abilities, and also,

the habits that children acquire in this period are reflected in the comprehensive motor development during life.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Committee of the University of Niš (Ref. No. 04-1186/2). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

AA and BK contributed to conception and design of the study. BK organized the database. BK and BM performed the statistical analysis. AA wrote the first draft of the manuscript. AA, BK, and BM wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Associations Between Physical Fitness, Objectively Measured Physical Activity and Academic Performance

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There is evidence that physical activity (PA) can improve the academic performance. We recruited healthy adolescent girls, aged 11–12 years, and measured their PA with the accelerometer ActiGraph GT3X for the consecutive 5 days. Physical fitness (PF) was measured with eight motoric tests and three anthropometry measures. Academic performance (AP) was assessed for the six academic narrated school subjects. The results revealed that the girls were more physically active during the week days and less active at weekend (557 vs. 516 counts/min). Physical education grade shows the highest overall correlations with the results of the PF test battery ($r = 0.53$–0.95, $p < 0.01$). Nevertheless, correlations surprisingly decrease for the combined daily PA ($r = 0.45$), especially the weekend PA ($r = 0.28$). Grade point average and PF correlated moderately ($r = 0.43$-0.64), while they were moderate to high for PA ($r = 0.59$–0.87). Many questions arose after the completion of the present study and several new topics opened up, such as the question of how parental education affects the duration of PA and AP of the children and the influence of the place of residence AP of the children.

Keywords: physical activity, academic performance, girls, physical fitness, mathematic grade, grade point average

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INTRODUCTION

Physical activity (PA) is defined as any bodily movement produced by the skeletal muscles and resulting in energy expenditure (1) that is greater than at rest (2). It has a positive effect on the physical and mental well-being and the general quality of life (3–6). In addition, the physical and psychological benefits of PA are widely acknowledged (7, 8), while there is not abundant evidence about direct effects of PA on cognition (9). Therefore, researching the influence of PA on the academic performance (AP) is a current research topic of great interest around the world due to increasing evidence about the positive effect of PA on cognitive functioning (10).

The studies on the cognitive benefits focus mainly on the development of learning skills and AP in relation to physical education (PE) and PA (11–13) in children and adolescents (14), which has been developed on the fact that PA increases oxygen saturation (15) and angiogenesis (16, 17) in brain areas responsible for the performance of tasks. Findings from the recent systematic reviews and meta analyses have shown that higher levels of PA are associated with the higher levels of AP (9, 18–20). Not all of these reviews took into account, the methodological quality of the studies included and examined only the AP of the pupils, who were usually assessed by evaluating their knowledge and scholastic aptitude in various subjects, with mathematics and literacy being

the most important (21). Recent studies have mostly investigated the impact of classroom breaks and physically active learning (22–24). That is problematic due to different underlying mechanisms of change, such as blood-flow, brain-derived neurotrophic factors, and plasma catecholamines (17, 19, 25–27).

The cognitive and academic training of children is to a large extent a task entrusted to the education system. To improve AP, teaching time for the core academic subjects is extended and protected, often at the expense of time spent in PE and other areas of the curriculum (19). Nevertheless, the fact that Slovenia has one of the best curricula for PE in the world (28, 29), such a trend could potentially also hurt the Slovenian educational system. To our knowledge, PA in Slovenia was usually estimated using questionnaires (30, 31), which are less reliable (32) than objective methods. Only recently have Slovenian researchers begun acquiring such data in a more objective way: with accelerometers (33, 34). Nevertheless, to the best of our knowledge, there is no evidence of a study dealing with the relationship between AP and objectively measured PA.

The aim of the present study was to investigate the relationship between physical fitness (PF), objectively measured PA of Slovenian girls and their AP, which was based on the grade point average (GPA) and separate grades of the four specific subjects.

MATERIALS AND METHODS

Participants

We recruited 20 primary school girls, aged 11–12 years (height 161.3 ± 0.52 cm; weight 52.1 ± 0.9 kg; triceps skinfold 16.3 ± 6.7 mm). Four of them were excluded from the study regarding the rule 70/80 (35) and illness. The study was conducted in accordance with the Declaration of Helsinki and all participants signed informed consent approved by the National Medical Ethics Committee (ID 138/05/13).

Procedures

Physical Fitness

The body height was measured when the subjects were in sportswear and did not wear shoes, using a mechanical stadiometer platform (Seca® 213, Hamburg, Germany) with a small technical error of measurement (TEM = 0.019%). Bodyweight was measured using the electronic scale (Tanita® BC544, Tokyo, Japan; TEM = 0.510%). The skinfold of the triceps was measured halfway between the acromion process and the olecranon process with the Harpenden skinfold caliper.

Physical abilities were determined using the SLOfit test battery. All tests have been evaluated on a sample of Slovenian population and have appropriate dimensional characteristics and are suitable for the use. For every PF indicator, one test was used: sit-ups, standing long jump, sit and reach, running 60 m and 600 m.

Physical Activity

In order to objectively assess the level of PA, participants have worn accelerometer Actigraph GT3X (Actigraph LLC, Pensacola, FL) for 5 days, comprising of three school days (Wednesday, Thursday, and Friday) and two weekend days (Saturday and Sunday). Counts signal was sampled in the 15-s epochs in the present study. Data of sleep and awake time were logical and coincided with diary logs and covered school time, extracurricular activities, after-school time and evenings (daytime, excluding mornings, and sleep time). If any accelerometer count was >16,000 counts/min, these were removed, because it is assumed to be beyond biologically plausible range (36). Likewise, if the device recorded the number of counts ≥0, which was constant for 10 min or more, these data were also removed, because it is assumed to be accelerometer malfunction (37). Furthermore, the wear time was calculated regarding the rule 70/80 (38). Wear time was defined from 7:00 to 21:30 (870 min), hence accepted wear time was 609 min or more per day. The sequences of 20 consecutive minutes of zeros were cleaned, because it was considered that ActiGraph was not being worn (39) and the zeros were changed to missing data.

Academic Performance

Academic performance was assessed in order to describe the different factors that may influence the success of pupils in school. AP was presented through average grades, calculated from all grades obtained during the whole school year 2014/15 from following school subjects: Mathematics, Slovene language, English language, and PE GPA. GPA was calculated as arithmetic mean grade of average grades from all subjects in that school year.

Data Collection

The data for the present study were collected at the primary school Ivana Groharja in Škofja Loka. PF data from the school's SLOfit database were evaluated, and PA was measured from Wednesday to Sunday in June 2014 using the ActiGraph GT3X accelerometer. AP was evaluated based on the school documentation provided. In addition, data on additional engagement in sport and the mode of commuting to school were assessed from PA diaries.

Data Processing and Statistical Analysis

All statistics were made in Microsoft Excel 2007 and IBM SPSS, 20.0. Microsoft Excel 2007 was used for removing the artifacts, counts >16.000, constant values ≥0, and sequences of zeroes, where the sequence was 20 or more zeroes. PA data were processed with the Actilife software (standardized for accelerometer ActiGraph), following the 70/80 rule (38) and non-wear time within a day (40). Testing for distributions of the normality was checked visually (histogram) and with the Kolmogorov–Smirnov test using IBM SPSS Statistics 25.0. Descriptive statistics were calculated for all variables (mainly as mean and standard deviation). Associations between derived estimates of grades, PF, and counts from accelerometer data were computed using the Spearman's correlation. The difference between weekday and weekend PA was assessed using the paired sample *t*-test. The effect size was determined using the Cohen's d. The Chi-square test was used to investigate the correlations between engaging in sport activities and PA and between modes of commuting to school and PA.

RESULTS

Table 1 shows the evaluated results of the PF of the pupils. It can be seen that the CV% value for the Bent Arm Hang test is very high, which indicates the high dispersion of a frequency distribution.

Figure 1 shows that the daily measured PA of pupils reached 536 ± 240 counts/min. The average PA on the weekend days was lower than PA on the school days (516 and 557, respectively). The variance of weekend PA counts was ±328, indicating significant differences in weekend PA among primary school pupils. The standard deviation of PA counts on the weekdays was ±199, indicating a uniform PA pattern of female pupils during the school hours, as the dispersion of the PA counts is lower than on weekends. Regardless of higher PA counts during weekdays, the paired sample *t*-test showed no significant differences in PA counts during weekdays and weekends.

Table 2 shows the prevalence of children taking part in additional sports during the day (in minutes/day) and the way they commute (in minutes/day). The Chi-square test showed no significant correlations between engaging in sport and type of PA and between the modes of commuting and the types of PA ($p = 0.42$ and $p = 0.12$, respectively).

As can be seen from the percentage distributions, the children who are engaging in additional sport or PA are reaching recommendations for PA (high PA). Similarly, the children who commuted actively are spending the most time in PA actively. The average grades were calculated for the school year 2014/2015. The calculation of the average grade took into account all grades of an individual school subject in the 2014/15 school

TABLE 1 | Descriptive statistics of the physical fitness of the pupils.

PF tests	Mean	SD	Min	Max	CV%
Taping (n)	42.3	2.8	37.0	47.0	6.7
Long jump (cm)	178.8	27.5	130.0	230.0	15.4
Polygon backwards (s)	13.5	8.7	8.4	45.0	6.5
Sit-ups (n)	49.3	10.8	30.0	63.0	21.9
Stand and reach (cm)	49.0	6.6	35.0	60.0	13.6
Bent arm hang (s)	51.7	36.1	3.0	120.0	69.8
Sprint 60 m (s)	9.9	1.0	8.6	12.2	9.9
Running 600 m (s)	150.8	33.5	109.0	215.0	22.2

Mean, averaged value; SD, standard deviation; Min, minimum value; Max, maximum value; CV%, coefficient of variation.

TABLE 2 | Sports participation and commuting of included participants.

PA or sports in min/day		Very low PA	Low PA	Normal PA	High PA
Engaging in sport	Additional sport	12,5%	25,0%	12,5%	50,0%
	Without additional sport	50,0%	12,5%	12,5%	25,0%
Commuting	Active	0,0%	28,6%	14,3%	57,1%
	Driven	55,6%	11,1%	11,1%	22,2%

Very low PA (<30 min of PA/day); low PA (>30 min PA/day <450 min PA/day); normal PA (>45 min PA/day <60 min PA/day); high PA (>60 min PA/day).

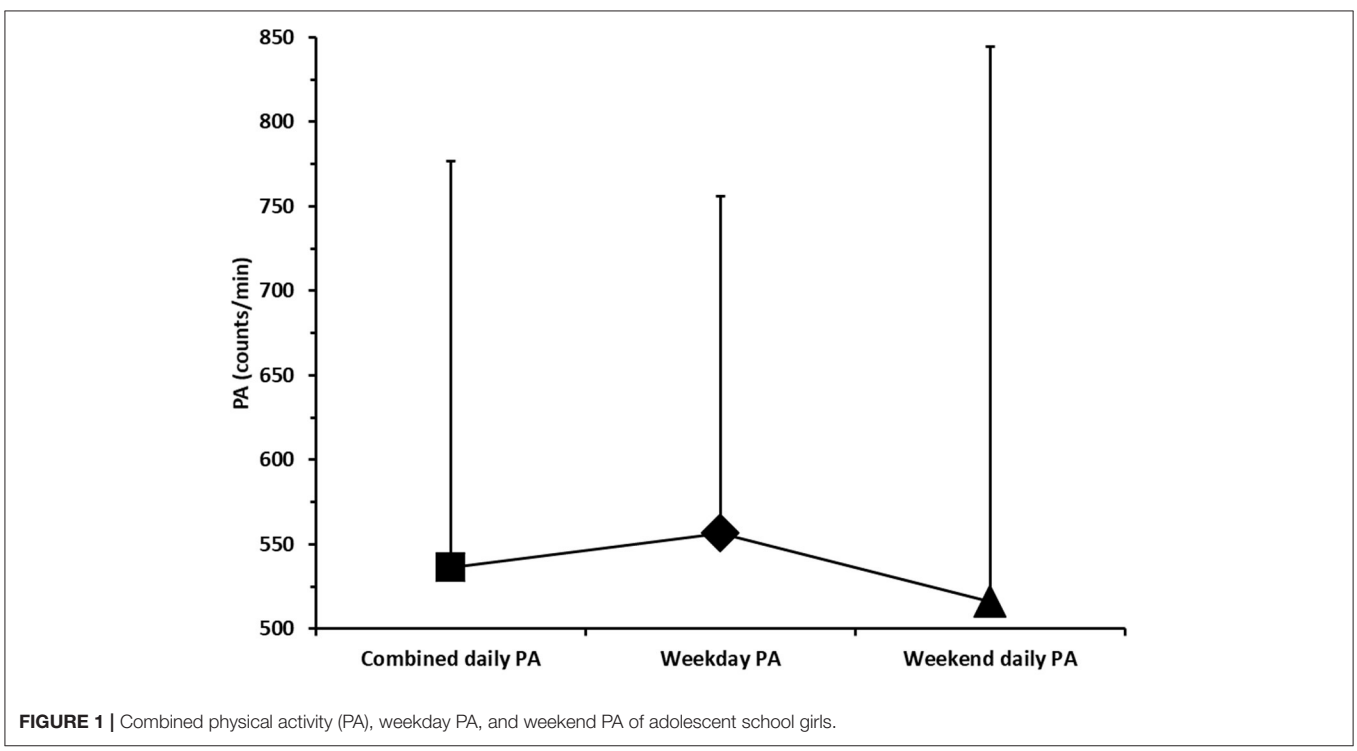

FIGURE 1 | Combined physical activity (PA), weekday PA, and weekend PA of adolescent school girls.

year. All grades and descriptive statistics on the AP are shown in **Table 3**.

Correlations between PF and AP and between PA and AP were identified using the Spearman's correlation analysis. **Figure 2** shows the above-mentioned correlations for 20 school girls.

Note that the correlation coefficients for the tests Polygon backward, Sprint 60 m and Running 600 m were negative. Nevertheless, we presented them as positive values, since lower values of the above-mentioned tests represented better results and, therefore, correlation was essentially positive. At first glance, it is noticeable that the PE grade shows the highest overall correlations with the results of the PF test battery ($r = 0.53$–0.95) at the significance level 0.01. Nevertheless, correlations surprisingly decrease for the combined daily PA ($r = 0.45$), especially the weekend daily PA ($r = 0.28$). The situation is somewhat different for GPA, where the correlations with PF were mostly moderate ($r = 0.43$–0.64; with the exception of Taping, where $r = 0.26$), while they were moderate to high for PA ($r = 0.59$–0.87). A similar trend was observed for grades in mathematics, native, and foreign languages. The overall lowest correlations with the PF results and one of the highest with PA were found for the grades of the native language.

TABLE 3 | Descriptive statistics for academic performance.

Subject	Mean grade	SD
Mathematics	3.44	0.93
Slovene language	3.78	0.80
English language	3.34	1.02
Second language	3.56	0.85
Physical Education	4.25	0.70
GPA	4.10	0.64

AP, academic performance; Mean grade, average grade throughout the school year for selected subject or GPA; SD, standard deviation; GPA, grade point average.

DISCUSSION

The results revealed that the girls were more physically active during the weekdays and less active at the weekend (557 vs. 516 counts/min). Despite statistically insignificant differences, the dispersion of results around the average PA during weekdays was lower compared to weekends, indicating more consistent patterns of PA among schoolchildren during the school days. The relatively large dispersion around the average PA could be explained by the relatively small sample size. It can also be explained by the large differences between the minimum and maximum values of the results obtained in a few tests. For example, the worst result in the Bent Arm Hang was only 3 s, which indicates that some of the girls had a large deficit in the upper body strength. In addition, 45 s in Polygon Backward indicates very poor coordination skills.

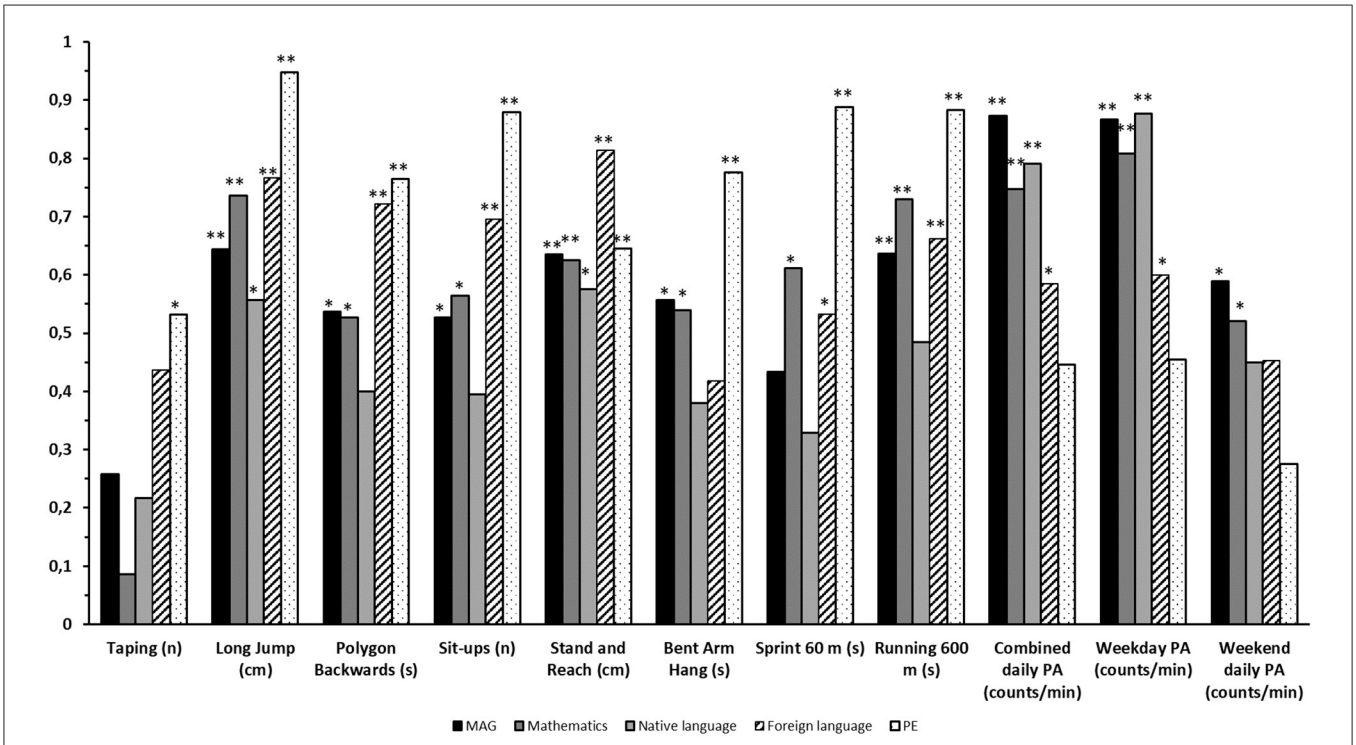

FIGURE 2 | Correlation between physical fitness and academic performance, and physical activity and academic performance. Statistically significant correlations were marked with $^{*}p < 0.05$ and $^{**}p < 0.01$.

Compared to many other countries, the Republic of Slovenia has a respectable PE curriculum compared to many other countries (29, 41). PE in the Republic of Slovenia is a standardized and compulsory subject in all primary and secondary schools (41), which is also confirmed when comparing overall activity minutes during weekdays and weekends. According to the results of the present study and following other Slovenian studies (41–43), we can say that the Slovenian primary schoolchildren are physically more active on weekdays, what is also in concordance with other studies (44, 45). In fact, all schools in the Slovenia offer their pupils the opportunity to engage in PA and the majority of Slovenian pupils can be physically active for up to 51 min a day during the school day (41). The decrease at weekends is largely due to a decrease in the intensity of light intensity bouts (44) and the lack of the structured school environment at weekends determine the different PA levels and patterns, which is particularly noticeable among girls (46). As we have included only girls in the present study, the actual PA counts of schoolchildren could be different, probably significantly higher for boys compared to girls, as found in other studies on the Slovenian schoolchildren (42, 47, 48).

Attention-grabbing results were found regarding the correlations between PF, PA, and AP. As expected, the correlation analysis revealed that the pupils with the highest PE grades had the highest level of PF. This could be explained, for example, by knowing that school PE programs routinely allow children to exercise their abdominal muscles and, therefore, a high correlation between PF score and PE grade could be expected. Remarkably, moderate to high correlations were found between the results of PF and GPA, mathematics, native, and foreign languages grades. This is in-line with the previous studies (49, 50).

Surprisingly, however, the same pupils with high grades had a low level of PA. Nevertheless, the trend was the same as for the others—they were more active on weekdays than at weekends. We can only discuss these findings. One reason for this could be that some of the girls took off the accelerometer during the training sessions and games, so this influenced the lower correlation. However, this assumption is probably not true, since the Chi-square test showed that the additional engagement in sports was not a significant factor for the average PA during the day ($p = 0.12$). However, although there was no significant correlation. **Table 2** shows that such results could be explained by the mode of commuting to school as an important factor. It has been shown that it is very important to separate commuting from home to school and *vice versa*, as it turned out that children who actively commute from school to home have higher VO2 max (51). A possible explanation could be playing in the playgrounds on the way of home and spending more time in the high-intensity PA. Inactive commuting to school in the morning is often associated with the parental convenience of dropping a child off at school on the way to work, and not necessarily with reservations about the active commuting or an active lifestyle. We speculate that the Chi-square test results would be significant if we had these data separated.

The results should be interpreted with caution and cannot be presented as if the increased PF or PA caused an improved AP or *vice versa*. Many questions arose after the completion of the present study and several new topics opened up, such as the question of how parental education affects the duration of PA and AP of the children and the influence of the place of residence on AP of the children. Self-reported results should be carefully interpreted in terms of the validity and reliability (52) of the measured data, and an objective measurement of PA should be considered to ensure the accuracy of the results. All questions raised in the present study should be considered and analyzed in future studies.

Strengths and Limitations

The results of this study indicate that there is a significant correlation between AP, PA, and PF for certain outcome measures. However, before outlining the benefits of PA and PF on AP, it is important to note that many factors influence AP. These include socio-economic status, parental involvement, PA, and participation in sport and other demographic factors such as place of residence.

There are methodological limitations to be considered in the current research: (i) the study was conducted with a relatively small sample size ($n = 20$) of schoolchildren; in order to generalize the results to larger groups, the study should have included more participants. Moreover, all the girls were picked from an extracurricular activity called "Healthy lifestyle," therefore, a potential bias in sample might occur; (ii) the children knew they had been monitored (53), therefore, we did not measure their habitual PA and the results cannot be generalized as a completely realistic measure for PA; (iii) accelerometers are not able to detect the static exercises (54), and the devices might underestimate PA in total; (iv) high device costs and an insufficient number of accelerometers did not allow the measurement of all girls in the same time interval, so that there might be differences in the duration of PA due to different weather conditions; (v) AP was evaluated based on a mathematical grade, Slovenian language grade, a natural science grade, and GPA. AP grades were based on the assessments of the school teachers, therefore, a possible "rater bias" might have been introduced so that the results can only be generalized to those instruments that assess AP; (vi) there was a lack of separate data on the mode of commuting from home to school and *vice versa*.

CONCLUSIONS

The purpose of this study was to investigate the level of PF, objectively measured PA of Slovenian girls, and the relationship between PF, PA, and their AP. The results showed that the girls were more physically active during the weekdays and less active at the weekends. As expected, the correlation analysis showed that the pupils with the highest PE grades had the highest level of PF but had surprisingly low to moderate correlations with the level of PA. The frequency of the PA type in relation to the mode of commuting to school showed that such results could be explained by the mode of commuting to school as an important factor. Based on our previous research, it is assumed that the main factor is commuting from school to

home. In addition, moderate to high correlations were found between the results of PF and GPA, mathematics, native, and foreign languages grades. The highest correlation was found between GPA and the combined daily PA. It has been shown that the PE system could influence the future PA and lifestyle of schoolchildren (55) and consequently health status and PF in adulthood.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by National Medical Ethics Committee (ID 138/05/13). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

VS and SĐ conceptualized the study design, recruited subjects into the study, and analyzed and interpreted the data. VZ conducted the research. VS, ŠB, SĐ, and VZ drafted and reviewed the manuscript. All authors have read and approved the final version of the manuscript.

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Gross Motor Coordination: We Have a Problem! A Study With the Körperkoordinations Test für Kinder in Youth (6–13 Years)

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The main goal of our cross-sectional research was to determine the current values of gross motor coordination (GMC) of Italian boys and girls between 6 and 13 years of age. Secondary goals were to study gender differences, and the four subtests trend with ages. Results were compared with the references proposed by KTK authors and with similar searches. Anthropometric measurements and KTK data from 2,206 schoolchildren (girls: $n = 1{,}050$; boys: $n = 1{,}156$) were collected. The KTK raw score (RS) increased with the age of the subjects ($r = 0.678$; $p < 0.001$). In 11–13-year-old subjects, the increase in results is less than in younger subjects. RS showed differences by gender ($F = 5.899$; $p = 0.015$) and age ($F = 269.193$; $p < 0.001$) without interaction gender × age. Motor quotient (MQ) tended to decrease with age ($r = -0.148$; $p < 0.001$); it showed differences by gender ($F = 79.228$; $p < 0.001$), age ($F = 14.217$; $p < 0.001$), and an interaction gender × age ($F = 2.249$; $p < 0.05$). Boys showed better performance than did girls in the raw scores of three of four subtests (JS: $F = 24.529$; MS: $F = 9.052$; HH: $F = 11.105$). Girls show better performances than did boys in the WB ($F = 14.52$). Differences between genders make us believe it appropriate to maintain a differentiated standardization. RS increased with age, and it seems reasonable, therefore, to maintain a GMC age-based normalization. On the contrary, MQ tended to decrease. All this makes us speculate that today's young people accumulate less significant motor experiences over the years compared to those achieved by their peers in the 1970s. Italian data were lower than German references and Belgian results but slightly higher than the Brazilian ones. The comparison among these four searches confirmed a worrying downward trend in GMC and its characterization by geographical and sociocultural areas. Updated parameters of the KTK can provide helpful references to improve policies to support physical activity, sport, and physical education in youth.

Keywords: gross motor coordination, KTK, youth development, children, physical activity, health, motor coordination (MC)

INTRODUCTION

Motor learning and control characterize children development and their adaptation to the physical and social environment. The manifestation of motor learning and control is the children's motor competence. It can be defined as mastery in fundamental movement skills (e.g., walking, throwing, and catching) and in more specialized movement sequences such as lifelong physical activity abilities like cycling, swimming, or sport-specific skills (1). Motor abilities are articulated in basic stability (static or dynamic balance), manipulation, object control, and locomotor abilities (2). Basic stability and locomotor abilities, often defined as "gross motor coordination" (GMC), involve the control of two or more body segments and/or the global movement of the body in space (3). These two aspects of movement are fundamental both in the acquisition of fundamental motor skills (FMS) and in the development of specialized movements and techniques of daily life and sport. FMS is generally categorized into basic locomotor skills that lead children to transfer the body in space (e.g., walking and running) and object control skills that allow them to manipulate and project objects (i.e., striking, kicking, etc.) (4). In both cases, both the stability and the coordination of the body segments are necessary for a mastery of the movements (2).

The GMC is essential for acquiring both advanced control of FMS and that of specialized movement techniques. Consequently, it is also necessary for the training of health-related physical abilities, such as strength, endurance, and flexibility, and for those related to sports performance. GMC provide the basis to reaching a high level of motor competence (MC), to develop adequately, maintain health, and gain athletic excellence (5). GMC, therefore, plays a crucial role in the development and active lifestyle (6). Children with a high level of coordination are more involved in physical activity (PA) and sport and tend to reach better performance (7, 8). On the other hand, children with a low level of coordination are less inclined to participate in physical activities (9–11). Numerous studies confirm the relationship between low motor skill levels in children, poor PA, and increased BMI during developmental age (12–14), especially in girls (15). Physical inactivity leads to a worsening of body weight and fat mass with a negative influence on GMC tasks (15, 16). Data from Lopes et al. (17) showed that clumsy children have higher BMI levels more frequently. The term GMC, in this paper, will be used to refer to the ability to execute a wide range of motor activities involving whole-body movement (3, 18).

GMC in childhood influences, directly and indirectly, health-related physical fitness and the development of long-term health outcomes in children and adolescents (19). Several researchers (11, 20–23) studied the coordination role in promoting health, yet it is still an open question. Poor GMC prevents children from reaching a good level of motor skills (24) and, consequently, does not allow them to participate safely and vigorously in sports practices (10). On the contrary, mastering motor skills in childhood seems to help children participate regularly in organized sports and spontaneous physical activities (12, 15, 25–28).

In the vast domain of exercise for health, the relationship between motor coordination and cognitive development also begins to show significant evidence (29, 30). Findings support the association between motor coordination and executive function in childhood (31, 32), adolescence (33) and in all other phases of life (34). Marchetti et al. (35) suggests that the cognitive demands of complex movement and sport tasks, as well as sensorimotor learning, may be responsible for the positive association of PA and sports with higher-level cognition and metacognition.

Despite this mass of evidence that assigns coordination a significant role in movement education and health promotion, there are some serious obstacles to study and structurally promote this aspect of motor skills. Assessing GMC is complex because it manifests itself in countless modes of movement: locomotion, object control, postural stability, and dynamic balance. Stability represents the most basic of the movement and sport. For this reason, stability begins to develop early in life and often children who are exposed to a variety of movement experiences have no difficulty developing fundamental stability abilities (2). Several literature reviews (1, 36–39) identify a second obstacle in the coordination study: the lack of a reference test shared by the entire scientific community. Several tests' batteries have been proposed and validated, some with the specific purpose of identifying subjects with coordination difficulties, others for measuring different aspects of coordination, others still applicable to FMS. Among these batteries, we find significant differences related to the type of movements investigated and the age groups in which they can be applied. Only some batteries provide standard values for girls and boys (36). All this results in the lack of a "Gold standard" to assess coordination. It is relevant to overcome these difficulties also from an educational perspective to promote motor literacy in young people. Indeed, PA guidelines for youth (40–44) indicate the necessity to develop a large patrimony of motor skills and a positive attitude toward motor learning. These goals, however, cannot be properly pursued and documented in the absence of a shared way to measure them. Lastly, since the assessment of GMC at a young age must be applied to a large number of people, such as in physical education classes and sports training, the assessment tools need the characteristics of applicability and simplicity of execution (36). Vandorpe et al. (45) suggested that GMC cannot be assessed independently from the pure fitness characteristics (e.g., strength, speed, endurance, and flexibility). Further, in terms of health, the physical components in relation to GMC have been evaluated extensively (45). The Körperkoordinations Test für Kinder (Body Coordination Test for Children) (46, 47) seems to be one of the batteries that can meet the requirements described above (48). It was conceived and validated, with a population of 1,228 German subjects between 5 and 14 years of age by Kiphard and Schilling in 1974 (46) and verified in 2007. The four subtests make it up to measure different aspects of the GMC, not related to specific sports skills (3). Gross motor coordination is always measured in association with some of the physical abilities such as strength, speed, endurance, and flexibility (45). Most test batteries consist of elements that measure both physical and coordination skills (49). KTK also measures GMC in movements that also involve strength and

speed characteristics (46, 47). The four subtests are "Walking backwards" (WB), "Jumping sideways" (JS), "Moving sideways" (MS), and "Hopping for height" (HH). The four subtests are used, with the same parameters, in all ages of test application, allowing, and so also longitudinal studies. The test takes about 20 min per child. The KTK is a battery suitable in different fields like physical education, sports, health promotion (48), and talent identification (50).

Some limitations of the KTK are the lack of indications for the control of objects, the tendency to overestimate the number of children with GMC problems, and the comparison with standardized values based on data from 1974 that may be obsolete (48). This last point can, however, be considered also a positive element because it allows the study of GMC's change over long periods.

GMC plays a critical role in youth development and active lifestyle, but these parameters are, however, lacking, particularly in Italy where, to our knowledge, only surveys have been carried out on small groups (51–55) or in pre-school age (56, 57).

The main goal of our cross-sectional research was to verify for the first time the current values of GMC of Italian boys and girls between 6 and 13 years of age based on a large cohort of Italian children. Our results were compared with the values proposed by Kiphard and Schilling (46) and with similar researches that used the KTK in more recent years (45, 58). Based on our previous unpublished studies as well as Vandorpe et al. (45) and Moreira et al. (58) data, it was assumed that the current coordination levels of Italian boys and girls are lower than the reference values of the KTK battery. Secondary goals were to study gender differences, and the four subtests trend with ages. In all four subtests, we assume an increase in raw values that slowed down with increasing age. We expected that girls exhibit similar or higher values than boys in the WB. In the JS and HH, boys should show overall values higher than those of girls due to higher strength levels. There are no known reasons to assume gender difference in MS.

METHODS

Participants

Two thousand two hundred six schoolchildren (girls: $n = 1{,}050$; boys: $n = 1{,}156$), aged between 6 and 13 years (**Table 1**), from 49 primary and lower secondary schools (private and public), representative of the Italian geographical areas (North Italy = Veneto; Center Italy = Lazio; South Italy = Sicily) were randomly recruited in this cross-sectional study (convenient sample), including urban and rural areas. The included schools were equipped with appropriate and similar sports facilities to conduct comparable measurements. Sample procedures considered the total number of schools (private and public), geographic regions (north, center, south), and urban and rural places. The population examined is similar to or greater than that of similar studies (45–51). The measurements were conducted from January 2019 to February 2020. The Ethical Boards of the Universities of Verona (N. 2019-UNVRCLE-0298910) and Palermo (N. 8/2019) as well as the Institutional Review Board of the University of Rome "Foro Italico" approved the study. The study complies with the criteria for the use of people in research defined in the Declaration of Helsinki. Moreover, school principals provided further research authorizations. After researchers explained the purpose of the investigation and the research methodology, all parents provided written informed consent before participating in the study. All the measures were taken during the Physical Education lessons as scheduled in the morning framework (8.00–12.00 a.m.). All assessments were carried out by trained supervisors (Physical Education teachers or specifically trained Sport Science's students) in the same gym school context. The presence and collaboration of the curricular PE teachers were guaranteed at any time to meet the confidence of the students. The trainer–pupil ratio was 1:10.

Anthropometric Measurements

To ensure that the subjects correctly represented the Italian population with regard to the proportion of underweight, normal weight, overweight, and obese subjects, weight and height measurements were collected. Anthropometric measurements were taken according to the standard procedures described by the International Society for the Advancement of Kinanthropometry (59). Height was measured with a stadiometer to the nearest 0.5 cm. Weight was measured to the nearest 0.1 kg with an electronic scale with the subject wearing minimal clothing. Children were classified as underweight, normal weight, overweight, and obese using age- and gender-specific cutoff points (60, 61).

Gross Motor Coordination Measurements

GMC was evaluated through Körperkoordinations Test für Kinder, referred to as KTK (46, 47), which consisted of four items:

1. Walking backwards—WB: walking backwards three times along each of three balance beams (3 m length; 6, 4.5, and 3 cm width, respectively; 5 cm height). A maximum of 24 steps (eight per trial) was counted for each balance beam, which comprises a maximum of 72 steps (24 steps × 3 beams) for this test.
2. Jumping sideways—JS: jumping laterally as many times as possible over a wooden slat (60, 4, and 2 cm) in 15 s. The number of jumps over two trials was summed.
3. Moving sideways—MS: moving across the floor in 20 s by stepping from one plate (25 × 25 × 5.7 cm) to the next, transferring the first plate, stepping on it, etc. The number of relocations was counted and summed over two trials.
4. Hopping for height—HH: jumping from one leg over an increasing pile of pillows (60 × 20 × 5 cm each) after a short run-up. Three, two, or one point(s) were/was awarded for successful performance on the first, second, or third trial, respectively. A maximum of 39 points (ground level plus 12 pillows) could be scored for each leg, yielding a possible maximum score of 78.

KTK test and its scoring were carried out according to the authors' indications (46, 47). Children were tested alone or in small groups, and the tasks were performed one child at a time, during the physical education lessons, in the school gymnasium.

TABLE 1 | Number of subjects, mean values of raw score (RS), and motor quotient (MQ) by gender and age.

		All sample	Girls	Boys	*P* for gender
6 years	Number	253	123	130	
	RS	108.97 (30.84)^	105.71 (30.50)	112.05 (30.95)	n.s.
	MQ	88.42 (14.99)	83.07 (14.60)*	93.48 (13.57)^	<0.001
7 years	Number	285	150	136	
	RS	135.96 (36.19)^	133.23 (35.97)	138.97 (36.34)	n.s.
	MQ	91.76 (16.11)	88.60 (16.27)^°#	95.24 (15.24)*^	<0.001
8 years	Number	366	184	182	
	RS	151.89 (38.26)^	150.18 (36.44)	153.82 (40.05)	n.s.
	MQ	88.50 (16.29)	87.32 (15.48)^§%	89.69 (17.03)#	n.s.
9 years	Number	357	163	194	
	RS	175.36 (41.88)^	173.07 (41.76)	177.28 (42.00)	n.s.
	MQ	87.06 (17.01)	82.79 (16.88)*	90.65 (16.32)°	<0.001
10 years	Number	370	178	192	
	RS	188.51 (39.07)^	189.46 (38.46)	187.64 (39.70)	n.s.
	MQ	84.30 (15.44)	82.30 (15.60)*	86.16 (15.09)	<0.05
11 years	Number	223	99	124	
	RS	205.23 (33.34)^&	203.40 (31.72)	206.69 (34.63)	n.s.
	MQ	86.89 (14.45)	84.78 (12.98)^	88.57 (15.37)	n.s.
12 years	Number	218	99	119	
	RS	211.76 (31.61)^&	210.85 (30.18)	212.51 (32.85)	n.s.
	MQ	81.25 (15.58)	78.25 (15.08)	83.75 (15.60)	<0.05
13 years	Number	133	54	79	
	RS	221.53 (32.01)^&	216.02 (32.32)	225.30 (31.44)	n.s.
	MQ	80.89 (17.47)	75.02 (16.78)	84.90 (16.88)	<0.001
All years	Number	2,206	1,050	1,156	
	RS	170.35 (49.83)	166.89 (49.49)	173.49 (49.95)	<0.05
	MQ	86.64 (16.22)	83.72 (15.92)	89.29 (16.04)	<0.05
Age	RS		$F = 269.193$; $p < 0.001$		
	MQ		$F = 14.217$; $p < 0.001$		
Gender	RS		$F = 5.899$; $p = 0.015$		
	MQ		$F = 79.228$; $p < 0.001$		
Ages × gender	RS		$F = 0.488$; $p =$ n.s.		
	MQ		$F = 2.249$; $p = 0.028$		

All sample: ^$p < 0.001$ between all couples, &$p =$ n.s. 13 vs. 12 and 12 vs. 11.
*Girls: *$p < 0.01$ vs. 13 years, ^$p < 0.001$ vs. 13 years, °$p < 0.01$ vs. 9 years, #$p < 0.01$ vs. 10 and 12 years, §$p < 0.01$ vs. 10 years, %$p < 0.001$ vs. 12.*
*Boys: *$p < 0.01$ vs. 8 and 11 years, ^$p < 0.001$ vs. 10, 12, and 13 years, °$p < 0.001$ vs. 12 years, #$p < 0.01$ vs. 12 years.*

Before each test, the children received an oral explanation about the procedure. For the raw score on the total test battery, a test–retest reliability coefficient of 0.97 was reported. For the four subtests, based on the raw score, sufficiently reliable coefficients were reported as well (WB: 0.80; MS: 0.84; HH: 0.96; JS: 0.95). Intercorrelations between the four subtests varied from 0.60 (WB/JS) to 0.81 (HH/JS) for the reference group of 1,228 children. Factor analysis revealed that the four subtests all load on the same factor, namely, GMC. The percentage of total variance of the KTK explained by the four subtests varied from 80.9 (age 6) to 97.7 (age 9) (46, 47). The KTK allows an objective and straightforward evaluation of a child's gross motor coordination only, with only limited interference of the child's physical fitness, which discriminates this test from most other instruments. The raw test scores from each of the four subtests can be transformed into gender- and age-specific motor quotients value (MQ), which were based on the performance of 1,228 normally developing German children in 1974. Scoring of the KTK test was performed according to the manual (47). The mean standardized value is 100 with a standard deviation of 15 (46, 47). MQ describes the level of GMC (45, 47), and values between 85 and 115 describe the normality (**Table 6**).

The measurements obtained from the KTK are the following:

- The raw results of the four tests that make up the KTK (WB raw, MS raw, JS raw, and HH raw);
- The sum of the four subtests raw values called "Raw score" (RS);
- The four normalized values of the subtests (WB, MS, JS, and HH), obtained from the normalization tables for age and

gender (41, 42). The mean of each of the four standardized values is 100 with a standard deviation of 15;
- The sum of the four standardized values (MQ raw);
- The "Motor Quotient" (MQ), obtained from the standardization tables. It summarizes the overall normalized value of gross motor coordination measured with the KTK.

In our research, we considered all the above measures except the sum of the standardized values of the four tests, which are largely represented by MQ.

Statistical Analysis

The Shapiro–Wilk-test for normality was initially used to evaluate the distribution of data. Number frequency was displayed to describe age and gender classes. The chi-square test was carried out to study any significance between frequencies of gender according to age groups. The scores of the KTK were calculated and showed as means and SDs by age and gender. A Spearman correlation was used for not normally distributed data and Pearson correlation for normally distributed data. The two-way ANOVA was run to examine if there was an interaction effect between the independent variables age and gender on all KTK scores. The comparison between the results of the various researches was carried out with one-way ANOVA using the values of the means, the number of subjects, and the standard deviations. The results of ANOVA were displayed through the F-values; significant interaction and main effects were examined with Bonferroni *post-hoc t*ests. Level of significance was set at $p < 0.05$. The software SigmaStat for Window, version 3.5 (Systat Software Inc., Erkrath, Germany), was used to perform the statistical analyses.

RESULTS

RS and MQ Analyses

Table 1 illustrates the characteristics of the subjects involved in the study that presents a homogeneous distribution by age and gender. It was also verified that the prevalence of underweight, normal-weight, overweight, and obese children was consistent with recent data on Italian children of the same age (62). In particular, the four BMI categories presented the following percentages: underweight = 8%, normal weight = 61%, overweight = 22%, obese = 9%. **Table 2** describes the mean values of all KTK parameters and their correlations with the age of the subjects.

RS increased with the age of the subjects ($r = 0.678$; $p < 0.001$) progressively reducing, however, the increase. Up to 11 years, the annual differences are always significant, while subsequently, it is between 11 and 13 years. RS shows differences by gender ($F = 5.899$; $p = 0.015$) and age ($F = 269.193$; $p < 0.001$) without interaction gender × age ($F = 0.48$; $p =$ n.s.). Overall, boys show higher RS values than girls (girls = 166.89 ± 49.49; boys = 173.49 ± 49.95; $F = 5.899$; $p < 0.05$), but the gender comparison for each age group does not show significant differences in any of the eight pairs (**Table 1**).

MQ tends to decrease with age ($r = -0.148$; $p < 0.001$) and shows differences by gender ($F = 79.228$; $p < 0.001$), age ($F = 14.217$; $p < 0.001$), and an interaction gender × age ($F = 2.249$; $p < 0.05$). Among the girls, 13-year-olds show a lower mean ($p < 0.01 \div 0.001$) than all the others except for the 12-year-olds; 7-year-old girls have better values than 9–13-year-olds ($p < 0.01 \div 0.001$); and 8-years-olds have better values than 10-year-olds ($p < 0.01$). Seven-year-old boys have better values than 8-, 10–13-year-olds ($p < 0.01 \div 0.001$); 6-year-olds have better values than 10-, 12-, 13-year-olds ($p < 0.001$); and 12-year-olds show a lower mean ($p < 0.01 \div 0.001$) 6–9-year-olds. In the analysis by age groups, boys always show higher values than girls except at 8 and 11 years.

Analysis of the Four Subtests: WB, MS, JS, and HH

Tables 3, **4** show, respectively, the raw score and standardized values of the four KTK subtests for gender and age. In the raw values of the four subtests, significant differences ($p < 0.001 \div 0.01$) by gender and age emerged without interaction gender × age. In standardized values of all subtests, significant differences ($p < 0.001$) by gender and age were found, with interactions gender × age in JS ($p < 01$) and HH ($p < 0.001$).

In WB raw, girls perform better than boys ($F = 14.52$; $p < 0.001$). Globally, WB raw increased with age ($r = 0.459$; $p < 0.001$). In the *post-hoc* analysis by age group, significant differences for all but five age groups were found: 6 vs. 7 years, 9 vs. 10 years, 11 vs. 12 years, and 13, 12 vs. 13 years (**Figure 1A**). The standardized mean value of WB is lower than the reference (respectively, 88.33 ± 17.27 vs. 100 ± 15; $F = 394.889$; $p < 0.001$) and significantly correlates with age (**Table 2**), although with a value very close to zero ($r = 0.078$; $p < 0.001$).

TABLE 2 | Means and standard deviation of all parameters of the KTK (RS, MQ, WB raw, WB, MS raw, MS, JS raw, JS, HH raw, and HH) and their "Spearman rank order correlation" with age.

		MQ	RS	WB raw	WB	JS raw	JS	MS raw	MS	HH raw	HH
	Means (sd)	86.64	170.35	38.64	88.33	53.87	99.28	34.02	80.68	43.81	90.76
		(16.22)	(49.83)	(16.92)	(17.27)	(17.40)	(18.27)	(8.85)	(18.90)	(20.83)	(20.89)
Age	Correlation coefficient (*r*)	−0.148	0.678	0.459	0.078	0.674	0.006	0.298	−0.331	0.545	−0.103
	p	<0.001	<0.001	<0.001	<0.001	<0.001	n.s	<0.001	<0.001	<0.001	<0.001

Number of samples = 2,206

TABLE 3 | Raw score (mean ± standard deviation) of the four KTK subtests (walking backwards, moving sideways, jumping sideways, and hopping for height) for gender and age.

	6	7	8	9	10	11	12	13	Age	Gender	Age × gender
Walking backwards raw score											
Girls	26.84 (12.95)	30.35 (13.46)	36.04 (15.78)	41.28 (16.46)	44.15 (15.77)	48.63 (14.74)	52.72 (15.04)	48.67 (15.71)	$F = 89.465$	$F = 14.52$	$F = 0.519$
Boys	25.65 (12.76)	28.20 (15.88)	31.99 (15.15)	37.79 (14.37)	40.69 (15.44)	45.53 (14.05)	48.99 (15.24)	49.29 (14.67)	$p < 0.001$	$p < 0.001$	$p =$ n.s.
Total	26.23 (12.84)	29.33 (14.67)	34.03 (15.58)	39.39 (15.43)	42.35 (15.67)	46.91 (14.41)	50.68 (15.23)	49.04 (15.05)			
Jumping sideways raw score											
Girls	31.54 (10.22)	40.96 (12.94)	46.56 (13.27)	52.77 (13.03)	58.17 (12.27)	63.22 (12.13)	67.63 (11.37)	71.87 (12.61)	$F = 266.349$	$F = 24.529$	$F = 0.487$
Boys	34.09 (11.70)	42.90 (11.70)	50.22 (12.60)	56.31 (13.50)	59.86 (13.66)	66.40 (13.38)	72.16 (14.06)	73.65 (13.56)	$p < 0.001$	$p < 0.001$	$p =$ n.s.
Total	32.85 (11.05)	41.88 (12.39)	43.38 (13.06)	54.69 (13.38)	59.05 (13.02)	64.99 (12.91)	70.10 (13.08)	72.92 (13.16)			
Moving sideways raw score											
Girls	25.70 (5.89)	31.07 (7.17)	33.71 (6.97)	34.14 (7.46)	35.91 (7.47)	34.49 (7.45)	36.46 (10.05)	37.17 (10.10)	$F = 50.91$	$F = 9.052$	$F = 0.97$
Boys	26.64 (7.30)	31.46 (7.64)	35.16 (7.77)	36.35 (8.24)	36.35 (7.76)	36.08 (9.22)	35.77 (10.64)	39.80 (12.72)	$p < 0.001$	$p < 0.01$	$p =$ n.s.
Total	26.18 (6.65)	31.26 (7.39)	34.43 (7.40)	35.34 (7.96)	36.14 (7.61)	35.38 (8.50)	36.09 (10.36)	38.73 (11.76)			
Hopping for height raw score											
Girls	21.63 (11.04)	30.85 (15.30)	33.88 (16.39)	44.87 (20.29)	51.23 (19.48)	57.06 (17.50)	54.04 (15.49)	58.31 (15.46)	$F = 136.186$	$F = 11.105$	$F = 0.903$
Boys	25.68 (11.70)	36.40 (14.68)	36.23 (18.84)	46.83 (21.20)	50.73 (20.57)	58.68 (17.64)	55.59 (15.48)	62.57 (14.60)	$p < 0.001$	$p < 0.001$	$p =$ n.s.
Total	23.71 (11.54)	33.49 (15.24)	35.05 (17.67)	45.94 (20.79)	50.97 (20.03)	57.96 (17.56)	54.89 (15.47)	60.84 (15.04)			

TABLE 4 | Standardized values (mean ± standard deviation) of the four KTK subtests (walking backwards, moving sideways, jumping sideways, and hopping for height) for gender and age.

	6	7	8	9	10	11	12	13	Age	Gender	Age × gender
Walking backwards (WB)											
Girls	91.10 (14.88)	87.93 (14.87)	87.33 (17.21)	88.99 (17.47)	89.95 (16.94)	93.23 (17.19)	96.10 (19.94)	87.70 (21.31)	$F = 6.683$	$F = 14.695$	$F = 0.592$
Boys	89.68 (14.64)	85.50 (17.55)	82.94 (16.54)	85.41 (15.32)	86.25 (16.45)	89.51 (16.54)	90.66 (20.84)	88.63 (19.87)	$p < 0.001$	$p < 0.001$	$p =$ n.s.
Total	90.37 (14.74)	86.78 (16.22)	85.15 (17.00)	87.05 (16.41)	87.98 (16.76)	91.16 (16.90)	93.13 (20.57)	88.26 (20.39)			
Jumping sideways (JS)											
Girls	90.92 (15.85)	96.66 (18.80)	98.02 (17.02)	88.60 (18.85)	89.85 (16.70)	95.12 (15.63)	92.55 (17.62)	90.54 (15.16)	$F = 6.638$	$F = 257.363$	$F = 2.944$ p
Boys	102.00 (16.09)	108.26 (15.61)	105.76 (16.31)	106.80 (16.05)	101.15 (17.62)	104.94 (17.28)	106.01 (18.72)	106.28 (18.14)	$p < 0.001$	$p < 0.001$	< 0.01
Total	96.61 (16.88)	102.18 (18.27)	101.87 (17.09)	98.49 (19.59)	95.71 (18.07)	100.58 (17.24)	99.89 (19.39)	99.89 (18.62)			
Moving sideways (MS)											
Girls	84.27 (13.58)	88.76 (16.67)	85.80 (16.54)	79.93 (15.42)	76.63 (13.85)	71.66 (15.73)	68.60 (20.42)	67.48 (21.69)	$F = 50.374$	$F = 11.876$	$F = 1.052$
Boys	86.64 (16.66)	89.71 (17.42)	89.33 (18.57)	84.83 (17.14)	77.89 (14.97)	75.28 (19.68)	67.33 (21.54)	73.97 (26.81)	$p < 0.001$	$p < 0.001$	p'= n.s.
Total	85.49 (15.25)	89.21 (17.01)	87.55 (17.64)	82.59 (16.54)	77.28 (14.44)	73.67 (18.08)	67.90 (21.00)	71.34 (24.98)			
Hopping for height (HH)											
Girls	81.71 (15.74)	91.70 (19.48)	90.00 (18.85)	89.59 (21.09)	89.21 (22.42)	93.34 (19.64)	75.94 (22.90)	77.26 (25.43)	$F = 16.729$	$F = 66.92$	$F = 7.048$
Boys	102.02 (12.36)	102.11 (16.29)	90.47 (20.08)	94.40 (20.71)	92.29 (20.51)	95.38 (21.14)	86.20 (19.72)	84.99 (24.20)	$p < 0.001$	$p < 0.001$	$p < 0.001$
Total	92.15 (17.37)	96.65 (18.74)	90.23 (19.45)	92.20 (20.99)	90.81 (21.48)	94.48 (20.47)	81.54 (21.79)	81.85 (24.91)			

In the other three subtests, boys performed better than girls (JS: $F = 24.529$; $p < 0.001$—MS: $F = 9.052$; $p < 0.01$—HH: $F = 11.105$; $p < 0.001$).

JS raw increased steadily with age ($r = 0.674$; $p < 0.001$), and significant differences between all age pairs were found except 12 vs. 13 years (**Figure 1B**). The standardized mean value of JS is no different from the reference (respectively, 99.28 ± 18.27 vs. 100 ± 15; $F = 1.387$; $p =$ n.s.) and not related to age (**Table 2**).

MS raw grow up to 8 years (6 vs. 7 years: $p < 0.001$; 7 vs. 8 years: $p < 0.001$); between 8 and 12 years, it does not show significant differences and, finally, at 13 years is greater than all the others except for 10 and 12 years (**Figure 1C**). The standardized mean value of MS is lower than the reference (respectively, 80.68 ± 18.90 vs. 100 ± 15; $F = 950.028$; $p < 0.001$) and decreases with age ($r = -0.331$; $p < 0.001$).

HH raw grow regularly with age ($r = 0.545$; $p < 0.001$). Significant differences were found between all age couples except for 7 vs. 8 years, 10 vs. 12 years, 11 vs. 12 years, 11 vs. 13 years, and 12 vs. 13 years (**Figure 1D**). The standardized mean value of HH is lower than the reference (respectively, 90.76 ± 20.89 vs. 100 ± 15; $F = 186.665$; $p < 0.001$) and decreases with age ($r = -0.103$; $p < 0.001$).

DISCUSSION

The main goal of our cross-sectional research was to verify, for the first time, the current values of GMC of Italian boys and girls between 6 and 13 years of age, based on a large cohort of Italian children living in the north, center, and south of Italy. It was assumed that the current coordination levels of Italian boys and girls are lower than the reference values of the KTK battery. Secondary goals were to study gender differences, and the four subtests trend with ages. In all four subtests, we assume an increase in raw values that slowed down with increasing age. We expected that girls exhibit similar or higher values than boys in the WB. In the JS and HH, boys should show overall values higher than girls due to higher strength levels. There are no known reasons to assume gender difference in MS. Our cross-sectional search has applied the KTK test battery to a large population between 6 and 13 years. Globally, GMC values of Italian youth were lower than reference (46). Boys showed better performance than girls in MQ, RS as well as in three on four subtests.

The relevant number of studies that adopted KTK permitted us to compare our overall results (RS and MQ) not only with 1974 references (46) but also with similar researches conducted by Vandorpe et al. (45) and Moreira et al. (58). To interpret MQ values, we were able to consider the Vandorpe et al. (45) and Kiphard and Schilling (46, 47) results but not those of Moreira that did not calculate this parameter (**Tables 5**, **6**). To compare RS and the four subtests among the four searches (**Table 7**), subjects between 6 and 10 years old, common to the four studies, were considered (45–47, 58). Despite this limitation, mandatory because Brazilian data were collected only for this age group, it was thought appropriate to consider Moreira data, gathered in a very different sociocultural reality but almost simultaneously with the Italian data. We compared, therefore, our data both on a worldwide geographical scale and on a time scale of about 45 years. The Kiphard 1974 German survey collected the original MQ data and was carried out on a population aged 5 to 14 years old. The Vandorpe Belgian survey investigated, in 2011, a population aged 6 to 11 years (45) while Moreira published her data from Brazilian children from 6 to 10 years old, in 2019.

Regarding MQ, significant differences between the three studies ($F = 385.832$; $p < 0.001$) were found. Both Belgian and Italian results were lower than the German references (Belgium = −3.5%; Italy = −13.36%; $p < 0.001$). The Italian values were significantly lower than Belgium ones (−10.22%; $p < 0.001$). This result seems to indicate a constant GMC reduction over time. **Table 6** describes, for the Italian search, the numbers and percentages of participants included in the MQ five levels. For the Belgian and German searches, the table reports only the participants' percentages at every level. The chi-square shows a significant difference in the distributions of subjects [X^2 (8, N = 5,904) =654.050, $p < 0.001$] with Italian "Bad" and "Low" groups much more numerous than others.

Table 7 presents the raw values of the four subtests and RS, obtained from the four studies, with significant differences among groups ($F = 3{,}332.086$; $p < 0.001$). The German's RS values are higher than Belgian ones (Germany 193.28 ± 10.07; Belgium = 175.28 ± 10.37; $p \leq 0.001$) while Italian data, lower than the first two ($p < 0.001$), are slightly higher than the Brazilian ones (Italy 154.77 ± 10.07; Brazil = 152.05 ± 7.24; $p \leq 0.001$). Comparison among these four searches seems to confirm a downward trend in GMC and its characterization by geographical and sociocultural areas (14, 63). RS shows an increase with age that, however, tends to decrease from 11 years onward. Similar trends were shown in the original German KTK data, whereas Vandorpe et al. (45) measured a substantially linear increase. Vaccari et al. (64) identified, in young Italians of the same age, a trend with a gradual slowing increase in performance with age also in measures of balance, cardiorespiratory fitness, and lower extremity power.

A secondary goal was to study the four subtest trends in the different ages and the two genders. Our study showed Italian results below the German and Belgian values for all raw values of the four subtests ($p < 0.001$). In comparison with the Brazilian data, the Italian WB and JS subtests were better (WB: Italy = 35.06 ± 7.02; Brazil = 34.09 ± 6.01; $p < 0.01$; JS: Italy = 47.51 ± 9.85; Brazil = 40.01 ± 7.72; $p < 0.001$), while it was the opposite for MS and HH (MS: Italy = 33.18 ±4 .37; Brazil = 35.57 ± 5.52; $p < 0.001$; HH: Italy = 39.01 ± 10.31; Brazil = 42.38 ± 7.53; $p <$ 0.001). Overall, the Italian standardized mean values of three out of four subtests were well below the German references (WB = −11.68%; MS = −19.32%; HH = −9.24%; $p < 0.001$). Only for JS were the Italian values similar (JS = 99.28; $p =$ n.s.).

Our results showed better performance in boys than girls in the raw scores of three of the four subtests (JS: $F = 24.529$; MS: $F = 9.052$; HH: $F = 11.105$), while girls had better performances than boys in the WB ($F = 14.52$).

Overall, the four subtests showed results that do not match those that emerged from the three other searches that we adopted as a comparison. The only univocal result in all searches regarded HH, which showed higher levels of boys than those of girls. In

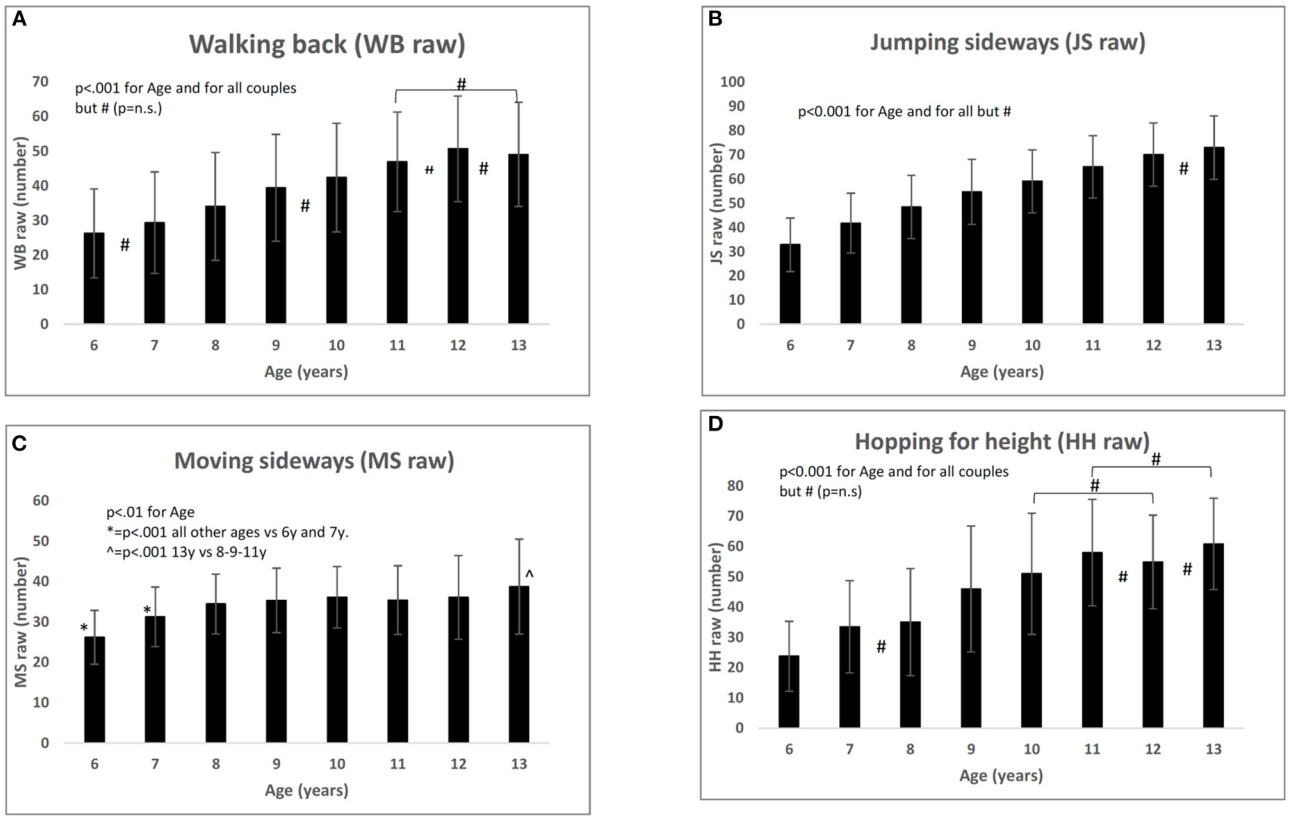

FIGURE 1 | Raw values of the four subsets between 6 and 13 years. **(A)** Walking Back (WB raw); **(B)** Jumping Sideways; **(C)** Moving Sideways; **(D)** Hopping for Height.

TABLE 5 | The number of subjects, means, standard deviations, and differences (percentages) of the motor quotient (MQ) in three comparable searches: Kiphard (46), Germany; Vandorpe et al. (45), Belgium; and our research, Italy, 2021.

Motor quotient (MQ)	Number of subjects	Mean	St. dev.	Δ% vs. Germany
Germany 1974	1,228	100*^	15	—
Belgium 2011	2,470	96.5^	14.3	−3.5
Italy 2021	2,206	86.64	16.22	−13.36

*$p < 0.001$ vs. Belgium, ^$p < 0.001$ vs. Italy.

WB, the best results of the girls were detected by our research and by Vandorpe; the German and Brazilian data, instead, showed no differences. In JS, the Italian data documented, like the German ones, better values of girls than of boys, while the Belgians and Brazilians have not found any differences. In MS, our data were the only ones to show a prevalence of the boys' performances.

For the HH test, it seems reasonable to attribute to the greater power developed by boys the cause of their better results in all searches (45, 65). The heterogeneity of the results of the other three subtests (MB, JS, and MS) suggests that the main factors potentially correlated with coordinative performance, such as the amount of PA, different types of sports practices, and body composition, but also less investigated factors such as sedentariness, sociocultural vulnerability conditions, and natural and urban environment, which act differently for girls and boys. We can, in this regard, consider a limitation of our research not having considered the many correlates and determinants of GMC. We consider, instead, a strong point of our work, the size of the population investigated in a nation, Italy, which did not have such extensive data in this field. Another element that seems relevant is the confrontation of our results with those of other searches that have used the KTK, carried out in different geographical areas and in a time ranging from 1974 to the present.

The overall picture of the results we have presented, first of all, makes us consider the continuing decline in GMC as worrying: the negative effects on health and lifestyles could weigh heavily on current generations. The significant differences between genders make us believe it appropriate to maintain a differentiated normalization. As was expected, RS increased with age, and it seems reasonable, therefore, to maintain an age-based normalization of the GMC. On the

TABLE 6 | Distribution of subjects in the five levels of motor quotient (MQ level) of three comparable searches.

Distribution in "MQ levels"	Italy 2020 (number)	Italy 2020 (%)	Belgium 2008 (%)	Germany 1974 (%)
Bad	368	16.7	4.3	2
Low	649	29.4	16.8	14
Normal	1,110	50.3	70.2	68
Good	72	3.3	8.3	14
Excellent	7	0.3	0.4	2
		Chi-square $p < 0.001$.		

MQ level based on MQ values: bad (56–70 MQ); low (71–85 MQ); normal (86–115 MQ); good (116–130 MQ); excellent (131–145 MQ).

TABLE 7 | Values of RS, WB raw, JS raw, Ms raw, and HH raw, in subjects from 6 to 10 years old.

	Mean	Number	Standard deviation	Between groups	Percentage difference vs. Germany 1974
Walking back (WB raw)					
Germany 1974	49,477*^°	677	8,121	$F = 733.35$	—
Belgium 2011	37,632^°	2,115	7,181	$p < 0.001$	−23.94%
Brazil 2019	34,086	566	6,008		−31.11%
Italy 2021	35,059#	1,631	7,020		−29.14
Jumping sideways (JS raw)					
Germany 1974	52,408^°	677	10,734	$F = 268.513$	—
Belgium 2011	52,147^°	2,115	9,999	$p < 0.001$	n.s.
Brazil 2019	40,011	566	7,719		−23.65
Italy 2021	47,515^	1,631	9,846		−9.34
Moving sideways (MS raw)					
Germany 1974	41,911*^°	677	5,655	$F = 527.406$	—
Belgium 2011	36,848^°	2,115	4,859	$p < 0.001$	−12.08
Brazil 2019	35,569°	566	5,519		−15.13
Italy 2021	33,183	1,631	4,368		−20.83
Hopping for height (HH raw)					
Germany 1974	49,479^°	677	11,542	$F = 344.367$	—
Belgium 2011	48,651^°	2,115	9,891	$p < 0.001$	n.s.
Brazil 2019	42,383°	566	7,535		−14.34
Italy 2021	39,014	1,631	10,306		−21.15
	Sum of means	**Number**	**Standard deviation**	**Between groups**	**Percentage difference vs. Germany 1974**
Raw score (RS)					
Germany 1974	193,275*^°	677	10,070	$F = 3,332,086$	—
Belgium 2011	175,278^°	2,115	10,365	$p < 0.001$	−9.31%
Brazil 2019	152,048	566	7,238		−21.33%
Italy 2021	154,771^	1,631	9,911		−19.92%

$^{*}p < 0.001$ vs. Belgium, $^{\wedge}p < 0.001$ vs. Brazil, $^{\circ}p < 0.001$ vs. Italy, $^{\#}p < 0.01$ vs. Brazil.
Data elaborated from Kiphard (46) (Germany); Vandorpe et al. (45) (Belgium); Moreira et al. (58) (Brazil) and from our present research (Italy).

contrary, MQ tended to decrease, confirming the observations of Giuriato et al. (55). It seems that today's young people accumulate less significant motor experiences over the years, from both a quantitative (66) and qualitative (1) point of view, compared to those achieved by their peers in the 1970s. This vicious circle favors an increase in weight and fat mass that is not proportionate to the increase in height (67). However, the possibility of a reverse dynamic must also

be considered, with overweight acting as a trigger to reduce PA (11).

It seems reasonable to argue, therefore, that greater use of GMC measures is useful to favor their better solicitation both in physical education and in youth sports training. It is believed that an improvement in GMC's parameters is achievable by improving both the structured physical activities and the spontaneous lifestyle of children and adolescents.

This implies a greater awareness of the reduction of this physical capacity by teachers, coaches, and policymakers. The first two will thus be able to adopt proposals for more appropriate physical activities while the latter will have a more updated and complete picture of the development needs of young people.

PERSPECTIVE

The availability of updated assessments of GMC will help physical education in schools, youth sports training, and the orientation of PA promotion policies. We believe that the KTK standards proposed by Kiphard and Schilling in 1974 (46) no longer correctly represent the benchmarks for GMC. It remains, in any case, the need to provide targets for improvement of today's results which show a wide reduction. We think, therefore, that the integration of recent results with data from the original search and the more recent past could provide new standards based on a wider population, achieving both the representativeness of different situations and the stimulus for the improvement of current coordination skills. Also, in light of the reduction of the results currently obtained by subjects up to 14 years, it seems reasonable to verify the applicability of the KTK test battery in subjects older than 14 years. If KTK were applicable in youth over 14 years, it could provide useful references to sustain policies that promote PA, sport, and physical education throughout the youth.

Finally, we believe that further longitudinal research should verify the actual development of GMC with age.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethical Boards of the Universities of Verona (N. 2019-UNVRCLE-0298910) and Palermo (N. 8/2019) as well as the Institutional Review Board of the University of Rome Foro Italico. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

ML, MB, MCG, MG, VB, and FS conceptualization and methodology. MG, VB, MCG, and GB data collection. ML and MG data analysis. ML, MG, FS, MB, LG, and CB data interpretation. ML, MG, and VB writing—original draft preparation. MG, VB, and GB writing—review and editing. LG, AP, CB, and FS supervision. All authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

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The Associations of Active Travel to School With Physical Activity and Screen Time Among Adolescents: Do Individual and Parental Characteristics Matter?

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Little is known about the relationship of active travel to school (ATS) with physical activity (PA) and screen time (ST) by individual and parental characteristics among adolescents, especially in China. To address the research gap, this study aimed to explore the difference of sex, age, living environment, parental occupation and education level in the relationship of ATS with PA and ST among students of grades 7–12 (aged 10–18 years) using cross-sectional data. In 13 cities of Hubei province, China, students from 39 public schools were recruited to engage in the survey. In total, 5,898 students (response rate = 89.6%) were invited into this study. Participants were required to report their ATS (including its types), PA and ST as well as sociodemographic information using a validated questionnaire. Descriptive analyses were used to report the information of all variables. Regression models were used to analyse the relationships of ATS and its types with PA and ST. In a total of 4,128 participants (boys: 50.9%; younger adolescents: 61.9%) included in the final analysis, the proportion of those with ATS was 47.3%. Regarding the types of ATS, walking accounted for over 30%, while cycling was 13.2%. Participants with ATS were more likely to have sufficient PA (OR = 1.26, 95% CI: 1.14–1.39), especially among boys, younger adolescents and those with lower parental education level. However, ATS was not associated with ST (OR = 0.94, 95% CI: 0.86–1.01). Participants with cycling had a higher odds ratio of being physically active (OR for cycling = 1.47, 95% CI: 1.27–1.70; OR for walking = 1.18, 95% CI: 1.06–1.32). The association of ATS types with PA and ST differed by gender, age, living environment and parental educational level as well as occupations. ATS may be a useful approach to increase PA among adolescents, but this should be explained by individual and parental characteristics.

Keywords: active travel, age, geographical location, parents, physical activity, school-aged children, screen time, sex

INTRODUCTION

A markedly ubiquitous international trend is that only a small proportion of adolescents fulfil the pervasively recognised physical activity (PA) and screen time (ST) guidelines (1–4). Recent data based on objective measures indicate that just 44.1% of children and adolescents met the PA guidelines [≥60 min of moderate to vigorous PA (MVPA)], while 39.3% of participants met the ST guidelines (<2 h per day) (5, 6). Conversely, meeting the PA and ST recommendations is correlated with more desired health outcomes (7–10). For example, higher PA levels were conversely related to (and greater time spent in ST was positively related to) the odds ratio of being obese (11). For more desirable health outcomes, concurrently promoting PA and discouraging ST among adolescents is an essential public health action.

Given the insufficient PA and higher ST among adolescents globally, researchers have sought effective interventions to change these harmful health behaviours (12, 13). To more effectively promote PA and limit ST among adolescents, active travel to school (ATS) plays a significant role. ATS is an essential source of PA behavioural components among adolescents. Well-documented evidence has presented how ATS is positively correlated with PA among adolescents (14). For example, Roth et al. (15) demonstrated that children and adolescents participating in walking or cycling (types of ATS) were more likely to meet the PA recommendation (OR = 1.31). A further recent investigation of Ecuadorian students similarly demonstrated that participants engaged in ATS were ∼3 times more likely to be engaged in sufficient PA as opposed to their peers (16, 17). Comparable results were established in another study conducted in the United Kingdom (17). Overall, the extant research supports the position that ATS can promote PA among adolescents. However, concerning the relationship of ATS with ST among adolescents, an ambiguous relationship remains (14). For example, certain researchers have posited that active travellers among adolescents had a reduced chance of spending time in ST (18–20), although this conclusion contrasted with other studies (21, 22). Collectively, the relationship of ATS with ST should be clarified further, drawing on the accumulated evidence. By drawing on the available literature, ATS may pose an effective means of increasing PA and decreasing ST, albeit with the relationship between ATS and ST being ambiguous (14).

With the increasing importance of ATS on overall PA, Chinese researchers have been devoted to ATS-related studies among Chinese young people. For example, Sun et al. (23) explored the health benefits of ATS, including lower body mass index and lower odds of depressive symptoms among nationally representative Chinese samples. In a cross-sectional study, Yang et al. (24) reported that there was a decline in ATS among 6- to 17-year-old Chinese students. Also, some recent studies identified the social or environmental factors of ATS, such as gated communities, intersection density, the presence of pedestrian streets and so on (25, 26). Within the limited literature, few studies investigated the relationship of ATS with PA and Gao et al. (27) reported that using a pedometer device, male schoolchildren with more steps during before- and after-school time showed higher levels of activity time, while female schoolchildren who had more steps during after-school time reported high activity. In Hong Kong, Huang et al. (28) found that ATS was related to maintaining a relatively higher level of PA. However, little is known about the relationship of ATS with ST among Chinese young people. Despite studies having presented evidence regarding the relationship of ATS with PA and ST, several research gaps still exist. One gap concerns the fact that the recent studies concerning ATS and PA, as well as ST, were based on adolescents from western countries (14, 23), whereas there is limited understanding about them concerning Chinese adolescents. Since evidence suggests that Chinese adolescents are insufficiently active (24), it is anticipated that ATS offers the potential to enhance their PA based on the findings of western studies. Such a relationship has not been investigated conclusively among Chinese samples. Understanding the relationship of ATS with PA is conducive to designing efficient interventions for enhanced PA among Chinese adolescents. Additionally, the correlation between ATS with ST continues to be unclear; thus, this correlation is worth investigating through additional studies (14). In this regard, replicating comparable studies is necessary to advance our knowledge of PA behaviour, which may also provide strategies for reducing ST among Chinese adolescents.

The ATS, PA, and ST are associated with substantial differences in individual and parental characteristics among adolescents. For example, Yang et al. (24) reported that adolescent ATS was significantly higher among younger groups, participants with lower educational attainment, or those residing in rural areas. Certain studies in western countries established that socioeconomic status parameters, for example living environment, parental education, and working status, were linked with ATS among adolescents (15, 17, 19). Such variables are associated with PA and ST among adolescents following the Social Ecological Model (29). Given the correlations between ATS, PA, ST, and socio-demographic variables, the correlation of ATS with PA and ST among adolescents may vary according to their individual and parental characteristics. As suggested in the review by Lubans et al. (30), investigating the overall relationship of ATS with outcomes (e.g., fitness or lifestyles behaviour) ignores the wider personal or social level correlates of behaviour. Therefore, it is necessary to investigate the correlation of ATS with PA and ST further, following the individual and parental characteristics. Nevertheless, across the limited literature, less research has scrutinised the relationship of ATS with PA and ST about socio-demographic factors. For instance, one study indicated that the relationship of ATS with PA was only significant among younger adolescents in Ecuador (16). Another study found that sex is a potential moderator of the relationship between ATS and PA among children and adolescents (21). Unfortunately, there is a dearth of the relevant evidence in this regard from China, which restricts our comprehension of the relationship of ATS with PA and ST among Chinese adolescents. Furthermore, there is limited understanding concerning investigations into the role of parental characteristics in this relationship.

Certain parental characteristics, for example, education and occupation, are associated with school travel choices.

For instance, higher parental educational attainment represents advantages in terms of income, with those parents potentially more likely to deliver their children to school using private vehicles (15, 18, 21). Subsequently, this could affect their children's active lifestyles. Nonetheless, whether the relationship of ATS with PA and ST varies according to parental characteristics has not yet been investigated. This is necessary to advance the knowledge in this field and capture information regarding the finer practical implications for adolescents affected by various parental characteristics. Although current findings from ATS-related studies among Chinese adolescents are inspiring, researches on the relationships of AST with PA and ST targeting Chinese samples are still scarce. Especially, little is known about how AST is associated with ST among Chinese adolescents. In addition, limited evidence is available on the relationship of ATS with PA and ST about socio-demographic factors, including individual and parental characteristics.

Therefore, as a means of contributing to resolving the evidence shortcomings in the extant literature and to develop an evidence foundation for PA- and ST-focused interventions for Chinese adolescents, this research aimed to analyse the relationship of ATS with PA and ST by the individual and parental characteristics among adolescents in China.

METHODS

Study Design and Research Ethics

This cross-sectional study was a questionnaire survey, undertaken between May and June 2019.The sample of participants was selected in Hubei province of China. Contact was made with the commission of education in 13 cities of Hubei province. Applying a convenience sampling method, we invited three public schools (one primary school, one middle school, and one high school) per city to participate in this survey. Through the administrative support provided by the commissions of education, 3rd to 12th-grade students in 39 public primary, middle, and high schools were selected across all the cities. In total, 6,583 students (aged 10–18 years, boys: 50.9%) were invited to participate in the survey. Of these, 5,898 responses with a complete self-reported questionnaire, providing a response rate of 89.6%. The research protocol and procedure were approved by the Institutional Review Board (IRB) of the Wuhan University of Technology in March 2019. The student participants and their legal guardians provided written consent. The anonymity and confidentiality of participants were ensured following the *Declaration of Helsinki*.

Measurements

Sociodemographic Information

The participants were asked, during their break time on school days, to provide self-reported data regarding sex (1 = boy, 2 = girl), grade (from 4 to 12) and current living environment (1 = urban, 2 = rural). A self-reported questionnaire was implemented to collect information from parents, including parental educational attainment (less than college/university; college/university, or higher), and occupation (office worker or manual labourer). The parents completed the paper-based questionnaire at home using a pencil.

Exposures (ATS)

A single-item question was included for measuring the ATS, which asked the participants: "In the last 7 days, how did you usually get to your school?" (23). This measure has been used in previously published studies (23). Participants were asked to indicate which of the travel modes represented their principal means of travelling to school and returning home. They were only given the option to select one principal transport mode, and data relating to multimode journeys (walking to or from public transport hubs, for example) was not obtained. Participants could select the following options as their responses: (1) walking independently; (2) cycling independently; (3) walking with parents or guardians; (4) cycling with parents or guardians; (5) taking school bus; (6) delivered by parents using automobile/private car/other motorised instruments; (7) other public transportation, such as public bus/underground/taxi. Overall, participants selecting options from 1 to 4 were considered *active*, whereas others were considered *passive*. According to the type of ATS, participants selecting 1 and 3 were regarded as walking; 2 and 4 were regarded as cycling; 5 were regarded as using school bus; 6 were regarded as delivered by parents, and 7 were regarded as using public transportation.

Outcomes (PA and ST)

PA was measured using the items derived from the Health Behaviour School-aged Children (HBSC) questionnaire, which has acceptable validity and reliability in the Chinese context (31). Two items collected the information on PA, namely, (1) "How many days did you engage in moderate to vigorous PA (MVPA) for at least 60 min on weekdays over the past week?", with responses: 0 = none, 1 = 1 day, 2 = 2 days, 3 = 3 days, 4 = 4 days, 5 = 5 days; and (2) "How many days did you engage in MVPA for at least 60 min during the weekend over the past week?", where responses included: 0 = none, 1 = 1 day, 2 = 2 days. Consistent with the Canadian 24-h Movement Guideline (3), sufficient PA following the definition of fulfilling the MVPA recommendation was equivalent to the participants reporting 60 min of MVPA daily for 7 days.

The following items of the HBSC questionnaire were used to obtain information relating to ST (31): (1) "How many hours did you spend watching TV or movies during your leisure time on weekdays and the weekend over the past week?" (responses: 1 = none, 2 = around half an hour, 3 = around 1 h, 4 = around 2 h, 5 = around 3 h or more); (2) "How many hours did you spend playing computer games during your leisure time on weekdays and on the weekend over the past week?" (responses: same as the above item); and (3) "How many hours did you spend on activities using electronic screen-based devices during your leisure time on weekdays and the weekend over the past week?" (responses: same as the above item). Consistent with the Canadian 24-h Movement Guidelines (10), limited ST was considered to be daily screen time of participants—including time watching TV/movies, playing computer games, and using electronic screen-based devices—of <2 h per day.

TABLE 1 | Characteristics of participants in this study.

	n	%
Overall	4,128	100
Sex		
Boy	2,101	50.9
Girl	2,027	49.1
Age group		
Younger adolescent	2,555	61.9
Older adolescent	1,573	38.1
Geographical location		
Urban	3,059	74.1
Rural	1,069	25.9
Parental occupation		
Officer worker	2,881	69.8
Manual labourer	1,247	30.2
Parental education level		
Less than college/university	2,935	71.1
College/university or higher	1,193	28.9
Travel to school		
Passive	2,175	52.7
Active	1,953	47.3
Modes of travel to school		
School bus	33	0.8
Delivered by parents	1,102	26.7
Public transportation	1,040	25.2
Walking	1,408	34.1
Cycling	545	13.2
MVPA*		
Insufficient	3,414	82.7
Sufficient	714	17.3
ST**		
Excessive	1,325	32.1
Limited	2,803	67.9

**MVPA Moderate to vigorous physical activity, insufficient denotes not meeting the guidelines; sufficient denotes meeting the guidelines (4).*

***ST Screen time, excessive denotes not meeting the guidelines; limited denotes meeting the guidelines (4).*

Statistical Analysis

Before initiating the formal analysis process, all responses with missing data were omitted from the sample. We opted to concentrate our analysis on 10- to 18- year-old adolescents (grades 7–12) only, with data about further school grades being excluded. Ultimately, the final sample size, included in the analysis, was 4,128. Descriptive statistical analysis was applied to report the percentage of sociodemographic variables (e.g., sex, age, living environment, parental occupation, and education), exposures (ATS: passive vs. active; its types: school bus, delivery by parents, or public transportation as passive, or walking or cycling as active) and outcomes (PA: sufficient vs. insufficient; ST: limited vs. excessive). A Chi-square test was performed to investigate the difference in PA and ST by ATS (its types), alongside the individual as well as parental characteristics. Logistic regression was undertaken to analyse the relationship of ATS and its types (exposure) with PA and ST (outcome). All variables were incorporated into the regression analysis as categorical variables. This research presents the logistic regression results as odds ratios (ORs) with 95% confidence intervals (CIs). When examining the relationship of ATS and its types with PA and ST, all sociodemographic variables were adjusted in the models, and $p < 0.05$ was established as the level of statistical significance. The statistical analyses procedures were performed using SPSS 24.0 (IBM Corp, Chicago, IL, USA).

TABLE 2 | Difference of PA and ST by ATS and its types.

	Sufficient PA ($n = 714$) %	*p*	Limited ST ($n = 2,803$) %	*p*
ATS				
Passive	14.8	0.000	68.4	0.213
Active	20.1		67.3	
Types of ATS				
School bus	15.2	0.000	53.3	0.000
Delivered by parents	15.9		73.0	
Public transportation	13.6		64.0	
Walking	19.0		69.5	
Cycling	23.0		61.7	

ATS, Active travel to school; PA, Physical activity; ST, screen time.

RESULTS

Table 1 presents the characteristics of participants in this study. Of all the included participants ($n = 4,128$), boys accounted for 50.9%. Younger adolescents accounted for over 60% of the participants. Over 70% of the participants lived in urban areas. Approximately 70% of participants had parents who were office worker or had an education degree of less than college/university. The proportion of participants using the passive mode of ATS was 52.7%. Regarding the types of ATS, participants who walked to school accounted for 34.1% (the largest proportion), while participants using the school bus made up the smallest proportion (0.8%). The prevalence of sufficient PA and limited ST was 17.3 and 67.9%, respectively.

In **Table 2**, the results of the difference in PA and ST by ATS and its types are presented. Participants with active ATS showed a higher percentage of sufficient PA compared to their counterparts (20.1 vs. 14.8%, $p < 0.001$). Participants taking cycling as ATS mode had the highest percentage of sufficient PA compared to others (23.0%, $p < 0.001$). There was no significant difference in the levels of limited ST among participants with different ATS groups. Participants taking the school bus as their mode of ATS had the lowest percentage of limited ST compared to those using other types of ATS (53.3%, $p < 0.001$).

The results of the difference of PA and ST by ATS and its types as well as individual characteristics are shown in **Table 3**. Regardless of sex, and living environment, a difference in PA was observed between the passive and active ATS groups as well as the types of ATS (all $p < 0.005$). However, there was

TABLE 3 | Difference of PA and ST by ATS and its types as well as individual characteristics.

	Sufficient PA (n = 714)				Limited ST (n = 2,803)			
	%	p	%	p	%	p	%	p
	Boy		Girl		Boy		Girl	
ATS								
Passive	17.8	0.000	12.3	0.040	66.5	0.562	70.0	0.621
Active	24.6		14.1		65.7		69.4	
Types of ATS								
School bus	18.2	0.000	10.8	0.010	58.2	0.000	45.9	0.000
Delivered by parents	19.6		13.3		70.8		74.5	
Public transportation	16.3		10.9		63.1		64.9	
Walking	24.5		13.4		68.7		70.3	
Cycling	24.9		17.5		60.5		65.2	
	Younger adolescents		Older adolescents		Younger adolescents		Older adolescents	
ATS								
Passive	17.4	0.000	11.6	0.116	72.0	0.010	63.9	0.559
Active	23.2		13.2		69.2		63.1	
Types of ATS								
School bus	12.5	0.000	17.3	0.002	55.0	0.000	51.9	0.000
Delivered by parents	17.3		12.6		73.5		71.8	
Public transportation	17.7		10.9		69.8		60.0	
Walking	21.9		11.0		70.9		65.5	
Cycling	27.8		16.6		63.6		59.2	
	Urban		Rural		Urban		Rural	
ATS								
Passive	14.9	0.000	14.6	0.000	68.5	0.050	68.0	0.414
Active	19.5		21.8		66.5		69.4	
Types of ATS								
School bus	16.9	0.000	12.1	0.000	55.9	0.000	48.5	0.000
Delivered by parents	16.2		14.9		73.3		72.2	
Public transportation	13.4		14.3		63.9		64.2	
Walking	17.9		21.9		68.7		71.8	
Cycling	23.5		21.7		61.0		63.6	

ATS, Active travel to school; PA, Physical activity; ST, screen time.

no significant difference in PA between the passive and active ATS groups among older adolescents ($p = 0.116$). Further, a significant difference was observed across groups of different types of ATS irrespective of sex, age, and living environment for limited ST. However, there was no significant difference of ST across groups of ATS except for younger boys ($p < 0.001$).

In **Table 4**, more participants with an active ATS had sufficient PA regardless of parental education levels compared to those with a passive ATS (less than college/university: 20.7% > 14.6%, $p < 0.001$; college/university or higher: 18.7% > 15.2%, $p = 0.006$), and particularly, participants who selected cycling had the highest percentages compared with the other ATS types. In terms of limited ST, participants who were delivered by parents had the highest percentages (less than college/university: 70.6%, $p < 0.001$; college/university or higher: 77.9%, $p = 0.004$). Similar to the parental education level groups, more participants using an active form of travel to school had sufficient PA regardless of their parent's occupations compared with those with passive ATS (office worker: 20.4% > 14.9%, manual labourer: 19.6% > 14.6%, both $p < 0.001$), and participants using cycling had the highest percentages compared with other ATS types (both 23.0%, both $p < 0.001$). Participants who were delivered by parents had the highest percentages of limited ST compared to those with other ATS types (office worker: 74.6%, manual labourer: 68.6%, both $p < 0.001$).

In **Table 5**, the results from the logistic regression model revealing the relationships of ATS with PA and ST are shown. Overall, participants with ATS were more likely to have

TABLE 4 | Difference of PA and ST by travel to school and its types as well as parental characteristics.

	Sufficient PA				Limited ST			
	%	*p*	%	*p*	%	*p*	%	*p*
Parental education	**Less than college/university**		**College/university or higher**		**Less than college/university**		**College/university or higher**	
ATS								
Passive	14.6	0.000	15.2	0.006	65.5	0.819	75.4	0.076
Active	20.7		18.7		65.2		72.7	
Types of ATS								
School bus	13.6	0.000	18.2	0.005	45.8	0.000	66.7	0.004
Delivered by parents	15.8		16.0		70.6		77.9	
Public transportation	13.5		14.0		61.1		72.3	
Walking	19.7		17.3		67.7		74.1	
Cycling	23.3		22.3		58.7		69.1	
Parental occupation	**Officer worker**		**Manual labourer**		**Officer worker**		**Manual labourer**	
ATS								
Passive	14.9	0.000	14.6	0.000	70.3	0.833	63.7	0.205
Active	20.4		19.6		70.1		61.6	
Types of ATS								
School bus	16.9	0.000	11.1	0.000	60.0	0.000	37.0	0.000
Delivered by parents	15.2		17.7		74.6		68.6	
Public transportation	14.4		11.8		65.8		59.9	
Walking	19.3		18.4		71.8		64.8	
Cycling	23.0		23.0		65.7		52.8	

ATS, Active travel to school; PA, Physical activity; ST, screen time.

TABLE 5 | The relationships of travel (modes) to school with MVPA and ST by different characteristics.

	MVPA						ST					
	OR	**95% CI**		**OR**	**95% CI**		**OR**	**95% CI**		**OR**	**95% CI**	
Active	**1.26**	**1.14**	**1.39**				0.94	0.86	1.01			
Passive		Ref						Ref				
	Boys			**Girls**			**Boys**			**Girls**		
Active	**1.41**	**1.24**	**1.61**	1.05	0.90	1.23	0.93	0.83	1.03	0.94	0.84	1.06
Passive		Ref			Ref			Ref			Ref	
	Younger adolescents			**Older adolescents**			**Younger adolescents**			**Older adolescents**		
Active	**1.35**	**1.20**	**1.52**	1.07	0.88	1.29	0.91	0.82	1.01	0.98	0.86	1.12
Passive		Ref			Ref			Ref			Ref	
	Urban			**Rural**			**Urban**			**Rural**		
Active	**1.23**	**1.09**	**1.38**	**1.40**	**1.15**	**1.70**	0.89	0.81	0.98	0.91	1.07	1.25
Passive		Ref			Ref			Ref			Ref	
	Less than college/university			**College/university or higher**			**Less than college/university**			**College/university or higher**		
Active	**1.30**	**1.16**	**1.47**	1.16	0.96	1.39	0.98	0.89	1.07	0.84	0.72	0.99
Passive		Ref			Ref			Ref			Ref	
	Officer worker			**Manual labourer**			**Officer worker**			**Manual labourer**		
Active	**1.26**	**1.11**	**1.41**	**1.26**	**1.05**	**1.51**	0.95	0.86	1.05	0.90	0.78	1.04
Passive		Ref			Ref			Ref			Ref	

MVPA, Moderate to vigorous physical activity; ST, Screen time.
Bold fonts denote statistical significance.

TABLE 6 | The relationships of types of active travel to school with MVPA and ST by different characteristics.

	MVPA						ST					
	OR	95% CI		OR	95% CI		OR	95% CI		OR	95% CI	
Walking	**1.23**	**1.07**	**1.41**				**1.17**	**1.05**	**1.30**			
Cycling	**1.52**	**1.29**	**1.79**				**0.88**	**0.77**	**0.99**			
School bus	1.06	0.59	1.89				**0.60**	**0.39**	**0.92**			
Delivered by parents	1.06	0.92	1.23				**1.34**	**1.19**	**1.50**			
Public transportation		Ref						Ref				
	Boys			**Girls**			**Boys**			**Girls**		
Walking	**1.41**	**1.18**	**1.69**	0.99	0.79	1.23	**1.16**	**1.01**	**1.34**	**1.17**	**1.01**	**1.37**
Cycling	**1.57**	**1.29**	**1.91**	**1.47**	**1.07**	**2.00**	**0.83**	**0.70**	**0.98**	0.97	0.77	1.23
School bus	1.10	0.54	2.22	0.98	0.34	2.82	0.75	0.43	1.30	**0.43**	**0.22**	**0.83**
Delivered by parents	1.07	0.88	1.32	1.01	0.81	1.27	**1.25**	**1.06**	**1.48**	**1.42**	**1.21**	**1.66**
Public transportation		Ref			Ref			Ref			Ref	
	Younger adolescents			**Older adolescents**			**Younger adolescents**			**Older adolescents**		
Walking	**1.29**	**1.08**	**1.53**	1.04	0.81	1.33	1.06	0.91	1.23	**1.23**	**1.04**	**1.44**
Cycling	**1.56**	**1.26**	**1.93**	**1.34**	**1.03**	**1.74**	**0.76**	**0.63**	**0.92**	0.99	0.82	1.20
School bus	0.65	0.25	1.69	1.71	0.81	3.60	**0.47**	**0.25**	**0.90**	0.69	0.39	1.20
Delivered by parents	1.01	0.84	1.22	1.23	0.95	1.58	1.15	0.98	1.34	**1.62**	**1.36**	**1.92**
Public transportation		Ref			Ref			Ref			Ref	
	Urban			**Rural**			**Urban**			**Rural**		
Walking	**1.21**	**1.03**	**1.42**	1.25	0.95	1.64	1.11	0.98	1.26	**1.33**	**1.08**	**1.65**
Cycling	**1.66**	**1.38**	**2.01**	1.09	0.78	1.51	0.86	0.74	1.01	0.94	0.73	1.23
School bus	1.17	0.58	2.35	0.95	0.32	2.83	0.65	0.38	1.09	0.52	0.26	1.05
Delivered by parents	1.17	0.98	1.38	0.77	0.56	1.04	**1.36**	**1.19**	**1.55**	**1.30**	**1.03**	**1.65**
Public transportation		Ref			Ref			Ref			Ref	
	Less than college/university			**College/university or higher**			**Less than college/university**			**College/university or higher**		
Walking	**1.22**	**1.04**	**1.43**	1.22	0.93	1.60	**1.25**	**1.11**	**1.42**	0.97	0.78	1.20
Cycling	**1.50**	**1.24**	**1.82**	**1.53**	**1.12**	**2.09**	0.90	0.77	1.05	0.82	0.63	1.07
School bus	0.97	0.45	2.09	1.29	0.52	3.24	**0.53**	**0.32**	**0.90**	0.70	0.33	1.48
Delivered by parents	0.99	0.83	1.18	1.23	0.93	1.62	**1.40**	**1.23**	**1.60**	1.19	0.95	1.49
Public transportation		Ref			Ref			Ref			Ref	
	Officer worker			**Manual labourer**			**Officer worker**			**Manual labourer**		
Walking	**1.19**	**1.01**	**1.41**	**1.30**	**1.01**	**1.69**	**1.17**	**1.02**	**1.33**	1.18	0.98	1.42
Cycling	**1.39**	**1.14**	**1.69**	**1.85**	**1.36**	**2.50**	0.95	0.80	1.11	**0.75**	**0.59**	**0.94**
School bus	1.09	0.56	2.12	0.92	0.27	3.15	0.73	0.44	1.22	**0.37**	**0.17**	**0.82**
Delivered by parents	0.99	0.83	1.18	1.27	0.96	1.69	**1.33**	**1.16**	**1.53**	**1.38**	**1.12**	**1.70**
Public transportation		Ref			Ref			Ref			Ref	

MVPA, Moderate to vigorous physical activity; ST, Screen time.
Bold fonts denote statistical significance.

sufficient PA (OR = 1.26, 95% CI: 1.14–1.39). In examining the relationships of ATS with PA and ST by sex, only boys with ATS had a higher chance of being sufficiently active (OR = 1.41, 95% CI: 1.24–1.61), compared with their counterparts. Significant relationships were also observed in participates of the younger age group (OR = 1.35, 95% CI: 1.20–1.52) and those whose parental education level was less than college/university (OR = 1.30, 95% CI: 1.16–1.47). Regardless of living environment and parental occupation, participants with ATS were more likely to have sufficient PA (all OR > 1.20). However, participants with ATS showed a non-significant relationship with ST.

Table 6 shows the results from the regression model for the relationships of types of ATS with PA and ST by individual and parental characteristics. In general, participants who selected walking or cycling were more likely to have sufficient PA overall, in boy, younger adolescents, and urban participants, and those who had parents with less than college/university education level or office worker occupation. Conversely, cycling had a likelihood of increasing the sufficient PA among girls, older adolescents, or those who had parents with a higher education level (college/university or higher) or manual labourer. Concerning the relationship of types of ATS with ST, participants with walking (OR = 1.17, 95% CI: 1.05–1.30) and delivered by

parents (OR = 1.34, 95% CI: 1.19–1.50) were more likely to have limited ST. Significant relationships were also found among boys and girls, older adolescents, those living in rural areas, those having parents with less than college/university education level, or with office workers.

DISCUSSION

To the best of our knowledge, this study is one of the first cross-sectional investigations into the relationship of ATS and its types with PA and ST among adolescents of the Chinese samples. This research analyses the correlation of ATS and its types with PA and ST about different individual and parental characteristics, which potentially offers significant practical implications and advances the knowledge in this field.

Summary of Findings

In this current study, the proportion of the sample engaging in ATS was 47.3%, with participants who walked (34.1%) constituting a greater percentage than those who cycled (13.2%). Regarding the question relating to levels of adequate PA and limited ST among the adolescents, only 17.3% attained the former, whereas the latter was under acceptable levels. Furthermore, we found that participants engaged in ATS had a greater chance of also participating inadequate PA levels, while ATS was not connected with limited ST. Regarding types of ATS, participants engaged in walking or cycling both had a higher chance of undertaking sufficient PA rather than being characterised by limited ST. The relationships of ATS and its types with PA and ST differed according to individual and parental characteristics.

Interpretations of Findings

Low PA levels among adolescents have been demonstrated across the literature (2, 4, 32). The present research indicated that only ∼20% of adolescents participated in the recommended level of PA [60 min of moderate to vigorous PA daily (5)], indicating a lower level of PA among adolescents. This result is consistent with the previously published studies of a regional nature (33, 34). Nevertheless, in contrast with the nationally representative surveys in China (32), the PA level established in the present study is lower. This reduced level is potentially explained by the varying measures adopted, which possibly produced inconsistencies in terms of estimating the amount of PA. Concerning the level of ST among adolescents in this study, our level is following studies based on Chinese adolescent samples (32–34). Despite the ST level exceeding 60%, limiting ST is a necessary mission for the promotion of adolescent health. Likewise, given the health benefits linked to sufficient PA among adolescents (7, 10), increased PA is further imperative. The Social-Ecological Model has summarised the correlates of PA and ST (29). Nevertheless, given the significant variations in China's economy, society and geography, investigating the correlates and determinants of PA and ST among adolescents across the country's various regions requires additional research (33).

Levels in Active Travel to School

The current study indicates that just below half of the participants (47.3%) engaged in ATS from home to school, which corroborates other studies on Chinese (23, 24) and North American samples (35, 36). Regardless, in contrast with studies of European countries (37, 38), the adolescents in our study showed reduced ATS performance. It is probable that the difference between our study and other research in ATS levels due to various measures used. Nevertheless, the ATS among Chinese adolescents has declined over the past decade (24), suggesting that they are less physically active (through walking or cycling). From this perspective, the ATS level among adolescents in our study is potentially unsatisfactory. This is a somewhat concerning situation that should be explained about local contexts and across various regions or cities (39). Given the health benefits of ATS for adolescents (30), the promotion of ATS among adolescents is to be encouraged.

Our research is one of the few investigations assessing types of ATS among Chinese adolescents. Among the participants engaged in ATS, the majority walked between school and home. This finding is consistent with previous studies (23). A Study in 2010 by Sun et al. found that 40.1 and 41.4% of Chinese 7–9 grader and 10–12 graders walked to school, while only 14.5 and 9.5% of 7–9 grader and 10–12 graders cycled to school. Our results showed lower percentages of walking as well as cycling. This declining trend had been indicated by prior research. For instance, Yang et al. (24) clarified that participation in walking or cycling between home and school has declined over the years. Presently, there is a dearth of understanding regarding walking or cycling trends among Chinese adolescents at the national or regional level. We suggest that future studies should seek to more effectively explore the patterns of either walking or cycling, thus providing evidence-based information for promoting ATS.

Overall Associations of ATS With PA and ST

Reflecting the findings of numerous previous studies (16, 21, 27, 28), the current study reaffirms that participants engaged in ATS have a greater chance of participating insufficient PA. Potential reasons may be that (1) ATS is an aspect of daily PA; thus, participants engaged in ATS are more likely to report higher PA; (2) participants engaged in ATS were similarly or more intensely engaged in other types of PA. Collectively, these two potential reasons may be responsible for the association of ATS with sufficient PA. Nevertheless, the ATS and PA were affected by different variables across various regions.

Accordingly, the mechanism connecting ATS and PA varies depending upon the social and environmental factors. Therefore, it is advocated that further studies should investigate the correlation of ATS and PA to a greater extent, implementing enhanced study designs and multiple data sources. Nevertheless, this study finds that ATS was not associated with ST among adolescents. A systematic review indicated that the relationship of ATS with ST was inconsistent across the literature (14), meaning the correlation between these two variables remains ambiguous. However, informed by the findings of this study, ATS potentially plays a role in promoting PA, as opposed to diminishing ST among adolescents.

Variations in the Association Between ATS and PA

We further discovered that the relationship of ATS with PA varies according to sex, age, and parental education. Specifically, the relationship between ATS and PA was found to be significant among boys, suggesting that only boys engaging in ATS have potentially involved insufficient PA (15). However, such a significant relationship was not observed among girls. This may be potential because parents grant greater freedom to boys to engage in ATS as opposed to girls. Thus, girls may be exposed to fewer opportunities to engage in ATS behaviour, ultimately restricting their ability to engage in sufficient PA levels. Moreover, the sex difference in the relationship of ATS with PA was similar to the age difference.

The present research found that younger adolescents, as opposed to their older peers were engaged more in ATS r and had a greater chance of also participating insufficient PA. This result is explainable according to the Chinese context. In our study, older adolescents were those in grades 10–12, which is a vital period that covers the college entrance test. During this period, adolescents tend to be delivered to school by their parents for time-saving reasons, allowing a greater amount of time to be spent on studying. Conversely, such a situation would not arise among younger adolescents due to lower academic pressure.

Among participants whose parents had lower educational attainment, those engaged in ATS had a greater prospect of attaining sufficient PA levels. Nevertheless, this significant relationship was not detected among participants whose parents had higher educational attainment levels. A potential reason is that parents with lower levels of educational attainment have lower levels of income compared with their counterparts. Consequently, it is less likely that those parents possess automobiles, which potentially causes their children to travel between home and school through walking or cycling.

This research has established that the relationships between types of ATS with PA vary according to individual and parental characteristics. We primarily identified that participants engaged in walking or cycling had a greater likelihood of participating insufficient PA compared with their counterparts. Unsurprisingly, when assessing the odds ratio of walking and cycling about sufficient PA, the former is lower than the latter. This finding is consistent with the results of the study of Roth et al. (15), where the association between cycling and overall PA (OR = 1.93) was stronger than that between walking and overall PA (OR = 1.17). Another study also provided a similar finding that there was a difference in the PA level between active walkers and cyclists (40). However, there is still no well-recognised explanation for this finding and more research is required into the social and environmental determinants of ATS with PA.

A similar relationship was identified among boys, younger adolescents, participants whose parents had reduced education levels or were office workers. Significantly, only girls engaged in cycling showed sufficient PA in our study, providing an inconsistency with the results for boys. Future studies should attempt to answer this difference for the relationship of types of ATS with PA based on the different subpopulations' characteristics and other factors.

A noticeable distinction is apparent in the relationship of types of ATS with PA according to the living environment. Specifically, in urban areas, adolescents engaged in cycling were more likely to be involved insufficient PA, whereas adolescents in rural areas who were engaged in walking had a greater prospect of undertaking sufficient PA. Unfortunately, no data provided by our study were able to clarify the variation. The differences in built environment between urban and rural settings may provide a plausible explanation for this. A similar finding was established for participants with different parental education levels and occupations. Given the limited evidence across the extant literature, more studies should address these research questions in the future.

Variations in the Association Between ATS and ST

When looking at the difference of individual and parental characteristics in the relationship of types of ATS with limited ST, some novel findings should be mentioned. In the current study, participants who walked and were delivered by parents had higher odds of having limited ST compared with their counterparts. To our knowledge, no data provided by previous studies were comparable with our study findings. Some possible reasons for explaining the findings are that (1) participants who walked to school could be regarded as a lower level of socio-economic status, and may not be able to afford as many screen-based devices, ultimately reducing their ST; (2) participants delivered by parents would be exposed to much stricter supervision that limits the time spent for screen-based activities. Owing to less research, more studies should confirm our assumptions. In addition to the overall findings, the individual and parental differences in the relationship of types of ATS with ST were found. Such variations should be explained by more factors, whereas the present study failed to provide this indicative information, future studies should answer the variations found by our study, which can provide more specific practical implications.

Implications and Future Recommendations for Research

Irrespective of the preliminary nature of the evidence regarding the variations in the relationship of ATS and its types with individual and parental characteristics, the present study affirmed the role of ATS in promoting PA among adolescents. This research has expanded on prior research, demonstrating that individual and parental characteristics show different relationships regarding ATS compared to PA. Nevertheless, given that ATS and PA are two complex behaviours that are affected by numerous variables, the relationships of ATS and its types with PA according to various characteristics requires further replication and clarification of the results to provide more robust evidence. Practically, the current study should prove beneficial in encouraging adolescent PA through ATS, with the design of effective policies and actions being necessary.

When designing ATS interventions for enhancing PA among adolescents, individual and parental characteristics must be considered. It is recommended that future research should concentrate on the mechanisms linking ATS with PA within

various contexts (for example sex and living environment). Based on the cross-sectional nature of our research, prospective longitudinal studies are necessary to confirm the relationships we observed, as well as to elucidate whether a potential causal relationship is apparent between ATS and PA. Moreover, it is necessary to undertake further experimental research to analyse the extent to which ATS interventions offer further effectiveness for promoting PA among adolescents.

Study Strengths and Limitations

This study offered certain advantages. First, the study adopted a relatively large sample size as a means of investigating the relationship of ATS with PA and ST, thus enhancing the generalizability of research findings. Second, the present study is one of the very limited number of investigations analysing the associations of ATS with PA and ST as they relate to different individual and parental characteristics. The research findings are potentially beneficial for designing specific PA and ST interventions. However, there are certain limitations to this study that should be clarified. Due to the cross-sectional nature of the study, the findings of the study should be interpreted with caution. Moreover, our study used a self-reported questionnaire to assess the ATS, PA, and ST, which was subjective to recall bias of measurement. Third, this study did not include/explore more potential confounders, such as time spent during ATS and car ownership, that may affect the relationship of ATS with PA and ST. Fourth, to better explain the relationship of ATS with PA or ST, additional psychological (e.g., attitude towards ATS), social (e.g., safety and parental awareness of ATS) and physical environmental (e.g., distance to school) factors should be considered for more reliable interpretations. Finally, the ATS and PA, as well as ST, are also affected by other factors, such as income level. We recommend further study of the relationship of ATS with PA and ST by income and other sociodemographic factors, particularly of longitudinal nature. Future studies should address these limitations to provide an improved evidence base.

CONCLUSIONS

Overall, our study indicated that approximately half of the adolescents engaged in ATS, with a majority of participants preferring to travel through cycling between home and school. ATS among adolescents was linked with sufficient PA as opposed to ST. Therefore, the relationships of ATS and its types with PA require further clarification by different contexts, including sex, age differences, and parental characteristics. Nevertheless, this study retains its specific significance to the implementation of PA promotional activities among adolescents.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

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

AUTHOR CONTRIBUTIONS

CH, YL, and S-TC conceptualised and designed this study. CH, JY, and YL analysed interpreted data and drafted the manuscript. AM and S-TC provided important intellectual roles in revision. All authors read and approved the final manuscript.

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The Association of Different Sedentary Patterns and Health-Related Physical Fitness in Pre-schoolers

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Background: The results of sedentary time (ST) and health-related physical fitness (HPF) are not completely consistent and the studies concentrated on pre-schoolers are very limited.

Methods: We measured ST and ST patterns (ST Bouts time, ST Breaks times) by accelerometer. The health-related physical fitness T-score (HPFT) was calculated by five indexes: height-weight standard score, 20 m shuttle-run test, grip strength, standing long jump and 2 × 10 m shuttle-run test.

Results: We included 375 pre-schoolers (211 boys, 164 girls) in the final analysis. The total ST and ST Bouts times negatively correlated with HPFT in pre-schoolers. HPFT reduced by 1.69 and 0.70 points per 10 min increased in total ST and ST Bouts times, respectively. HPFT of the highest quartile group reduced by 9.85 points in total ST, and 10.54 points in ST Bouts time compared with the lowest quartile group. However, the HPFT increased by 0.09 points per 10 times increased in ST Breaks times; the HPFT increased by 16.21 and 15.59 points when moderate to vigorous physical activity (MVPA) replaced total ST and ST Bouts time.

Conclusions: HPF negatively correlated with the Total ST and ST Bouts times, but positively correlated with ST Breaks times; and HPF significantly improved when MVPA replaced ST in pre-schoolers.

Keywords: health-related physical fitness, total sedentary time, ST Bouts time, ST Breaks times, pre-schoolers

INTRODUCTION

Health-related physical fitness (HPF) is an essential indicator for evaluating the physical and mental health of human body, and good HPF is positively related to a person's cognitive development and academic performance (1, 2). Moreover, evidence shows that the HPF is also related to intellectual maturity in pre-schoolers (3). However, children's health problems keep coming up in recent years,

such as the increased rate of obesity and weakened level of physique (4, 5). Thus, it is necessary to improve the level of HPF in young children.

Sedentary time (ST) is defined as behavior energy consumption < 1.5 METs when awake, such as sitting, leaning, or lying down postures (6). Although the results are not entirely consistent in studies that aimed to identify the relationship between ST and HPF in pre-schoolers (7, 8), most results showed that more ST was negatively related to HPF (9, 10). Therefore, the public health departments recommend that children under 5-year-old should have ST < 2 h and screen time within 1 h per day (11, 12). Besides, it was worth noting that ST patterns, such as ST prolonged for 20 min and the number of ST interruptions, may be related to HPF (13, 14).

The phenomenon of less movement not only exists in adults, but also in young children. Previous findings indicated that ST accounts for 34–94% of the daily awake time in pre-schoolers (15). Moreover, previous studies have shown that engaging in physical activity (PA) is beneficial for HPF (16), but few studies describe whether it can reduce the negative effects of ST accumulation on health when replacing ST with PA in pre-schoolers. At present, the relationship between ST, ST patterns and HPF is still inconsistent. Besides, most studies about the relationship between ST and HPF focused on children, adolescents, or the elderly. Research on pre-schoolers was still very limited.

Therefore, given shortcomings in the current study, this study aims to explore: (1) the relationship between total ST, ST patterns (Bouts time, Breaks times) and HPF in pre-schoolers and (2) whether the HPF level will change when ST is replaced by physical activity, based on the multiple linear regression and Isotemporal substitution model (ISM) in pre-schoolers. We hypothesize that lower HPF level correlates with longer total ST and ST Bouts times, and higher HPF level correlates with more ST Breaks times and physical activity time. The study results will provide evidence to determine the specific relationship between ST and HPF and give suggestions to improve HPF levels in pre-schoolers.

MATERIALS AND METHODS

Participants

The study is cross-sectional research. The data were from the primary data of an observational study in 2013–2014 and a parallel intervention study in 2018. Both trials have been approved by the ethics review committee of Shanghai University of Sport, and has been registered in Chinese Clinical Trial Registration Center (Ethics approval number: 2015028, ChiCTR-OOC-15007439; Ethics approval number: 2017023, ChiCTR1900021552).

Inclusion criteria are: (1) pre-schoolers aged 3–6 years; (2) parents/guardians understood the whole experiment process and signed an informed consent form. Exclusion criteria are: (1) pre-schoolers who had a score < 75 points on the Wechsler Intelligence Scale; (2) who had cardiovascular or respiratory diseases; (3) who had been screened by a parent/guardian medical questionnaire and confirmed could not join in the moderate-intensity exercise.

We recruited a total of 471 participants in the two trials, and 375 participants (211 boys, 164 girls; average age 4.56 years) were included in the final statistical analysis (**Figure 1**).

Measurements

Basic Morphological Measurement and Family Status Survey

According to the Chinese National Physical Fitness Measurement Standards (Kindergarten Version), this study evaluates the height and weight of participants. The basic family status survey form was filled out by their parents, including the participant's sex, age, parents' education (Doctorate, Master, Undergraduate, Middle school and below), and monthly household income (below 2,000 yuan, 2,001–4,000 yuan, 4,001–8,000 yuan, 8,001–15,000 yuan, 15,001–30,000 yuan).

Total ST, ST Patterns and PA Measurement

ST and PA were measured by the three-axis accelerometer ActiGraph GT3X+ (Actigraph LLC, Pensacola, FL). The monitor has been proved effective to evaluate pre-schoolers' ST and PA (17). Participants need to wear GT3X+ for continuous 7 days to measure daily ST and PA (5 working days + 2 weekend days). The monitor was fixed on the waist belt and placed on the upper right hip, and it was required to be worn at all times except for bathing, swimming, and sleeping. The staff took back the monitor on the 8th day and used the Actilife software (Version 6.11.5) to download and view the data. We carried out the additional test for participants whose data did not meet the requirements or was missing after obtaining their parental consent.

The epoch was set to 1 s, and we processed ST, light physical activity (LPA), moderate to vigorous physical activity (MVPA) according to different cut points. The ST was defined using the

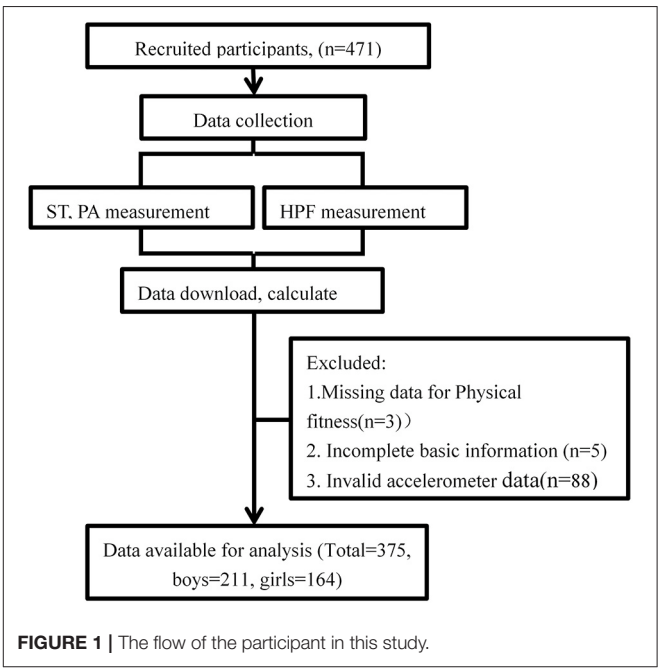

FIGURE 1 | The flow of the participant in this study.

cut-point of Evenson (<25 counts/15 s) (18), and Pate's cut-points were used to distinguish LPA (25 counts/15 s ≤ counts < 420 counts/15 s) and MVPA (≥420 counts/15 s) (19). We defined the non-wearing time according to Choi's law (20), and the participants' valid data contained the complete data for at least 3 days (2 working days + 1 weekend day, effective daily wearing time was ≥480 min).

The definitions of ST Bouts times and ST Breaks times are related to the Epoch, and there is no standard for their purposes at present (13). We defined that each ST bouts must maintain at least 180 epochs (≥180 s), and 10% tolerance time was allowed during the process. An interruption lasts for at least one epoch or above (≥1 s) was considered an ST Breaks time.

Health-Related Physical Fitness Measurement

The HPF was assessed according to Chinese National Physical Fitness Measurement Standards (Kindergarten version). Given the importance of cardiorespiratory fitness to children's cognitive function, and quality of life and health showed in previous results; we added the evaluation of cardiorespiratory fitness to the HPF (21). Thus, the HPF of pre-schoolers included height-weight standard score, strength fitness (grip strength, standing long jump), cardiorespiratory fitness (20-meter shuttle-run test, 20 m-SRT) and speed-agility fitness (2 × 10 meters shuttle-run test, 2 × 10 m-SRT). The details of each testing item were described as below:

(1) According to the Chinese National Physical Fitness Measurement Standards (Kindergarten Version), we used the instruments of *Jianmin* brand (GMCS-I), which were designed instruments for Chinese National Physical Fitness Measurement when measuring the height and weight of participants, and to score in the same age and sex group.

(2) Strength fitness was evaluated by grip strength and standing long jump test. Before the grip strength test start, we adjusted the distance between the lower bar and the upper edge of the grip meter to be 4 cm, which had been proved to be a suitable distance for the pre-schoolers (22). Participants held a grip meter TKK-5401 (Takei, Niigata, Japan) with their dominant hand, standing vertically and naturally. The angle between the arm and body was about 10 degrees, and then held the bar as hard as possible until the value stopped changing. The test was conducted two times and we recorded the maximum value (accurate to 0.1 kg) as a result.

The staff made a demonstration first before the standing long jump test started. Participants stood naturally behind the start line, swung hands back and forth, bending knees, and then jumped forward in the air as far as possible. We used a tape to measure the straight-line distance from the start line to the participant's heel (accurate to 0.1 cm). We tested two times and recorded the best result.

(3) Cardiorespiratory fitness was evaluated by a 20 m-SRT. Participants ran to the rhythm of music from slow to fast between two lines separated 20 meters. The initial running speed was 8.5 km/h and increased by 0.5 km/h per 1 min. The test stopped when the participant could not step on or step over the end line within the specified time for two consecutive times, or felt unable to accomplish after repeated encouragement. An adult tester led the entire test because the participants were too young to understand the rules and requirements of the test thoroughly. We measured once and recorded the number of finished laps (20 meters is one lap).

(4) This study applied 2×10 m-SRT to evaluate the speed-agility fitness of pre-schoolers. Participants ran straight along two lines, 10 meters apart. Participants touched the marker when reached the finishing line, and then returned to the starting line. We recorded, using a stopwatch, the time from when the participants started to when they returned to the starting line. Participants accompanied an adult tester to ensure the test was successful. We tested two times and recorded the fastest time as result (accurate to 0.01 s).

Data Analysis

We used the mean (M), standard deviation (SD), the frequency and percentage (*N*, %) to describe the distribution of continuous and categorical variables. The formula of standard *T*-score was: $T=50+10*(X-M)/SD$, X is a personal performance. Besides, we multiplied the results of the 2 × 10 m-SRT by −1 when calculating the T-score, because the smaller the value was, the better the result would be. The HPFT was the sum of the standard T-score of five indexes in different sex groups. $HPFT = T_{\text{Height−weight standard score}} + T_{\text{20 m−SRT}} + T_{\text{2×10m−SRT}} + T_{\text{Standing long jump}} + T_{\text{Grip}}$.

A multiple linear regression model was used to explore the relationship between total ST, ST patterns and HPFT in pre-schoolers. Total ST, ST Bouts times were standardized for the total behavior time using the residual method (23). Similarly, ST Breaks times was standardized for the total ST in the same way. We put the total ST and ST patterns into the linear regression model as continuous variables and quartile groups (Q1–Q4) two forms, and HPFT of pre-schoolers is regarded as dependent variables. We put the median of each quartile groups (Q1–Q4) as a new variable into the regression model to obtain the trend test results. The model was adjusted for sex, age, household income, father's and mother's education.

The ISM was used to explore the change of outcome when a behavior replaced another behavior, and it has been used as an effective, simple model in epidemiological research (24). We used ISM to explore the HPF change when 30-min ST, and ST Bouts times were replaced by MVPA in pre-schoolers, while keeping other activities time consistent.

Additionally, the piece-wise linear regression model was used to explore whether there was a non-linear relationship between the ST patterns and HPFT after adjusting for confounding factors.

SPSS 21.0 and Empower software based on R language were used to analyze data; we consider it is statistically significant if $P < 0.05$.

RESULTS

We found girls were higher than boys in ST Bouts time, but inverse in ST Breaks times. It indicated that boys are more active than girls in pre-schoolers (**Table 1**). Besides, the results of multiple linear regression and the ISM analysis have no

TABLE 1 | Basic information of the participants.

	Boys ($n = 211$)	Girls ($n = 164$)	Total ($n = 375$)
Anthropometric			
Age (y)	4.58 ± 0.46	4.53 ± 0.47	4.56 ± 0.46
Height (cm)	111.63 ± 4.88	110.07 ± 4.92	110.95 ± 4.95*
Weight (kg)	20.64 ± 3.52	19.06 ± 2.73	19.95 ± 3.29*
Sedentary behavior			
Total ST (min/d)	576.49 ± 28.74	589.13 ± 27.20	580.19 ± 64.01
ST Bouts time (min/d)	394.61 ± 69.80	412.75 ± 71.00	402.52 ± 70.81*
ST Breaks times (times/d)	2,439.64 ± 401.31	2,287.55 ± 347.71	2,373.36 ± 390.10*
Physical activity			
LPA (min/d)	99.10 ± 18.06	91.79 ± 16.58	95.90 ± 17.78*
MVPA (min/d)	73.50 ± 18.37	66.67 ± 15.05	70.52 ± 17.31*
Total behavior time	749.11 ± 74.85	743.88 ± 66.93	746.82 ± 71.44
Health-related physical fitness			
Standing long jump (cm)	85.62 ± 16.51	82.27 ± 16.01	84.16 ± 16.35*
Grip strength (kg)	6.95 ± 2.33	6.04 ± 2.26	6.55 ± 2.34*
2 × 10 m shuttle-run test (s)	7.25 ± 0.93	7.34 ± 0.77	7.29 ± 0.86
20 m shuttle-run test (laps)	12.43 ± 4.56	12.91 ± 4.92	12.64 ± 4.72
HPFT	250.91 ± 32.56	248.83 ± 30.71	249.97 ± 31.96
Socioeconomic status			
Father's degree			
Less than middle school	7 (3.35%)	8 (4.91%)	15 (4.03%)
Middle school	26 (12.44%)	22 (13.50%)	48 (12.90%)
High school	51 (24.40%)	41 (25.15%)	92 (24.73%)
Undergraduate	73 (34.93%)	55 (33.74%)	128 (34.41%)
Master	41 (19.62%)	26 (15.95%)	67 (18.01%)
Doctor	11 (5.26%)	11 (6.75%)	22 (5.91%)
Mother's degree			
Less than middle school	4 (1.92%)	7 (4.29%)	11 (2.96%)
Middle school	35 (16.83%)	19 (11.66%)	54 (14.56%)
High school	55 (26.44%)	52 (31.90%)	107 (28.84%)
Undergraduate	73 (35.10%)	49 (30.06%)	122 (32.88%)
Master	30 (14.42%)	27 (16.56%)	57 (15.36%)
Doctor	11 (5.29%)	9 (5.52%)	20 (5.39%)
Household-income (RMB/m)			
Under 2,000	2 (0.97%)	7 (4.32%)	9 (2.44%)
2,000–4,000	11 (5.31%)	6 (3.70%)	17 (4.61%)
4,001–8,000	44 (21.26%)	33 (20.37%)	77 (20.87%)
8,001–15,000	87 (42.03%)	69 (42.59%)	156 (42.28%)
15,001–30,000	55 (26.57%)	36 (22.22%)	91 (24.66%)

ST, sedentary time; LPA, light physical activity; MVPA, moderate to vigorous physical activity; Total behavior time, ST + LPA + MVPA; HPFT, Health-related physical fitness T-score. Data was described by Mean ± SD or N (%); "" means P for sex < 0.05.*

interaction between gender, so all the data are combined for analysis (**Tables 2**, **3**).

Results showed total ST and ST Bouts time negatively correlated with HPFT after adjusting for confounding factors such as sex, age, household income, father's and mother's education. HPFT reduced by 1.69 points (95% CI = −2.78, −0.60) and 0.70 points (95% CI = −1.20, −0.20) per 10 min increased in total ST and ST Bouts time, respectively. HPFT of highest quartile group of children reduced by 9.85 points (95% CI = −18.58, −1.11) in total ST, and 10.54 points (95% CI = −19.20, −1.89) in ST Bouts time compared with the lowest quartile group, respectively. However, the HPFT increased by 0.09 points (95% CI = 0.004, 0.17) when ST Breaks times increased per 10 times (**Table 2**).

Moreover, HPFT significantly increased by 16.21 points (95% CI = 9.35, 23.07) and 15.59 points (95% CI = 8.57, 22.61), respectively, when 30-min MVPA replaced the total ST, ST Bouts time and kept other activities time unchanged (**Table 3**).

TABLE 2 | The association between ST patterns and HPFT.

	HPFT (β, 95% CI)		
	Model 1 (n = 375)	**Model 2 (n = 371)**	**Model 3 (n = 369)**
Total ST (per 10 min/d)	**−1.62 (−2.73, −0.50)**	**−1.72 (−2.77, −0.67)**	**−1.69 (−2.78, −0.60)**
Total ST quartile (min/d)			
Q1 (394.73–534.65)	0 (ref)	0 (ref)	0 (ref)
Q2 (534.66–582.06)	0.23 (−8.86, 9.33)	−1.40 (−9.78, 6.99)	0.55 (−7.99, 9.09)
Q3 (582.07–623.79)	**−9.55 (−18.62, −0.48)**	**−10.85 (−19.26, −2.44)**	**−9.09 (−17.70, −0.49)**
Q4 (623.80–838.97)	**−9.36 (−18.43, −0.29)**	**−9.74 (−18.24, −1.24)**	**−9.85 (−18.58, −1.11)**
P for trend	**0.01**	**<0.01**	**<0.01**
ST Bouts time (per 10 min/d)	**−0.69 (−1.21, −0.17)**	**−0.69 (−1.18, −0.20)**	**−0.70 (−1.20, −0.20)**
ST Bouts Time quartile (min/d)			
Q1 (202.01–354.51)	0 (ref)	0 (ref)	0 (ref)
Q2 (354.52–398.41)	1.51 (−7.55, 10.57)	1.22 (−7.15, 9.60)	3.79 (−4.76, 12.34)
Q3 (398.42–446.27)	**−9.87 (−18.93, −0.81)**	−8.12 (−16.54, 0.30)	**−7.27 (−15.80, 1.25)**
Q4 (446.28–650.81)	**−11.44 (−20.48, −2.41)**	**−11.16 (−19.56, −2.75)**	**−10.54 (−19.20, −1.89)**
P for trend	**<0.01**	**<0.01**	**<0.01**
ST Breaks times (per 10 times/d)	**0.10 (0.01, 0.18)**	**0.09 (0.01, 0.17)**	**0.09 (0.004, 0.17)**
ST Breaks times quartile (times/d)			
Q1 (1,339–2,094)	0 (ref)	0 (ref)	0 (ref)
Q2 (2,095–2,392)	6.73 (−2.43, 15.88)	9.16 (0.77, 17.56)	7.75 (−0.85, 16.36)
Q3 (2,393–2,640)	7.89 (−1.26, 17.05)	7.39 (−1.01, 15.80)	6.49 (−2.17, 15.16)
Q4 (2,641–3,411)	**9.32 (0.19, 18.45)**	**9.30 (0.80, 17.80)**	7.92 (−0.84, 16.69)
P for trend	0.05	0.06	0.11

Model 1: no adjusting.
Model 2: adjusting for age, sex.
Model 3: adjusting for age, sex, father's education, mother's education, household income.
The bold values were statistically significant.

TABLE 3 | The ISM results of MVPA and HPFT (30 min/d).

	HPFT (β, 95% CI)	
MVPA	**Model 1**	**Model 2**
Replace total ST	19.59 (12.35, 26.84)	16.21 (9.35, 23.07)
Replace ST Bouts time	18.47 (11.03, 25.92)	15.59 (8.57, 22.61)

Model 1: adjusting for total behavior time.
Model 2: adjusting for total behavior time, age, sex, father's education, mother's education, household income.

Finally, after adjusting for confounding factors, no non-linear relationship was observed between ST patterns and HPFT.

DISCUSSION

Main Finding

The study aims to explore the relationship between total ST, ST patterns and HPFT in pre-schoolers. We found the total ST and ST Bouts times negatively correlated with HPFT, and ST Breaks times positively correlated with HPFT after adjusted for confounding. Besides, HPFT increased significantly when 30-min MVPA replaced total ST and ST Bouts time in ISM.

Comparison With Similar Research

This study showed a negative correlation between total ST, ST Bouts time and HPFT, which was consistent with most previous studies. Findings showed that individuals with more ST had a higher risk of central obesity, a higher weight value, and ST was also negatively related to cardiorespiratory fitness (9, 25, 26); and ST Bouts time negatively correlated with health indicator among adolescents (27). However, some studies have not found that the total ST and its change trajectory were related to HPF and body composition in pre-schoolers (28, 29); and results also showed no relationship between total ST and risk of cardiovascular disease, or cardiorespiratory fitness in children and adolescents (30, 31). The reasons for inconsistent results may be as follows: (1) Different tools were used to measure ST. Questionnaires, parental reports (8) or objective accelerometer (7, 29) were used in studies. Findings showed a big difference between subjective and objective ST, and the time measured by objective tools was closer to the actual value (32). (2) The parameter settings are different when measuring ST. The rules for including data, such as valid days were used at least 3 days (8) or 1 day (33) in different studies. (3) Participants accumulated different total ST in studies. The total ST of pre-schoolers may not reach the threshold that could affect the relationship between itself and HPFT in some studies (7, 28). Thus, given the possible shortcomings of previous studies, we choose the accelerometer to measure the total ST and selected valid data for at least 3 days in the final statistical analysis, to ensure the measured value was closer to participants' actual state. Furthermore, this study further analyzed and found a significant negative correlation between ST Bouts time and HPFT in Pre-schoolers, thus further revealing the relationship between different ST patterns and HPFT.

In addition, our results were consistent with previous studies that the more ST Breaks times, the higher HPFT in pre-schoolers.

Some scholars had proposed increasing ST Breaks times as a method to change people's long-term sitting position, and to prevent health problems caused by ST a long time ago (34). Studies have found that ST Breaks positively impacted the health in children and adolescents (35). Even a simple standing interrupting behavior could induce beneficial metabolic changes, such as making insulin, total cholesterol content and fast blood sugar in an inevitable decline (36). Besides, findings were also observed that ST Breaks times could significantly improve the body's glucose metabolism with no increase in total energy intake among overweight and obese children (37), and positively reduce postprandial hypoglycemia and insulin responses among adults (38). The result seems to provide an effective way to improve the overweight state of children and adolescents. According to the positive correlation between ST Breaks times and HPFT, we conjecture that ST Breaks times may be related to PA. Pre-schoolers may improve HPF by performing PA during the ST Breaks. So far, most of the previous studies which identified the relationship between ST patterns and HPFT focused on children or adolescents (13, 14, 23). Obviously, findings of this study provide additional evidence to this research field.

Otherwise, we used the ISM to explore whether PA can attenuate the antagonistic relation between ST and HPFT. Results showed that the HPFT of pre-schoolers significantly increased when 30-min MVPA replaced total ST and ST Bouts time. It was also in line with our initial hypothesis and consistent with studies on adolescents (39). Does replacing the ST with any intensity of PA have such an effect? We found no similar change when replacing 30-min ST with LPA as with MVPA. In previous studies, the ISM was rarely used to explore the relationship among PA, ST and physical fitness in pre-schoolers. Our findings showed that the relationship between MVPA and HPFT was closer than that between LPA and HPFT. It indicated that accumulating more MVPA might be an appropriate way to improve physical fitness, which was consistent with the recommendation of at least 60 min per day of MVPA in pre-schoolers (11, 12). Unfortunately, only a small percentage of pre-schoolers met the age-specific recommendations of PA. For instance, only 13.7% of pre-schoolers reached at least 60 min per day of MVPA recommendation in a Canadian study (40). Moreover, a meta-analysis covered 6,309 pre-schoolers (from 29 articles in 7 countries) reported that the average daily MVPA was only 42.8 min (95% CI: 28.9–56.8) (41). In short, this study comprehensively considers the relationship between total ST, ST patterns and HPF in pre-schoolers. Results provide support for improving the HPF of pre-schoolers by controlling ST.

Strengths and Limitations

There are some advantages in this study: (1) The study includes total ST and ST patterns, which show the relationship between the variables more realistically; (2) The study is carried out in the pre-schoolers, enriched research evidence of different populations; (3) The study combines multiple linear regression with the ISM to explore the relationship, made the results more reliable. There are also some limitations: (1) The participants are regional and the results cannot represent that in other ethnic, regional populations; (2) The study is cross-sectional research, which can only reflect the relationship between ST and pre-schoolers at the time point, cannot explain the cause and effect relationship; (3) The accelerometer fails to distinguish the posture of the participants' ST, and this is a restriction in monitoring the upper limb activities, but the accelerometer is the most accurate and standard tool to measure ST at present.

Recommendations for Future Research

We suggest more detailed ST patterns research can be carried out in future, for example, (1) Dividing ST Bouts time into different phases (1–10 min, >10 min); (2) Carrying out more longitudinal and experimental studies to explore the cause and effect relationship between ST patterns and HPFT; (3) Considering the interaction of ST, PA and sleep on health indicators and optimal time allocation plan.

CONCLUSIONS

Total ST, ST Bouts times negatively correlated with HPF, and ST Breaks times positively correlated with HPF in pre-schoolers. Besides, HPF significantly improved when MVPA replaced ST. We should decrease the ST and increase ST Breaks times to promote good physical development in pre-schoolers.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Review Committee of Shanghai University of Sport (2015028, 2017023). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

MQ, YLu, TZ, MS, LL, CF, and WH: substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data. YLu, YLi, and MQ: drafting the article or revising it critically for important intellectual content. All authors: final approval of the version to be published.

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Physical Activity and Executive Function in Children With ADHD: The Mediating Role of Sleep

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This study examined the mediating role of sleep in the relationship between physical activity and executive function in children with attention deficit hyperactivity disorder (ADHD). Fifty-six children with ADHD were recruited from Shenzhen Children's Hospital. Participants wore an accelerometer for seven consecutive days to measure physical activity and sleep quality. Activity counts were analyzed to measure moderate-to-vigorous physical activity (MVPA). Four sleep parameters, including sleep latency (SL), sleep efficiency, total sleep time, and wake after sleep onset were recorded from the actigraph. Three core executive functions, inhibitory control; working memory (WM); and cognitive flexibility (CF), were assessed from computer-based tasks: the flanker task, and the Tower of London and Trail Making Tests, respectively. The regression results showed that MVPA was negatively associated with SL (−0.169; 95%CI [−0.244, −0.112]). WM (total scores) was positively related to MVPA (0.028, 95%CI [0.008, 0.048]), but negatively related to SL (−0.105, 95%CI [−0.167, −0.030]). CF (part B errors) was negatively associated with MVPA (−0.031, 95%CI [−0.055, −0.005]) and positively correlated with SL (0.184, 95%CI [0.092, −0.260]). The indirect effect of SL was found for MVPA and WM (0.018, 95%CI [0.015, 0.034]), supporting the indirect partial mediation. Similarly, the indirect effect of SL was found between MVPA and CF (−0.031, 95%CI [−0.060, −0.012]), supporting the indirect partial mediation. The mediating role of SL in children with ADHD suggests that the intensity of physical activity plays a key role in linking sleep quality and executive function in this group.

Keywords: ADHD, physical activity, sleep quality, executive functions (EF), children

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INTRODUCTION

Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental condition, commonly diagnosed in childhood (1), with a global prevalence of 7.2% among children and adolescents (2). ADHD is generally characterized by age-inappropriate behaviors, including inattention, hyperactivity, and/or impulsivity (3). Disorder-related symptoms are associated with different levels of problems, including physical inactivity (4), executive dysfunction (5) and sleep problems (6).

Executive functions (EFs) are a set of cognitive skills that are involved in top-down control processes used in planning, organizing, and monitoring complex, goal-directed behaviors (7). EFs distinguish between three core functions [inhibitory control (IC), working memory (WM), and cognitive flexibility (CF)] and higher-level functions (e.g., reasoning, planning, and problem-solving) (8). EF skills are indispensable for all ages, including the school performance of children and adolescents (8), sleep duration and quality (9, 10), and physical and mental health (11). Moreover, EF is a higher-order cognitive function (12) that contributes to successful learning in school, management of stress-related activities, and inhibition of inappropriate behaviors in the daily lives of children with ADHD (13).

Physical activity (PA) has emerged as a promising compensation method that can positively affect cognitive function from early childhood (14) to adulthood (15) and can be used to reduce the risk of age-related cognitive decline (16). Studies have documented that for children and adolescents, enhanced cognitive functioning resulting from PA was most clearly seen in EFs (7, 17). Furthermore, preliminary evidence suggests that participation in regular PA is associated with reduced severity of ADHD symptoms (18), the development of motor proficiency (19) and improved sleep problems (20). These documented beneficial effects may be due to improved EFs that are in turn due to PA engagement (7, 21). However, there is still limited understanding of the mechanisms by which PA exerts its effects on human cognition (22), especially with children with neurodevelopmental disorders (e.g., ADHD and autism spectrum disorder).

Among the numerous potential mechanisms for the relationship between PA and cognition, sleep has been proposed as one possible mechanism (23). Participation in regular PA and exercise may facilitate sleep regulation, and sleep can lead to enhanced cognitive functioning. Sleep is an essential health indicator for children (24). Another study found a positive relationship between sleep patterns and PA levels (25). These findings, however, are generally observed in individuals who do not have disabilities and are not at risk of sleep problems. Seventy percent of children with ADHD experience sleep problems frequently, including bedtime resistance, night waking, and daytime sleepiness (26–28). Indeed, sleep problems may exacerbate existing ADHD symptoms, academic impairment, and adverse effects on health-related quality of life for children with ADHD and their families (29, 30). Poor sleep (e.g., short total sleep time) has been associated with poorer WM in young adults without disabilities (10) and parent-reported sleep problems (bedtime resistance) have been associated with poorer WM in children with ADHD (31).

PA and sleep are positively related to cognition, especially in EFs (17). One recent review found that chronic exercise interventions with moderate levels of PA promoted EFs in children and adolescents with ADHD (32). However, it is unclear if there are mechanisms (e.g., mediators) linking PA and EFs among ADHD populations, especially children. Scant attention has been paid to the role of sleep in understanding cognitive performance (e.g., IC, WM, and CF) and the relationships among PA, sleep, and EFs in children with ADHD. Given the known positive relationships among PA, sleep, and WM (10, 25), this study expected that (i) PA would be positively associated with sleep quality; (ii) sleep quality would, in turn, be positively linked with EFs; and (iii) sleep quality would mediate the relationship between PA and domains of EFs. The proposed model is illustrated in **Figure 1**.

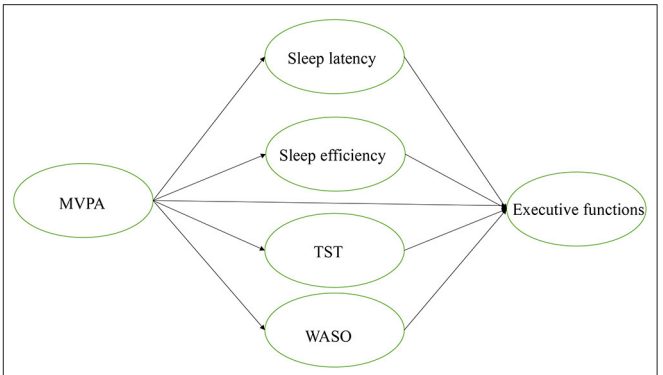

FIGURE 1 | Hypothesized model. MVPA, moderate to vigorous physical activity, TST, total sleep time; WASO, waking after sleep onset.

MATERIALS AND METHODS

Participants

Children aged 6–12 years old and diagnosed with ADHD were recruited from local children's hospital. The inclusion criteria was a diagnosis of ADHD by psychiatrists based on the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (3). They had to have a neuropsychiatric interview with their parents by a psychiatrist based on the *Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and lifetime Version* (33, 34). Exclusion criteria were; other comorbid psychiatric or neurological disorders and a full-scale IQ of less than 80, as measured by the *Chinese Wechsler Intelligence Scale for Children, fourth edition* (35). Finally, 56 children (M_{age} = 8.82, SD = 1.49, 84% boys) with ADHD who met all inclusion criteria were included. Written consent was obtained from the children's parents or guardians. This study design complies with the Declaration of Helsinki ethical standards and was approved by the Survey and Behavioral Research Ethics Committee, The Chinese University of Hong Kong (Reference No. SBRE-19-244).

Study Design and Procedures

This study utilized a cross-sectional design. Participants were instructed to complete three computer-based EF tasks and self-reported questionnaires. Instructions for wearing an actigraphy accelerometer and for filling in a sleep log, assisted by their parents, were provided to participants. Each participant completed all computer tasks individually assisted by trained research assistants; there were practice trials for each task to ensure that the instructions were understood by the participants. To determine body mass index (BMI), participants' height and weight were measured after the tasks.

PA Measures

Objectively Measured PA (Actigraph GTX3)

Children's PA levels were assessed using accelerometry (GT3X model; ActiGraph, Pensacola, FL), an objective and widely used PA measure with children with ADHD (36–38). All participants were asked to wear the accelerometer around the non-dominant wrist for seven consecutive days (5 weekdays and 2 weekend days), follow their daily routines and remove the accelerometer only for bathing or swimming. Activity counts were analyzed to determine step counts per minute, the proportion of time spent in moderate-to-vigorous PA (MVPA).

Cognitive Tasks

EFs were assessed through the following cognitive tasks. All three computer tasks were validated for assessing EFs in children with ADHD summarized by previous review (32). These instruments were administered *via Inquisit Lab*^{TM} *5* (Millisecond Software, Inc., Seattle, WA, USA).

Flanker Task

IC was measured using a computer-based Eriksen flanker task (39). In the task, target stimuli are arrows pointing to the right or the left, presented at the center of the screen. The target arrow's direction indicates whether the child needs to press the left or the right response button. Two distracters surround the target stimulus on both sides (left and right). Two trial types were used: congruent and incongruent. Participants were asked to respond to a central arrow's direction in either congruent or incongruent trials as quickly and as accurately as possible. In a congruent trial, the target arrow was flanked by arrows pointing in the same direction as the target, whereas in incongruent trials, the flankers pointed in the opposite direction. Each participant was engaged in the experiment for ∼5 mins. The outcome measures of task performance were reaction-time and response-accuracy in congruent and incongruent conditions. Short reaction-time and high response accuracy indicated better IC.

The Tower of London

The Tower of London test was used to assess WM and problem-solving skills (40) through the movement of three different colored balls on three different-sized pegs. Each participant was required to rearrange the three colored balls (red, blue, and green) to match a target picture shown on the screen. Before the practice trial, each participant was informed that only one ball could be moved at a time and that the underneath ball could not be moved if another ball was on top of it. The goal of the test is that the colored balls should be positioned using a minimum number of moves to achieve the target position. Participants were allowed to reset a round of the game if they realized making a mistake. This task consisted of 12 trials and progressed from easier trials (could be completed with a minimum of two moves) to more difficult trials (could be completed with a minimum of five moves). Total score, defined as the sum of the individual problem scores, was recorded; the maximum achievable score was 36.

Trail Making Test

CF was measured using a computer-based Trail Making Test (41). This test was performed in two parts: part A (numbers only) and part B (letters and numbers), with each part including a trial. Before each trial, each participant was instructed to complete part A by connecting numbers in order (e.g., 1, 2, 3) to 25, and to finish part B by connecting each number to the corresponding letter in numerical and alphabetical order (e.g., 1-A-2-B-3-C, etc.) to 13, using the mouse. The Trail Making Test performance was recorded by errors and the total completion time in part A and part B, respectively. A shorter total completion time and fewer errors indicated a better performance.

Sleep Measures

Objectively Measured Sleep Quality

Four sleep parameters, including sleep latency (SL, length of time in minutes to fall asleep), sleep efficiency (SE, the percentage of actual sleep time divided by the time between sleep onset and sleep offset), total sleep time (TST, actual sleep time), and wake after sleep onset (WASO, length of wake time in minutes between sleep onset and sleep offset) were measured using an actigraph accelerometer and a sleep-log book. Participants' parents were asked to record the sleep onset, sleep offset, and total sleep length in a sleep log during assessment week. The accelerometer has been widely used to measure sleep in children with and without ADHD (38). The Sadeh algorithm (42), the most commonly used algorithm for sleep–wake scoring in children, was implemented to identify sleep onset and sleep offset (43).

Statistical Analysis

Descriptive statistics were calculated to characterize the sample, regarding information on participants' gender, age, BMI, and ADHD symptoms. Skewness and Kurtosis tests were performed to assess if the data were normally distributed. Bivariate correlations among the variables were calculated Using Mplus (version 7.0), a path analysis with a maximum likelihood estimation was conducted to explore the overall direct and indirect relationships among the variables. A bootstrapping method was used for estimating direct and indirect effects with multiple mediators (SL, SE, TST, and WASO) in which the effects of PA on EFs were mediated through four mediators. All statistical tests were two-tailed, and significance was set at $p < 0.05$. A 5,000-bootstrapping method was used to test the significance of the total and indirect effects. The 95% confidence intervals for the coefficients calculated by bootstrapping methods were considered statistically significant if the confidence intervals did not include zero.

RESULTS

Participant Characteristics

Of the 59 participants, 3 were excluded from analysis due to: (1) missing accelerometer data ($n = 1$) or (2) having fewer than five valid days (four weekdays and one weekend day) of accelerometer data ($n = 2$). Of the remaining 56 participants (9 girls; 47 boys), 25 were diagnosed with ADHD-I (inattention), 7 with ADHD-H (hyperactivity), and 24 with ADHD-C (combined)(**Table 1**).

TABLE 1 | Demographic and physical characteristics of the participants ($n = 56$).

Characteristics	Mean(±SD)/N (%)
Gender	47 boys (83.9%), 9 girls (16.1%)
Age (years)	8.82 (± 1.49)
Weight (kg)	30.79 (± 10.13)
Height (cm)	132.86 (± 11.40)
BMI (kg/m^2)	17.01 (± 3.15)
Type of ADHD	ADHD-H 7 (12.5%) ADHD-I 25 (44.6%) ADHD-C 24 (42.9%)

BMI, body mass index; ADHD-H, attention-deficit hyperactivity disorder-hyperactivity; ADHD-I, attention-deficit hyperactivity disorder-inattention; ADHD-C, attention-deficit hyperactivity disorder-combined.

Preliminary Analysis

As shown in **Table 2**, MVPA was negatively correlated with the sleep latency, positively correlated with working memory (total scores), and negatively related with errors of cognitive flexibility. Regrading the sleep quality, the sleep latency was negatively related to the working memory (total scores), and positively related to errors of cognitive flexibility. All significant levels reached at $p < 0.05$.

Path Analysis

The hypothesized model (**Figure 1**) was tested to examine the direct relationships among MVPA, sleep quality (SL, SE, TST, and WASO), and Efs (IC, WM, and CF). The mediating role of sleep quality in MVPA and EF was also investigated.

The regression results showed that MVPA was associated with WM and CF *via* the mediation of SL. Specifically, MVPA was negatively associated with SL (−0.169; 95%CI [−0.244, −0.112]). WM (total scores) was positively related to MVPA (0.028, 95%CI [0.008, 0.048]) but negatively related to SL (−0.105, 95%CI [−0.167, −0.030]). CF (part B errors) was negatively associated with MVPA (−0.031, 95%CI [−0.055, −0.005]) and positively correlated with SL (0.184, 95%CI [0.092, −0.260]). The regression results for testing mediation were showed in **Figure 2**. These results support that sleep latency partial mediated the association between MVPA and WM (indirect effect = 0.018, $SE = 0.009$, 95%CI [0.002, 0.038]). Similarly, the indirect effect of SL was revealed in the link between MVPA and CF (part B errors) (indirect effect = −0.031, $SE = 0.014$, 95%CI [−0.065, −0.008]), supporting the indirect partial mediation. The mediating effect of sleep quality between MVPA and IC was not supported (**Figure 2**).

DISCUSSION

We examined the relationships between MVPA and EFs to better understand the mediating role of sleep quality on MVPA and EFs among children with ADHD. We observed that with greater amounts of MVPA during the daytime, participants' SL decreased. This is a novel finding, as previous studies have shown that increasing PA may promote sleep quality (44) and that high PA levels would be expected to show healthy sleep

TABLE 2 | Correlations among MVPA, sleep quality, and executive functions.

	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. MVPA (mins)	87.34	38.25	–													
2. SL (mins)	20.29	12.34	−0.53**	–												
3. SE (%)	78.62	0.06	−0.40	−0.143	–											
4. TST (mins)	408.03	30.66	−0.13	0.07	0.75**	–										
5. WASO (mins)	92.98	38.00	0.20	−0.17	−0.94**	−0.68**	–									
6. C-ACC (%)	0.975	0.058	−0.01	−0.03	−0.09	−0.03	0.10	–								
7. IC-ACC (%)	0.933	0.148	−0.10	0.12	−0.21	−0.07	0.18	0.66**	–							
8. C-RT (sec)	853.98	370.27	−0.04	−0.09	0.02	0.05	0.02	−0.09	−0.30*	–						
9. IC-RT (Sec)	1,046.29	502.35	−0.03	−0.05	−0.003	−0.05	0.007	−0.28*	−0.39*	0.86*	–					
10. WM (total)	27.82	3.40	0.48**	−0.53**	−0.05	−0.23	0.19	−0.04	−0.08	−0.02	0.03	–				
11. CF-error A	2.16	2.14	0.12	0.07	−0.03	−0.03	0.005	−0.19	−0.18	0.31*	0.35**	−0.20	–			
12. CF-CTA (sec)	134,526.35	56,382.68	0.06	0.12	−0.17	−0.11	0.13	−0.13	−0.22	0.52**	0.57**	−0.03	0.59**	–		
13. CF-error B	5.22	4.58	−0.52**	0.63**	0.05	0.20	−0.22	−0.20	−0.21	0.15	0.20	−0.50**	0.09	0.27*	–	
14. CF-CTB (sec)	222,304.38	11,2997.68	−0.03	0.11	−0.13	0.003	0.12	−0.10	−0.22	0.54**	0.54**	−0.14	0.35**	0.70**	0.47**	–

$^*p < 0.05$ and $^{**}p < 0.01$. MVPA, moderate-to-vigorous physical activity; SL, sleep latency; SE, sleep efficiency; TST, total sleep time; C-ACC, accuracy rate in the congruent condition; IC-ACC, accuracy rate in the incongruent condition; C-RT, reaction time in the congruent condition; IC-RT, reaction time in the incongruent condition; WM, total scores of working memory; CF-error A, errors of part A of cognitive flexibility; CF-CTA, completion time of part A of cognitive flexibility; CF-error B, errors of part B in the cognitive flexibility; CF-CTB, completion time of part B of cognitive flexibility.

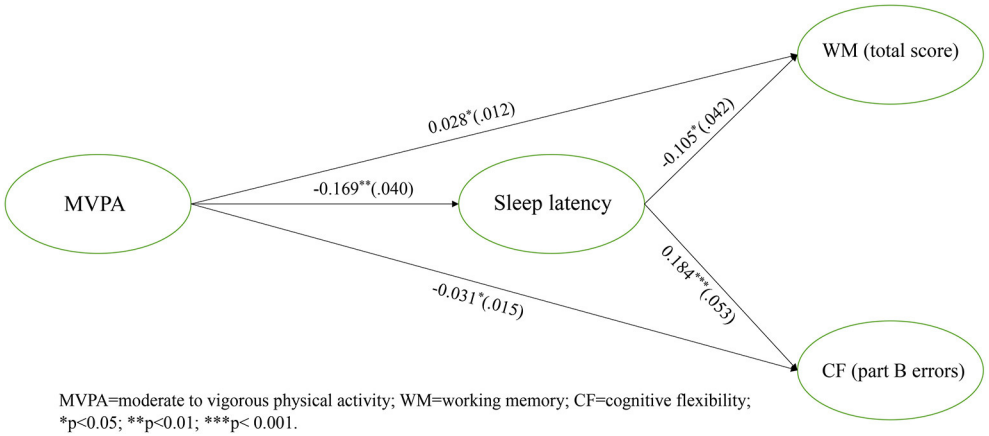

FIGURE 2 | Final model with significant standardized estimates and standard errors. MVPA, moderate to vigorous physical activity; WM, working memory; CF, cognitive flexibility; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

patterns (45). However, these findings were based on typically-developing children without sleep problems. Using the objective measurement of sleep quality and PA, our results extend the understanding about previous analysis of healthy children and focus more on PA intensity in children with ADHD. The latest *WHO Guidelines on Physical Activity and Sedentary Behaviors* recommend that children and adolescents with disabilities should engage in at least 60 mins of MVPA daily, primarily aerobic PA, throughout the week (46). A previous study also indicated that higher daytime activity is associated with shorter SL. More specifically, vigorous PA was significantly related to a decrease in SL (47). Prior review studies also found that the level of daytime exercise was a critical factor influencing the length of SL in children (48). Higher amounts of PA and aerobic exercise have been associated with increased sleep quality ratings (23). Therefore, PA intensity should be considered in designing exercise intervention studies to improve sleep quality in children with ADHD.

Furthermore, SL significantly predicted EF performance in the participants. A longer duration of SL was significantly associated with poorer performance in WM and CF. In contrast, we observed no predictive association between SL and inhibition. Thus, sleep quality might be a critical contributor to the development of EFs, as reported in previous studies showing that high sleep quality leads to better cognitive performance (22, 49). Another study reported a relationship between longer sleep-onset latency and poorer WM in school-aged children with typical development (50). Similarly, studies focusing on children with ADHD reported that bedtime resistance and sleep-onset delay were associated with poorer WM (31, 51).

Our results also strengthen the association between SL and WM in children with ADHD. Another novel finding was that longer SL duration was significantly related to poorer CF in children with ADHD. Previous studies investigating CF are rare in both children with ADHD and their typically-developing peers (52). This is due to the fact that CF is frequently associated with WM and inhibition in early childhood, but gradually improves until adolescence (53). Furthermore, few studies have investigated the relationship between sleep quality and CF in children with and without ADHD. Only one recent study reported an association between poorer sleep quality and poorer CF performance, as measured by the Stroop test in healthy older adults (54). Cognitive inflexibility was frequently observed in individuals with ADHD; (52, 55) this specific EF domain is related to learning and academic readiness (56), as well as predicted social understanding from middle childhood (57). Therefore, CF is essential for children with ADHD, and appropriate interventions targeting sleep quality and CF should be provided.

This study is the first to report that SL significantly mediates cross-sectional associations between MVPA and WM and CF. These novel findings are consistent with the broad view that poor sleep can have serious consequences on cognition (58) and that this process may be improved by PA (17). To date, only one study has included objectively measured PA, sleep, and cognition in one model to test if sleep quality (SE/TST) can account for the relationship between PA and executive control in young and older adults (17). The results of that study reported that SE, rather than TST, significantly mediated the relationship between PA and WM, switching, verbal fluency, and processing speed (17).

Our findings are consistent with the view that sleep quality changes are linked to both PA and cognition (22). The mechanisms underlying the relationships among PA/exercise, sleep, and cognition are unclear. One possible explanation is that PA stimulates changes in body temperature and produces melatonin before sleep, resulting in later changes in body thermoregulation during sleep cycles (59). The increasing body temperature during exercise promotes higher melatonin production, which decreases sleep onset and improves sleep quality and quantity further (23). Another possible explanation for mechanisms among PA, sleep quality and cognitive functions

may be the cerebral blood flow. PA may boost the cerebral blood flow regulation, resulting in improvement of cognitive processing by a change in cerebral oxygenation during sleep cycles throughout the day (60, 61). One recent study focusing on children with autism reported that acute exercise with MVPA levels of intensity showed a change in cerebral oxygenation and IC (62). This change in cerebral blood pressure may better explain an association between PA and EFs by improved sleep quality (23). Therefore, examining this relationship among PA, sleep, and cognition is critical and has clinical implications. Determining the optimal intervention for exercise may improve sleep health and cognitive development, as well as lead to the discovery of a method to reverse executive dysfunctions in ADHD populations.

The current study benefited from several strengths (e.g., the use of an actigraph to objectively measure PA and sleep and the use of computer tasks to measure Efs). However, several limitations should be acknowledged. First, the sample size was relatively small to detect mediation. The recommended sample size to test a small to moderate mediation effect using the bootstrapping method should include 50–100 participants (22). Second, as this study adopted a cross-sectional design, causal mediation could not be established. Future exercise-intervention studies should be conducted to test the hypotheses used in this study. Third, the sleep-onset and sleep-offset times were determined by the sleep diary recorded by participants' parents. Although the actigraph was valid in measuring PA and sleep, it is possible that the results may have been influenced by an underestimation or overestimation of sleep or PA. Lastly, considering sleep latency, as the only significant mediator in this study, was probably the most vulnerable indicator affected by core ADHD symptoms (inattention and hyperactivity) compared to other sleep metrics (e.g., sleep efficiency, total sleep time). The potential confounding role of ADHD symptom severity might mediate the effects of MVPA on EF through sleep latency. However, considering the unbalanced distribution of ADHD subtypes underlying this disorder, it is difficult to conduct subgroup analysis to detect whether the effects are robust for specific subgroups.

CONCLUSION

SL was found to mediate statistically the significant relationships between MVPA and two core aspects of EF (WM and CF). This mediating role of SL was observed in children with ADHD, suggesting that the intensity of PA plays a key role in linking sleep quality and EF in children with ADHD. Exercise interventions with higher levels of intensities (e.g., MVPA) should be provided for children with ADHD to improve sleep quality and EFs.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Survey and Behavioral Research Ethics Committee, the Chinese University of Hong Kong (Reference No. SBRE-19-244). This study design complies with the Declaration of Helsinki ethical standards. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

XL and CS were responsible for the conceptualization, investigation, and hypothesis of the research. XL and RL conducted the data collection and completed all statistical analyses. CS, SW, RS, PW, and BY reviewed and edited initial draft and its revisions. All authors read and approved the final manuscript.

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Influence of Geographical Area and Living Setting on Children's Weight Status, Motor Coordination, and Physical Activity

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This study was aimed (i) to examine the effect of living setting (rural vs. urban), geographical area (North vs. Center vs. South), and gender (boys vs. girls) on weight status, motor coordination, and physical activity (PA) level of Italian school-age children; (ii) to examine differences in the neighborhood walkability of different school areas from different geographical areas and living settings; and (iii) to examine whether motor coordination, PA level, geographical areas, living setting, neighborhood walkability, and gender could predict children's weight status. We assessed anthropometric parameters, gross motor coordination, and PA level in 1,549 children aged between 8 and 13 years. Results revealed that Central children had higher BMI than Northern and Southern children ($\eta^2 = 0.01$). Moreover, Northern children showed the highest motor quotient ($\eta^2 = 0.148$) and PA level ($\eta^2 = 0.02$), followed by Southern and Central children, respectively. Children from the South of Italy attended schools located in neighborhoods with the highest Walk Score®. Urban children attended schools located in neighborhoods with a higher Walk Score® than rural children. Lower motor quotient (MQ), lower PA level, and living in a rural setting and in a car-dependent neighborhood were associated with a higher relative risk for obesity. Being a girl was associated with a lower relative risk for obesity. The alarming high percentage of overweight and obesity in children as well as motor coordination impairments revealed the urgent need of targeted PA interventions in pediatric population.

Keywords: overweight, obesity, movement skills, gender, geographical area, living setting, health cities

INTRODUCTION

The prevalence of overweight and obesity in childhood is increasing at an alarming rate worldwide, particularly in industrialized countries. The excess of body weight is strongly correlated with sedentary lifestyles and therefore is related to low levels of motor competence (1, 2). It can be defined as mastery in fundamental movement skills such as walking, running, or jumping and in more specialized movement sequences such as lifelong physical activity abilities like cycling, swimming, or sport-specific skills, and it describes the ability to perform both gross and fine motor skills (3). Studies reported a substantial decline in children's motor competence over the last 4 decades due to the decline of physical activity (PA) and the increase of sedentary behaviors (4). Interestingly, recent studies conducted on Italian populations report that more than 30% of Italian children are affected by overweight or obesity (5, 6), 18% are sedentary, while 41% perform more than 2 h of screen activities a day. Sallis and Glanz identified several environmental and demographic variables affecting children's PA level and obesity (7). Urban and rural settings appear as important conditioning factors for participation in PA and for the development of fitness and coordination (8). Studies have been conducted to identify the association between the PA of children and adolescents and the setting in which they live (7, 9). The ease of access to safe and outdoor sites promotes PA in children, who therefore improve their physical fitness and coordinative abilities (1, 10). Contrarily, the lack of sidewalks and recreational facilities, the absence of ease of access to schools, the need to cross busy streets, traffic congestion, and air pollution discourage children from playing outside or from walking and biking to school (7, 10, 11), favoring an obesogenic environment (12). Therefore, PA, obesity levels, and the associated motor competence during childhood, might correlate with the level of urbanization. Recent studies investigated the influence of the living setting on anthropometric parameters, PA level, and motor competence in children, with inconsistent and contrasting results (13, 14). No consensus exists concerning a definition of residential areas in terms of urban and rural specificity since most studies define urban and rural setting only on population density (14). Furthermore, obesity in childhood could be influenced by the spatial structure of street networks and by the aspects of the built environment (15) that modify neighborhood walkability and, thus, PA levels (16). The Italian peninsula, mostly within the Apennine mountain range, stretches for about 1,200 km, in NW–SE striking sets leading to many different historical and geographical characteristics that determine significative socio-economic and lifestyle differences among northern, central, and southern regions and, also, between urban and rural settings (17).

Considering the scientific evidence reported, we hypothesized that the geographical area and living setting could influence the weight status, motor coordination, and PA level of Italian school-age children. Therefore, the first aim of the present cross-sectional study was to examine differences in weight status, motor coordination, and PA level between boys and girls from different geographical areas (North vs. Center vs. South) and living settings (rural vs. urban). The second aim was to examine differences in the neighborhood walkability of different school areas from different geographical areas and living settings. Finally, the third aim was to examine whether motor coordination, PA level, geographical areas, living setting, neighborhood walkability, and gender could predict children's weight status.

MATERIALS AND METHODS

Participants

An open invitation to representatives of private and public schools of the Italian geographical areas (North Italy = Veneto and Trentino-Alto Adige; Center Italy = Lazio; South Italy = Sicily) was done, and a total sample of 2,206 schoolchildren were recruited after school principals/administrators had been informed about the whole project and accepted to participate in the study. A final sample of 1,149 schoolchildren aged between 8 and 13 years volunteered to participate in this study and completed all measurements. The population included subjects from 38 different Italian primary and middle schools. The classroom demographics broke down to 391 grade 3 children (8–9 years of age), 362 grade 4 children (9–10 years of age), 351 grade 5 children (10–11 years of age), 234 grade 6 children (11–12 years of age), and 211 grade 7 children (12–13 years of age). The participating schools were enrolled to be broadly representative of Northern, Central, and Southern schools, including the capital city (Rome) and the urban and rural areas, and to have appropriate and similar sports facilities to conduct comparable measurements. The measurements of this study were conducted in the participating schools from January 2019 to February 2020 during the regular school hours and in the respective school gyms.

The University Ethical Committees of the University of Rome (Rif 5500 Prot. 1070/19), of the University of Verona (No. 2019-UNVRCLE-0298910), and of the University of Palermo (No. 8/2019) in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. Additional authorization was provided by school principals/administrators. Written informed consent forms were obtained from parents prior to study participation.

Anthropometric Measurements

As for the anthropometric measurements, children's body weight and height were collected. Anthropometric measurements were taken according to the standard procedures described by the International Society for the Advancement of Kinanthropometry (18). Children's body weight and height were measured using a scale and a stadiometer to the nearest 0.5 kg and 0.1 cm, respectively. Subjects wore minimal clothing and were barefoot. Body mass index (BMI) was calculated as weight in kilograms divided by the square of height in meters. All measures were collected by examiners who were trained in the measurement methods of height and weight. Children were classified as underweight (UW), normal weight (NW), overweight (OW), and obese (OB) using age- and gender-specific International Obesity Task Force cut-off points (19).

Gross Motor Coordination Measurement

Gross motor coordination was assessed by the Körperkoordinations Test für Kinder (Body Coordination Test for Children, referred to as KTK) battery (20), consisting of the following subtests:

- walking backward three times along each of three balance beams (3-m length; 6-, 4.5-, and 3-cm width, respectively; 5-cm height). A maximum of 24 steps (eight per trail) were counted for each balance beam, yielding to a maximum of 72 steps (24 steps × 3 beams) for this test.
- moving across the floor in 20 s by stepping from one plate (25 × 25 × 5.7 cm) to the next, transferring the first plate, stepping on it, etc. The number of relocations was counted and summed over two trials.
- jumping from one leg over an increasing pile of pillows (60 × 20 × 5 cm each) after a short run-up. Three, two, or one point(s) were/was awarded for successful performance on the first, second, third trials, respectively. A maximum of 39 points (ground level + 12 pillows) could be scored for each leg, yielding a possible maximum score of 78.
- jumping laterally as many times as possible over a wooden slat (60 × 4 × 2 cm) in 15 s. The number of jumps over two trials was summed.

The test–retest reliability coefficient for the raw score on the total test battery was reported as 0.97, while corresponding coefficients for individual tests ranged from 0.80 to 0.96. Both factor analysis and inter-correlations indicated acceptable construct validity (20).

The raw test scores from each of the four subtests were then transformed into gender- and age-specific motor quotient (MQ) values, which were based on the performance of 1,228 normally developing German children. Scoring of the KTK test was performed according to the manual (20). MQ is a global indicator of gross motor coordination, and values between 86 and 115 describe the normality (20).

In the present study, children were categorized as "children with MQ impairments" (MQ score $\leq$ 85) or "children with no MQ impairments" (MQ score $\geq$ 86) (20).

Physical Activity Level Measurements

The Italian version of the Physical Activity Questionnaire for Older Children (PAQ-C-It) was adopted to measure the children PA level (21). This instrument is a valid and reliable self-administered, 7-day recall instrument designed to measure general levels of PA in children aged 8–14 years. The questionnaire consists of nine questions about sports and games, physical activities at school, and those during leisure time that a child might have done in the last 7 days, including the weekend. Each question is scored from 1 (low PA) to 5 (high PA), with the final score obtained through the means of the question scores. The final score represents the activity level of the child (21). Three different activity levels were defined according to Chen's specific cut-offs (22): low ($\leq$2), moderate ($>$2 and $\leq$3), and high activity ($>$3) level. For the present study, children were subdivided into "inactive" (PA score $\leq$ 2) or "active" (PA score $>$ 2) (22).

Geographical Area and Living Setting

Three different geographical areas were considered: North, Center, and South of Italy. Moreover, two different settings were considered: urban and rural settings, defined by population density (www.reterurale.it). According to this classification, urban areas have a population density higher than 150 inhabitants/km^2 and rural areas have a population density lower than 150 inhabitants/km^2 (23). Population density was determined according to the most recent data provided by ISTAT (Istituto Nazionale di Statistica, Census, www.istat.it).

Seven hundred and seventy-two children came from the North of Italy (535 urban and 237 rural children), 411 children came from the Center of Italy (181 urban and 230 rural children), and 366 children came from the South of Italy (268 urban and 98 rural children) (**Table 1**).

Northern-urban children comprised pupils attending 14 different schools located in Bolzano, in Verona, and in the provinces of Treviso (Castello di Godego), of Verona (Lugagnano, San Bonifacio, Bovolone, Castelnuovo del Garda, and Mozzecane), of Mantova (San Giorgio Bigarello), and of Padua (Casale di Scodosia), while northern-rural children included pupils attending seven different schools located in the province of Verona (Roverchiara, Casaleone, Minerbe, and Poiano) and of Padua (Castelbaldo, Masi, and Merlara). Central-urban children comprised pupils attending six different schools located in Rome, while central-rural children included pupils attending four different schools located in the province of Rome (Montelibretti, Montorio Romano, Monteflavio, and Nerola).

Southern-urban children included pupils attending six different schools located in Palermo and in the province of Palermo (Villabate), while southern-rural children included pupils attending one school in the province of Messina (Mistretta).

Neighborhood Walkability of School Areas

Walkability measurements of the different school areas were collected using the free open software Walk Score® (WS; www.walkscore.com). Walk Score® is a valid measure of estimating neighborhood walkability in many geographic locations (24). Each child's school address was manually entered into Walk Score®, and from here the walkability of the different school areas was analyzed. For each address, Walk Score® calculates all the different walking routes to nearby amenities (public transit stations, grocery stores, retail stores, parks, schools) producing, through an algorithm, a score ranging from 0 to 100. A score of 100 is assigned to districts that have amenities within a 5-min walk (400 m), whereas areas with more distant amenities report a lower score, with a 0 score given after a 30-min address-amenities walking (when the amenities are more distant than 1 mile).

In the present study, the different school areas were categorized as "walkable area" (50–100 scores) or "car-dependent area" (0–49 scores) (www.walkscore.com).

Statistical Analysis

General characteristics of the total group and for boys and girls as well as for urban and rural residents and for Northern, Central,

TABLE 1 | Characteristics of the subjects by geographical area, living setting, and gender (n = 1,549).

	North (n = 772)				Center (n = 411)				South (n = 366)			
	Rural (n = 237)		Urban (n = 535)		Rural (n = 230)		Urban (n = 181)		Rural (n= 98)		Urban (n = 268)	
	Boys (125)	Girls (112)	Boys (270)	Girls (265)	Boys (130)	Girls (100)	Boys (97)	Girls (84)	Boys (54)	Girls (44)	Boys (143)	Girls (125)
Age (years)	10.9 ± 1.4	10.4 ± 1.4	10.4 ± 1.6	10.4 ± 1.7	9.5 ± 1.0	9.4 ± 0.9	10.7 ± 1.3	10.5 ± 1.2	10.5 ± 1.3	10.2 ± 1.0	10.3 ± 1.4	10.2 ± 1.4
Weight (kg)	40.2 ± 9.8	39.3 ± 9.6	37.9 ± 9.9	36.8 ± 10.8	37.9 ± 10.2	37.3 ± 11.2	40.9 ± 11.1	39.2 ± 11.6	40.2 ± 11.6	35.6 ± 7.4	39.5 ± 11.6	38.5 ± 10.4
Height (cm)	145.1 ± 10.1	141.3 ± 9.2	143.4 ± 11.2	141.6 ± 12.1	138.4 ± 7.3	137.1 ± 9.0	144.1 ± 11.0	142.5 ± 11.0	146.5 ± 10.3	143.8 ± 7.8	144.4 ± 11.0	143.0 ± 10.2
BMI (kg/m^2)	19.0 ± 3.3	19.5 ± 3.7	18.2 ± 3.0	18.0 ± 3.2	19.6 ± 4.2	19.5 ± 4.2	19.4 ± 3.2	19.0 ± 3.9	18.5 ± 4.0	17.2 ± 3.1	18.6 ± 3.6	18.6 ± 3.4
MQ (scores)	96.1 ± 16.0	92.4 ± 13.6	92.8 ± 15.6	86.9 ± 15.5	82.1 ± 11.8	76.2 ± 12.5	78.6 ± 13.8	76.5 ± 13.1	81.8 ± 13.9	70.6 ± 11.8	86.1 ± 17.0	81.0 ± 14.8
PA level (scores)	2.7 ± 0.6	2.6 ± 0.4	2.6 ± 0.5	2.6 ± 0.4	2.4 ± 0.7	2.0 ± 0.6	2.5 ± 0.9	2.4 ± 0.7	2.6 ± 0.6	2.5 ± 0.6	2.4 ± 0.6	2.3 ± 0.6

Data are expressed as mean ± SD.
BMI, body mass index; MQ, motor quotient; PA, physical activity.

and Southern residents were described by means, standard deviations, and frequencies. The chi-square test was used to compare the frequencies of variables among groups (gender, geographical area, and living setting). The chi-square test was also used to compare the frequencies of children attending schools located in walkable and "car-dependent" areas between groups (gender, geographical area, and living setting).

ANOVA was performed to examine differences and interactions on BMI (kg/m^2), MQ (scores), and PA levels (scores) between boys and girls from different geographical areas and living settings.

ANOVA was also performed to examine differences in neighborhood walkability (Walk Score®) of different school areas from different geographical areas and living settings. These analyses were followed by *post-hoc* analysis (Bonferroni adjustment) when significant main effects or interactions were observed. Effect size was also calculated using Cohen's definition of small, medium, and large effect size (as partial $\eta^2 = 0.01, 0.06, 0.14$, respectively) (25).

A multinomial logistic regression analysis was used to assess whether MQ (scores), PA level (scores), geographical area (North vs. Center vs. South), living setting (rural vs. urban), walkability ("car-dependent area" vs. "walkable area"), and gender (boys vs. girls) predicted BMI categories. Underweight and normal weight children were combined as "NW_UW category," which was set as the reference group. Geographical area, living setting, walkability, and gender were added as factors, MQ and PA level were included in the analyses as covariates. All variables were tested in the same model, controlling the effect of each other. Statistical significance was set at $p \leq 0.05$, and all analyses were performed using IBM SPSS statistics version 25.

RESULTS

Characteristics of the Population

Characteristics of the subjects by gender, geographical area, and living setting are shown in **Table 1**.

Globally, the results demonstrated that the prevalence of overweight and obesity was 22.0% (n = 303 children) and 9.9% (n = 136 children), respectively (sample n = 1,377). Within the overweight category, 171 children were boys (56.4%) and 132 were girls (43.6%); 122 were Northern (40.3%), 98 were Central (32.3%), and 83 were Southern (27.4%) children; and 115 were rural (38.0%) and 188 were urban (62.0%) children. Within the obesity category, 70 children were boys (51.5%) and 66 girls (48.5%); 43 were Northern (31.6%), 65 were Central (47.8%), and 28 were Southern (20.6%) children; and 76 were rural (55.9%) and 60 were urban (44.1%) children. The chi-square test detected that the proportion of OW_OB children was different between the three geographical regions (North 27.1% vs. Center 39.9% vs. South 30.8%, $p < 0.001$) and the two living settings (rural 37.2% vs. urban 28.7%, $p = 0.001$).

Regarding gross motor coordination, 47.9% of the total sample (n = 1,549) showed MQ impairments (n = 742). Of these children, 352 were boys (47.4%) and 390 were girls (52.6%). Moreover, 259 were Northern (34.9%), 274 were Central (36.9%), and 209 were Southern (28.2%) children; 272 were rural (36.7%)

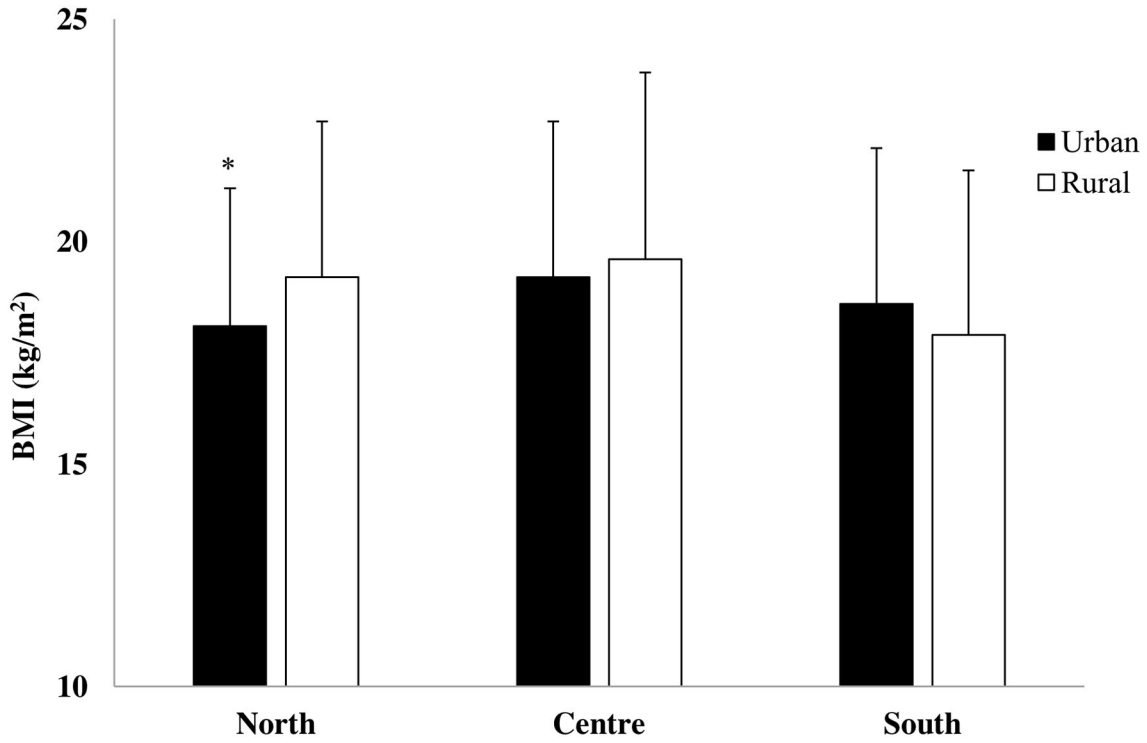

FIGURE 1 | Body mass index (BMI) in urban and rural children of the North, Center, and South of Italy (*$p = 0.0001$ urban vs. rural).

and 470 were urban (63.3%) children. The chi-square test revealed that the proportion of children with MQ impairments was different among the three geographical regions (North 33.5% vs. Center 66.7% vs. South 57.1%, $p < 0.001$). In addition, there was a higher proportion of MQ impairments in girls than in boys (53.4 vs. 43.0%, respectively, <0.001).

Regarding PA level, 29.0% of the children ($n = 793$) were inactive ($n = 230$): 106 were boys (46.1%) and 124 were girls (53.9 %); 14 were Northern (6.1%), 116 were Central (50.4%), and 100 were Southern (43.5%) children; and 114 were rural (49.6%) and 116 were urban (50.4%) children. The chi-square test detected that the proportion of inactive children was different between the three geographical regions (North 9.6% vs. Center 38.0% vs. South 29.3%, $p < 0.001$). Furthermore, there was a higher proportion of inactive children in girls than in boys (34.1 vs. 24.8%, respectively, $p = 0.004$).

Finally, the chi-square test revealed that the proportion of children attending schools located in "car-dependent" areas is different among the geographical regions (North 36.9% vs. Center 56.0% vs. South 0%, $p < 0.001$). Moreover, there was a higher proportion of "car-dependent areas" in rural as compared to urban schools (79.8 vs. 6.5%, respectively, $p < 0.001$).

Differences of Gender, Geographical Area, and Living Setting on BMI

Differences for geographical area ($F_{1,1365} = 9.62$, $p < 0.001$, $\eta^2 = 0.01$) revealed that children from Central Italy had higher BMI than Northern and Southern children (19.4 ± 3.9 vs. 18.5 ± 3.3 vs. 18.4 ± 3.5 kg/m^2, respectively).

Interestingly, geographical area x living setting interaction ($F_{2,1365} = 6.51$, $p = 0.002$, $\eta^2 = 0.01$) showed that in the North of Italy, rural children had higher BMI than urban children (**Figure 1**).

Differences of Gender, Geographical Area, and Living Setting on Gross Motor Coordination (MQ)

Differences for gender ($F_{1,1537} = 43.86$, $p < 0.001$, $\eta^2 = 0.03$) revealed that boys had higher MQ than girls (88.0 ± 16.2 vs. 83.1 ± 15.6 scores, respectively).

Differences for geographical area ($F_{2,1537} = 133.14$, $p < 0.001$, $\eta^2 = 0.148$) showed that Northern children had the highest MQ, followed by Southern and Central children (91.3 ± 15.7 vs. 81.8 ± 15.9 vs. 78.7 ± 12.9 scores, respectively).

Geographical area x living setting interaction ($F_{2,1537} = 15.88$, < 0.001, $\eta^2 = 0.02$) showed that in the North of Italy, rural children had a higher MQ than urban children, while in the South of Italy, urban children had a higher MQ than rural children (**Figure 2**).

Differences of Gender, Geographical Area, and Living Setting on PA Level

Differences for gender ($F_{1,780} = 6.03$, $p = 0.014$, $\eta^2 = 0.01$) revealed that boys had a higher PA level than girls (2.5 ± 0.7 vs. 2.3 ± 0.6 scores, respectively).

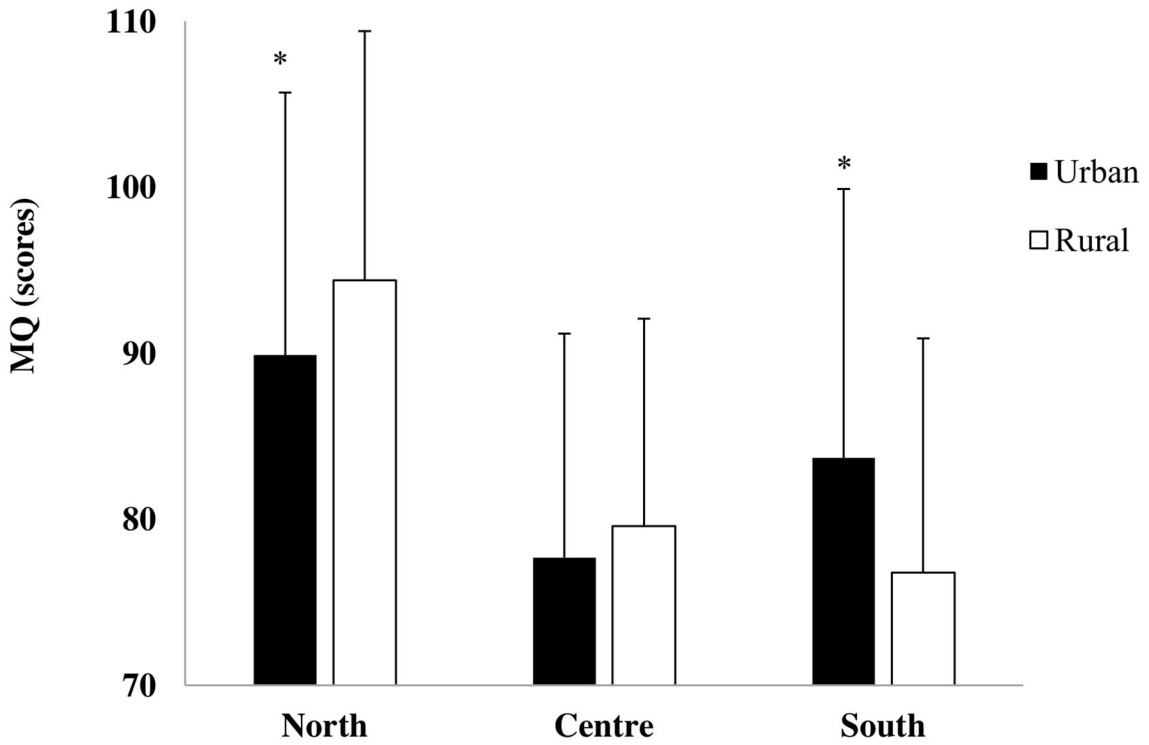

FIGURE 2 | Motor quotient (MQ) in urban and rural children of the North, Center, and South of Italy (*$p = 0.0002$ urban vs. rural).

Differences for geographical area ($F_{2,780} = 7.39$, $p = 0.001$, $\eta^2 = 0.02$) showed that Northern children had the highest PA level, followed by Southern children and then Central children (2.6 ± 0.4 vs. 2.4 ± 0.6 vs. 2.3 ± 0.8 scores, respectively).

Geographical area x living section interaction ($F_{2,780} = 9.12$, $p < 0.001$, $\eta^2 = 0.02$) showed that in the Center of Italy, urban children had a higher PA level than rural children, while in the South of Italy, rural children had a higher PA level than urban children (**Figure 3**).

Differences of Geographical Area and Living Setting on Neighborhood Walkability

Differences for geographical area ($F_{2,1543} = 170.76$, $p < 0.001$, $\eta^2 = 0.18$) revealed that children from the South of Italy attended schools located in neighborhoods with the highest Walk Score®, followed by children from the North and then by children from the Center of Italy (75.7 ± 16.6 vs. 61.6 ± 18.8 vs. 59.4 ± 28.8 score, respectively).

Differences for living setting ($F_{1,1543} = 4{,}304.10$, $p < 0.001$, $\eta^2 = 0.74$) showed that urban children attended schools located in neighborhoods with a higher Walk Score® than rural children (78.4 ± 13.5 vs. 39.9 ± 11.1 score, respectively).

Geographical area x living setting interaction ($F_{1,1543} = 167.68$, $p < 0.001$, $\eta^2 = 0.18$) revealed that in the North, the Center, and the South of Italy, rural children attended schools located in neighborhoods with a lower Walk Score® than urban children (**Figure 4**).

Determinants of BMI Categories

In order to model the relationship between BMI categories and several potential predictors (MQ, PA level, living setting, geographical area, walkability, and gender), a multinomial logistic regression was performed. MQ [$\chi^2_{(2)} = 93.54$, $p < 0.001$], PA level, [$\chi^2_{(2)} = 5.77$, $p = 0.056$], living setting [$\chi^2_{(2)} = 7.19$, $p = 0.027$], gender [$\chi^2_{(2)} = 10.58$, $p = 0.005$], and walkability [$\chi^2_{(2)} = 11.28$, $p = 0.004$] contributed significantly to the model. **Table 2** presents the results of the multinomial logistic regression. Lower MQ was associated with a higher risk for being affected by overweight and obesity. Lower PA level was associated with a higher risk for being obese, and girls showed a lower risk for being obese. Interestingly, living in a rural setting was associated with a higher risk for overweight and obesity and living in a "car-dependent" area was associated with a higher risk for obesity. Finally, living in North, Center, or South of Italy did not predict the BMI categories.

DISCUSSION

The first aim of the present study was to examine differences in weight status, motor coordination, and PA level between boys and girls from different geographical areas and living settings. The hypothesis we formulated was confirmed because our findings showed that children from the Center of Italy had a higher BMI than their peers from the North and the South, revealing the higher proportion of overweight and obese children

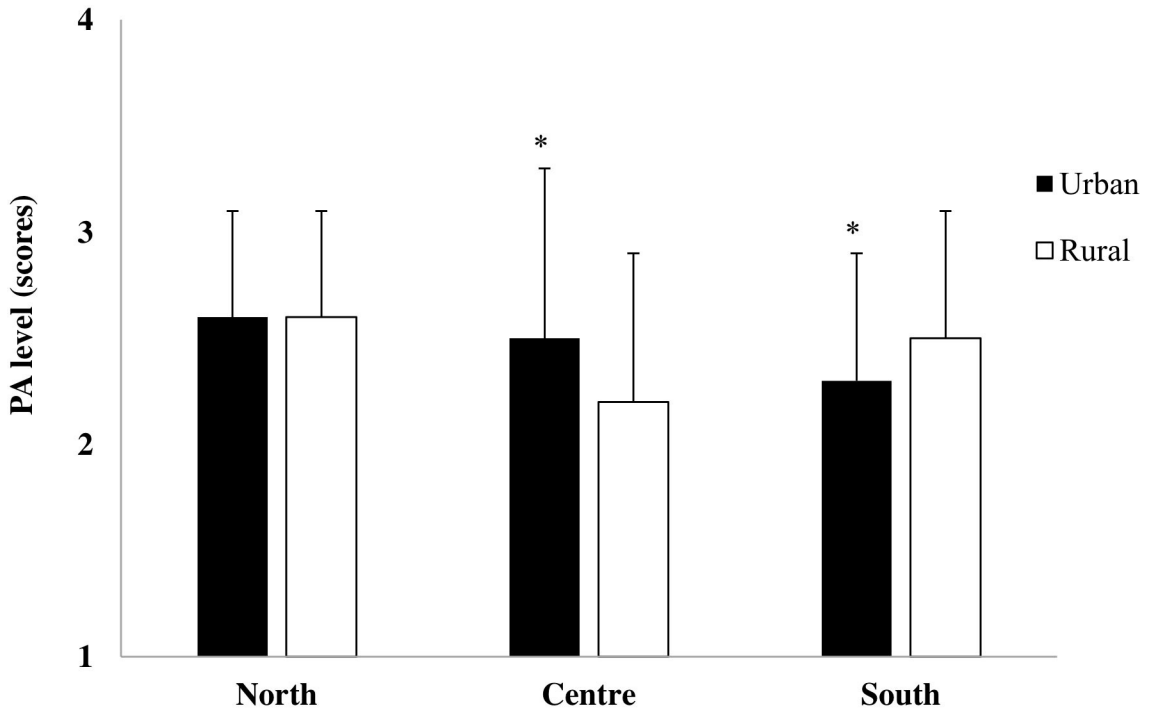

FIGURE 3 | Physical activity (PA) level in urban and rural children of the North, Center, and South of Italy (*$p \leq 0.01$ urban vs. rural).

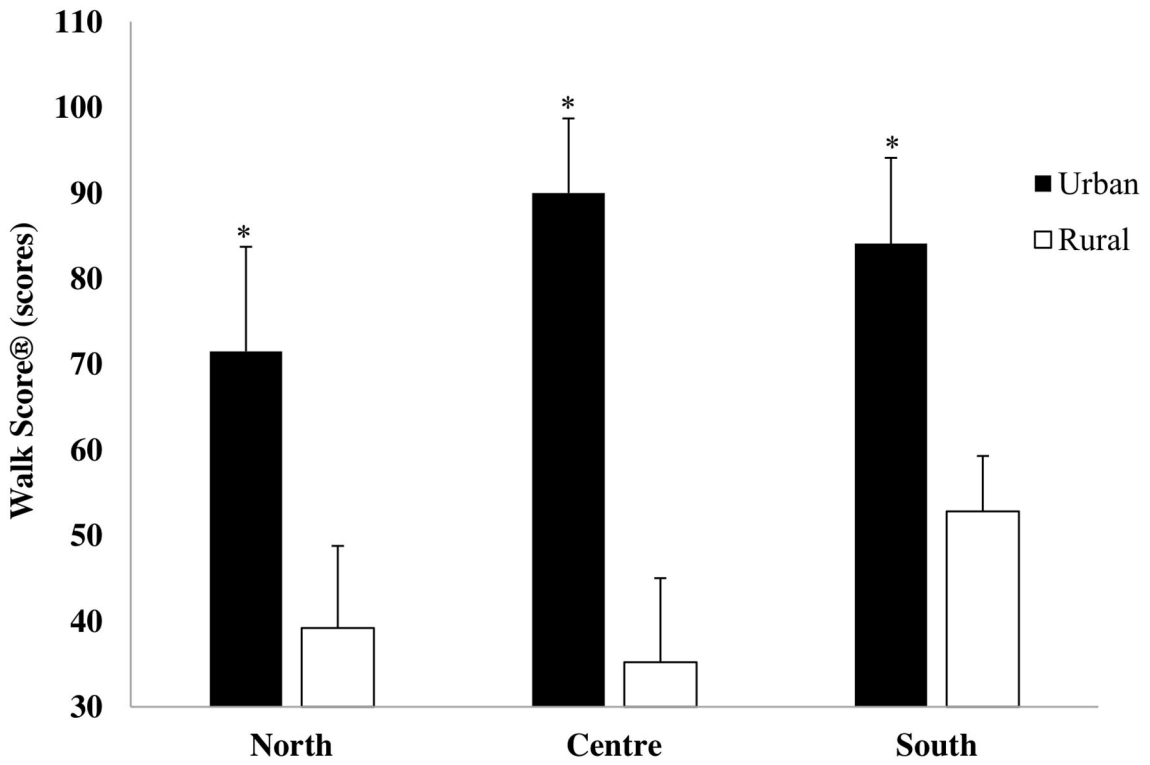

FIGURE 4 | Walk Score® in urban and rural children of the North, Center, and South of Italy (*$p < 0.0001$ urban vs. rural).

TABLE 2 | Multinomial logistic regression predicting BMI categories.

	OW OR (95% CI)	OB OR (95% CI)
Gender[a]		
Girls	0.70 (0.48–1.02)	0.47 (0.29–0.77)***
MQ (score)	0.96 (0.94–0.97)****	0.93 (0.91–0.95)****
PA level (score)	0.75 (0.56–1.01)	0.69 (0.47–1.01)*
Geographical area[b]		
North area	0.95 (0.54–1.68)	0.88 (0.37–2.08)
Center area	0.79 (0.44–1.42)	0.91 (0.41–2.02)
Living setting[c]		
Rural setting	0.54 (0.29–1.02)*	0.33 (0.12–0.95)**
Walkability[d]		
Car-dependent neighborhood	2.16 (0.93–5.00)	6.89 (1.94–24.43)***

NW_UW was chosen as the reference group for the outcome.
[a]Reference category is "boys."
[b]Reference category is "South area."
[c]Reference category is "urban setting."
[d]Reference category is "walkable neighborhood."
All variables were tested in the same model, controlling the effect of each other.
**p = 0.05, **p < 0.05, ***p ≤ 0.01, ****p < 0.0001.*
OW, overweight; OB, obese; NW_UN, normal weight and underweight; OR, odds ratio; CI, confidence interval; MQ, motor quotient.

in the Italian Central regions. These results were not in line with previous research findings that reported the higher prevalence of children's and adolescents' overweight and obesity in the South regions of Italy when compared with the Center and the North regions (5, 6, 17, 26). Our Central children also showed the lowest PA level and the worst walkability of neighborhoods when compared with their Northern and Southern peers, which could have negatively affected their weight status. Moreover, the greater BMI of children living in rural areas of North Italy was consistent with results reported for children living in rural areas of Midwest in the United States (27) and for children living in rural areas of Croatia (13). In addition, considering the different weight status categories, it appeared that rural children had higher overweight/obesity prevalence than urban children, underlining the severe situation of youth living in this setting. Although in the present study socio-economic factors were not measured, rural children were often associated with a low family income (28). Therefore, we could speculate that this low socio-economic status of rural children leads to an unhealthy lifestyle, which is directly related to low levels of PA, to an unhealthy diet (29), and to a high prevalence of overweight and obesity (17).

Our results revealed a higher prevalence of motor impairments in girls than in boys, indicating that boys at comparable ages are more coordinated than girls. Similar results, previously observed in Portuguese children, suggested that these differences could be due to different motor skills refinements, body growth, and physical fitness levels between boys and girls (30). This significant difference between the MQ of boys and girls could also be explained by referring to gender stereotypes in PA and sport practice (31, 32). Sport (i.e., football, athletics, basketball) has a strong masculine connotation, probably favoring males' participation and practice in out-of-school settings and therefore their higher performance in motor tests (31, 32). Moreover, our results revealed that boys had a higher PA level than girls. The higher prevalence of physical inactivity among girls was consistent with results reported by other studies (5, 29). The low levels of gross motor coordination in combination with low levels of PA in girls suggest that this population needs to be targeted for priority intervention programs to promote PA and sport participation in girls.

Northern children showed better gross motor coordination level when compared with Central and Southern children. These results could be explained by good leisure time facilities and the strong emphasis to promote exercise and sport practice in many Northern municipalities (5), thus providing an environment that could promote children's active behaviors. In fact, Northern children were the most active, showing a higher PA level than Southern and Central children. Contrarily, Central areas had more barriers to PA due to the lack of safety, green spaces, sports facilities, and walkable neighborhoods that could determine the worst MQ scores of children from the Center of Italy (**Figure 2**) (33). Moreover, our Northern rural children had a higher MQ than their urban peers, showing an opposite scenario in the South of Italy, where urban children had a higher MQ than their rural peers. These controversial results were in line with results reported in previous studies conducted in different European countries. Northern rural children scored better in the KTK test battery than their urban peers, similarly to Spanish schoolchildren living in rural areas, who obtained significantly better results in motor competence than children who lived in urban areas (8). Contrarily, Southern urban children showed higher KTK scores than rural children as also reported by Novak et al., who showed that middle school Croatian students living in urban areas had better motor abilities than their rural counterparts (13). It seems that there is not a univocal link between the living setting and the level of motor coordination. Therefore, children's gross motor coordination level and its relationship with living setting is a topic that needs to be better investigated, particularly in Italian context.

The more active children were the Northern children. National data showed that the most of active children attend schools where at least 2 h of weekly PA is performed and where there are initiatives promoting PA (34). Moreover, school playtime could contribute to children's daily PA levels (35). In this perspective, school might play a fundamental role to affect PA level and sedentary behaviors in children. The school environment seems to be the ideal setting for the practice of PA, since it provides opportunities to a great number of children to be physically active during physical education classes and recess (32). Nevertheless, only 34.5% of the classes from the primary schools of the Center of Italy attend at least 2 h of weekly PA, while more than 50% of the classes from the primary schools of the North and the South of Italy attend at least 2 h of weekly PA (www.epicentro.iss.it/okkioallasalute) (5). It seems that Italian schools have some barriers, such as the lack of appropriate areas, equipment, and organized activities during the school day (36), which limit children's opportunities to accumulate PA during the school day. Our urban children of the Center of Italy showed higher PA levels than their rural peers, while children

of the South of Italy showed higher PA levels than their urban peers (**Figure 3**). These conflicting outcomes agreed with other controversial results of PA pattern in rural and urban children and adolescents in the United States (14).

The second aim of the present study was to examine differences in the neighborhood walkability of different school areas from different geographical areas and living settings. The characteristics of neighborhoods were investigated by using Walk Score®, which is a descriptor of the walkability of different areas. Our results showed that the higher proportion of schools in car-dependent neighborhoods were in the Center of Italy. These results were consistent with other Italian reports that showed the low level of walkability in urban areas of the Center of Italy (33). These results would emphasize the criticalities of the neighborhood that limit walkability and could be a basis to support public decisions to intervene in the development of the neighborhoods aimed at encouraging PA. We defined urban or rural setting by population density. However, most rural schools of the present study were in car-dependent neighborhoods where most errands require a car, limiting the use of active transportation such as walking or biking. Therefore, considering the peculiarity of geographical and built environment characteristics of Italy, a new criterion to distinguish urban from rural areas could be introduced based on Walk Score®.

The present study showed the high incidence of overweight and obesity among Italian children. Previous studies revealed that these conditions could lead to health problems such as hypertension, cardiovascular, and metabolic diseases (26, 37). Therefore, to avoid immediate or future health complications, it is fundamental to understand which factors could be related to overweight and obesity in youth. Thus, the last aim of this study was to examine whether motor coordination, PA level, geographical areas, living setting, neighborhood walkability, and gender could predict children's weight status. The multinomial logistic regression results showed that lower MQ, lower PA level, and living in a rural setting were associated with a higher risk for being overweight and/or obese. A Danish study reported similar results showing a significant relationship between body fatness and motor competence (38). A previous Italian investigation reported that lower PA level was associated with a higher risk for being obese (26). The association between rural setting and children's obesity could be due to their lower socio-economic status (28) and therefore to the lower possibility to conduct a correct diet composed by healthy food (29) and to perform organized physical activities (39). It was demonstrated that rural residency was associated with low levels of PA (40). Children's PA levels that could influence children's weight status were often associated with structural influences, such as the physical environment (e.g., access to facilities, safety of neighborhoods, weather conditions) (40). Some environmental investigations showed that neighborhood walkability and the spatial structure of street networks affect PA and weight status condition in children (15, 16). In our study, living in a car-dependent neighborhood was associated with a higher risk for obesity. However, living in walkable areas is not strictly associated with positive walking behaviors (41). This relationship between walkability and BMI categories suggests conducting future studies to investigate the perceived availability of PA opportunities in youth. It might be possible that children perceived barriers to PA even in areas defined as walkable by an objective descriptor such as Walk Score®. According to the theory of functioning and capabilities, well-being is given not only by the simple availability of services and resources of an area, but also by the capability of the population to use them (42). It might be possible that a neighborhood or a region offers infrastructures or recreational areas where children can be active, but they are not able to use them as real resources (42).

Finally, although girls of our study had lower gross motor coordination and PA levels than boys, the logistic regression showed that being a girl was associated with a lower risk for being obese. These conflicting results could be explained by the fact that weight status categories were based on children's BMI. We could speculate that boys had a different body composition from girls, physiologically caused by different hormonal and metabolic factors (43). These factors could characterize boys' body composition by higher lean body mass than girls, explaining their better gross motor coordination performances. It would be necessary to conduct body composition evaluations in future studies to verify it. However, our results were consistent with scientific literature that observed a higher prevalence of overweight and obesity among boys than girls although boys were more active than girls (44), who contrarily showed higher sedentary behaviors than boys (44). Moreover, studies reported gender differences concerning behavioral determinants of overweight and obesity as different eating habits between boys and girls. Girls were more likely to eat healthy than boys, paying more attention to foods, calorie intake and nutrients, and preferring vegetables and fruits with respect to boys (44).

STRENGTHS AND LIMITATIONS

The main strength of the study is the large Italian sample recruited. Furthermore, among the strengths, it should be noted that the present work, belonging to a multicenter study (3), is an innovative contribution in understanding the links between children's health-related parameters and urban and rural settings in different Italian regions.

Some limitations to this research should be noted. Since it was a cross-sectional study, causal relationships cannot be inferred. The Central children were from the Lazio region, and the Southern children were from the Sicily region. Future studies should include children from more different regions to generalize the findings of the study to all Italian regions. In addition, we compared the Metropolitan City of Rome with medium-sized cities. Future studies should include cities with similar size and population density. We investigated children's BMI, but we did not have indications regarding their body composition, eating habits, perceived availability of PA opportunities, parental factors, and socio-economic conditions that could influence the weight

status. Our data were based on an age group (8–13 years old) that could make difficult to extend our conclusion to younger or older children and adolescents. Finally, walkability was referred as walkability of different school areas. In Italy, primary and secondary schools are very delocalized in the territory, and therefore, we assumed that school address and home address matched (same zip code). Further investigations are needed to verify if children's home address may be a more sensible approach to represent neighborhood walkability.

PERSPECTIVE

Globally, Northern children showed better health-related parameters (lower BMI, higher MQ scores, and PA levels) than Central and Southern children, suggesting that Northern children are able to benefit from the available services or interventions. Considering the alarming high percentage of children with motor coordination impairments, targeted PA interventions are mandatory. Moreover, the high percentage of overweight and obese children suggests additional efforts to facilitate an active lifestyle and integrated healthy eating programs in Italian children.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University Ethical Committees of the University of Rome (Rif 5500 Prot. 1070/19), the University of Verona (No. 2019-UNVRCLE-0298910), and the University of Palermo (No. 8/2019), in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. Additional authorization was provided by school principals/administrators. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

MG, SM, CB, and LG: conceptualization and methodology. VB, MG, MG, and LF: data collection. GZ, GB, and MB: data analysis. MG, GZ, ML, FS, and AP: data interpretation. MG and LF: writing—original draft preparation. LG: writing—review and editing. CB and ML: supervision. All authors contributed to the article and approved the submitted version.

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Twelve-Week Game-Based School Intervention Improves Physical Fitness in 12–14-Year-Old Girls

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The aim of this study was to determine the effects of a twelve-week game-based school intervention on physical fitness in girls aged 12–14 years. Fifty-nine adolescent girls (13.2 ± 0.3 years) were randomly assigned to a group that participated in a game-based after-school program (EXP) or a control group (CON) that participated only in mandatory physical education. The EXP group had the additional program twice a week after school for 40 min/session for 12 weeks alongside with regular physical education classes. The EXP program consisted mainly of small-sided games of football, basketball, handball, and volleyball. The assessment included a physical fitness assessment with standardized tests for this age group: countermovement jump (CMJ), standing long jump, bent arm hang, overhead medicine ball throw, sit-ups for 30 s, and Yo-Yo Intermittent Recovery Level 1 Test (YYIRT1). There was a significant interaction between group (EXP vs. CON) and time (pre-test vs. post-test) for the standing long jump ($p < 0.001$), overhead medicine ball throw ($p < 0.001$), 30 s sit-ups ($p = 0.030$), bent- arm hang ($p < 0.001$), and YYIRT1 score ($p = 0.004$). In addition, a significant main effect was found for time in countermovement jump ($p < 0.001$). The results of this study indicate that the after-school game-based intervention significantly improves adolescent girls' physical fitness compared to regular physical education. The overall conclusion suggests that as few as two additional sessions per week are sufficient to produce significant changes in physical fitness in adolescent girls.

Keywords: sport, adolescents, physical fitness, team games, school intervention

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INTRODUCTION

Physical fitness is considered as one of the most important predictor for healthy and active lifestyle (1–4). However, the level of physical fitness of children and adolescents has decreased significantly over the years (5, 6). Consistent participation in physical activities has been shown to be very important in young children and has great fitness benefits in both the short and long term (7). Some of these are reflected in body composition as well as physical, psychological, and social parameters (8). It is recommended that children engage in 60 or more minutes of moderate physical activity daily (9). More recent recommendations in children and adolescents include vigorous activities and thus recommending an average of 60 min/day of moderate-to-vigorous intensity aerobic physical activity across the week for providing health benefits (10).

Children spend most of their time at schools, mostly indoors (11), which could have impact on their physical fitness and accordingly overall health. Therefore, school-based interventions are probably the most effective way to improve physical fitness and to promote physical activity in children. Moreover, recent study showed that physical education and organized sport have significant contribution for the achievement of the physical activity recommendations (12).

Modified games can be a methodical approach that helps develop quite relevant tactical/technical knowledge in a short period of time (13). These games are better known as small-sided games (SSG). These games are thought to have their origins in the variety of games children used to play in the street, often being forced to change the rules to fit the game into the given space or to make it appropriate for the number of players available (14). There are few studies that have looked at the effects of SSG in children, however, their sample usually consisted of athletes (15, 16). Some studies that have focused on the effects of SSG in overweight children, as well as those that have used a specific program based on SSG for a specific sport, in most cases soccer (17, 18). Larsen et al. (19) investigated the effects of SSG in school on cardiovascular adaptations in children aged 8–10 years. The results showed that 10 months of SSG with 3 × 40 min per week during school lessons can have positive effects on cardiovascular health in children. In addition, an 11-month study showed that an SSG-based program increased VO2max by 9% and reduced body fat by 7% in children aged 15 years. Therefore, game-based training is considered to be a good strategy to contribute to the maintenance of a fitness level and a healthy lifestyle in children.

Increased participation in game-based training performed in the school setting may increase physical fitness performance in children and adolescents. However, there is only one study with school-aged children that showed that frequent low-volume ball games had positive fitness effects in 8–10-year-old children. Moreover, to the author's knowledge, there is not a single study that has examined the effects of game-based training on physical fitness in girls aged 12–14 years. Having in mind that girls tend to engage in less physical activity compared to their male peers, the aim of this study was to determine the effects of a 12-week game-based school intervention on physical fitness in girls aged 12–14 years. It was hypothesized that a game-based school intervention would improve physical fitness parameters in girls aged 12–14 years.

MATERIALS AND METHODS

Subjects

The present study was a randomized experimental trial comparing a game-based after-school program with traditional physical education. Sixty-four adolescent girls (aged 12–14 years) were invited from a single school to participate in this study. Fifty-nine girls (13.2 ± 0.3 years) chose to undergo evaluation for the baseline testing. After the baseline testing, the girls were randomly assigned to a group that participated in a game-based after-school program (EXP) or a control group (CON) that participated only in compulsory physical education. The general characteristics of the participants are shown in **Table 1**.

TABLE 1 | General characteristics of the participants.

Variable	EXP group (n = 30)	CON group (n = 29)
BH (cm)	163.9 ± 10.1	165.4 ± 9.4
BW (kg)	52.3 ± 9.9	54.1 ± 9.6
BMI (kg/m²)	19.2 ± 2.3	19.3 ± 1.9
Age (years)	13.3 ± 0.3	13.2 ± 0.4

BH, body height; BW, body weight; BMI, body mass index; EXP, experimental; CON, control; n, number of participants. Values are defined as mean ± standard deviation.

Table 1. Before the intervention began, all participants and their parents or guardians were familiarized with the experimental procedures and signed an informed consent form. The study procedures were approved by the local ethics committee (Ref. No. 11/2019) and were conducted in accordance with the Declaration of Helsinki.

Procedures

All tests were performed by the same investigators during a single visit after an overnight fast. The tests included an examination of body composition and physical fitness. Body height was measured to the nearest 0.5 cm using a wall-mounted stadiometer. Weight was measured on a calibrated beam scale with an accuracy of 0.1 kg.

Both groups participated in regular physical education classes twice a week for 45 min, with the EXP group additionally participating in the game-based training program. The game-based training sessions were led by students from the Faculty of Sport and took place twice a week after school for 40 min/session for 12 weeks. Each session began with a 5–7 min warm-up with moderate-intensity running and exercises relevant to the game/sport of that session. The main part of the session consisted of two different games played for 30 min. The main activity was followed by a 3–5 min cool-down exercises. The programme consisted mainly of small-sided football, basketball, handball, and volleyball games, which have been shown to have high participation and training intensity for all children (20). For practical reasons, different small games were occasionally played with different numbers of players and on different sized playing fields, and both outdoor and indoor facilities were used depending on the weather. The control group participated only in the traditional physical education activities planned for that semester, aimed at training various team and individual sports.

Physical Fitness Testing

Countermovement Jump

Countermovement jump (CMJ) (21) height was measured using the Optojump system (Optojump photocell system; Microgate, Italy). The girls were instructed to swing their arms during the CMJ and to extend through their knees and ankles during the jump phase. After two familiarization jumps, participants had three attempts, with the best attempt included in the analysis. The intraclass correlation coefficient and coefficient of variation were 0.922 and 2.98 %, respectively.

TABLE 2 | Physical fitness results and and changes from pre- to post-test in EXP and CON group.

Variable	Group	Pre-test	Post-test	ES	% Change	*p*-value, η^2_p
Countermovement jump (cm)	EXP	31.9 ± 3.6	34.3 ± 3.3	+0.69	+7.5	Group: $p = 0.343$, η^2_p: 0.016
	CON	31.3 ± 4.4	33.0 ± 5.3	+0.35	+5.4	Time: $p < 0.001$, η^2_p: 0.272
						Interaction: $p = 0.489$, η^2_p: 0.008
Standing long jump (cm)	EXP	171.1 ± 13.8	178.2 ± 12.6	+0.54	+4.1	Group: $p = 0.787$, η^2_p: 0.001
	CON	176.8 ± 12.0	174.3 ± 11.9	−0.21	−1.4	Time: $p = 0.003$, η^2_p: 0.146
						Interaction: $p < 0.001$, η^2_p: 0.424
Overhead medicine ball throw (m)	EXP	6.2 ± 1.0	6.5 ± 1.1	+0.29	+4.8	Group: $p = 0.084$, η^2_p: 0.051
	CON	5.9 ± 1.1	5.8 ± 1.2	−0.09	−1.7	Time: $p = 0.022$, η^2_p: 0.089
						Interaction: $p < 0.001$, η^2_p: 0.242
Sit-ups 30s (score)	EXP	18.1 ± 5.3	19.2 ± 3.7	+0.24	+6.1	Group: $p = 0.435$, η^2_p: 0.011
	CON	19.7 ± 4.2	19.3 ± 4.2	−0.10	−2.0	Time: $p = 0.208$, η^2_p: 0.028
						Interaction: $p = 0.030$, η^2_p: 0.080
Bent arm hang (seconds)	EXP	39.9 ± 14.5	42.4 ± 14.6	+0.17	+6.1	Group: $p = 0.009$, η^2_p: 0.113
	CON	32.7 ± 10.2	32.1 ± 10.2	−0.06	−1.8	Time: $p = 0.002$, η^2_p: 0.158
						Interaction: $p < 0.001$, η^2_p: 0.345
YYIRT1 (meters)	EXP	964.7 ± 242.3	1066.7 ± 265.9	+0.40	+10.6	Group: $p = 0.527$, η^2_p: 0.007
	CON	947.6 ± 286.2	994.5 ± 290.9	+0.16	+4.9	Time: $p < 0.001$, η^2_p: 0.542
						Interaction: $p = 0.004$, η^2_p: 0.139

EXP, experimental group; CON, control group; ES, Cohen d effect size; YYIRT1, Yo-Yo intermittent recovery test level 1. Values are defined as mean ± standard deviation.

Standing Long Jump

Participants were instructed to jump as far as possible and land with their feet together and in an upright position (22). The distance was measured in centimeters from the starting line to the heel of the participant. Initially, two familiarization jumps were performed, then participants had three attempts, with the best jump selected for analysis.

Overhead Medicine Ball Throw

Participants were instructed to hold a 2-kg medicine ball behind their head and throw it as far as possible above their head (23). The result was recorded in centimeters from the line of throw to the point of contact of the ball. They had three trials, with the best result being used in the analysis. The intraclass correlation coefficient and coefficient of variation were 0.841 and 3.91%, respectively.

Sit-Ups 30 S

The task was to perform as many complete sit-ups as possible in a 30 s time frame (24). The participant had to lie on his back with his knees bent and hands clasped behind his head. From this position, he had to rise as quickly as possible to a seated position and back to the starting position. The number of correctly performed sit-ups in 30 s was evaluated.

Bent Arm Hang

This test was used to assess muscular endurance of the upper limbs. Participants had to undergrip the bar and remain in a pull-up position with their chin above the bar for as long as possible (25). They had one attempt, which was measured in seconds.

Yo-Yo Intermittent Recovery Level 1 Test (YYIRT1)

YYIRT1 was performed according to the guidelines of Krustrup et al. (26). Participants had to run 2 × 20 m with 180° turns back and forth. After 40 m, participants jogged 2 × 5 m for active recovery. The audio device controlled the speed by beeps. The test was completed when a shuttle run was not finished within the sound signal. The total distance in meters is included in the analysis.

Statistical Analysis

Data were analyzed using SPSS, version 23 (SPSS Inc., Chicago, IL, USA). The mean ± standard deviation was calculated for all results. Normality of data was assessed using Kolmogorov–Smirnov test and showed that all data were normally distributed ($p > 0.05$). Levene tests were also performed for all test variables. A two-way repeated measures ANOVA was calculated to test for main effects and interactions for time (baseline vs. post-intervention) and group (EXP vs. CON) on the selected outcomes. Effect size (ES) was tested using Cohen's d within each group according to Hopkins et al. (27) and was classified as <0.2 (trivial); 0.2–0.6 (small); 0.6–1.2 (moderate); 1.2–2.0 (large); >2.0 (very large); and >4.0 (extremely large). In addition, partial Eta (η) squared (28) was applied to test the difference between the EXP and CON group [0.01 (small effect), 0.06 (moderate effect), and 0.14 (large effect)]. Significance was assumed at $p \leq 0.05$.

RESULTS

Table 2 shows results of EXP and CON group. Results indicate a significant group (EXP vs. CON) × time (pre test vs. post test)

interaction for standing long jump [$F_{(1,57)} = 41.994$; $p < 0.001$], overhead medicine ball throw [$F_{(1,57)} = 18.224$; $p < 0.001$], sit-ups 30 s [$F_{(1,57)} = 4.981$; $p = 0.030$], bent arm hang [$F_{(1,57)} = 30.018$; $p < 0.001$], and YYIRT1 score [$F_{(1,57)} = 9.230$; $p = 0.004$]. Additionally, a significant main effect for time was found in countermovement jump [$F_{(1,57)} = 21.306$; $p < 0.001$].

DISCUSSION

Early adolescence could be considered crucial for the development of physical activity behavior, especially in girls, as there is a significant decline in moderate- to-vigorous intensity of physical activity between the ages of 11 and 14 (29, 30). Hence, there is a call for interventions that could promote physical activity in adolescent girls. Recent discussion has suggested playing various team sports that have a positive impact on adolescent health (31). Therefore, the purpose of the current study was to determine the effects of a 12-week game-based school intervention on adolescent girls' physical fitness. The main findings of the current study were the improvement in aerobic fitness in the experimental group after a relatively short program. In addition, our game-based program over 12 weeks improved musculoskeletal fitness with the exception of CMJ, where there were no differences between groups.

Low aerobic fitness is associated with various cardiovascular diseases (32). Previous studies have shown positive effects on YYIRT1 performance in prepubertal and adolescent school children (20, 33–35). The current results suggest that a game-based school intervention is effective in improving aerobic fitness, as YYIR1 performance improved by 10.6%. A similar study using ball training showed no significant differences between groups for YYIRT1 performance after 10 months (33). However, due to the long intervention and already high levels of YYIRT1 performance in some participants, an additional median-split analysis showed positive effects in the participants with the poorest baseline levels. Two other studies showed smaller improvements than in our study after school-based volleyball program (2.4%) (35) and recreational soccer program (2.2%) (34). However, baseline YYIRT1 scores (947–964 m) were significantly lower in the current study compared to the aforementioned studies (1,292–1,504 m). Therefore, a possible discrepancy in the results could be due to the differences in baseline scores as well as the poor baseline scores of the participants in the current study. As for the differences between the EXP group and the CON group in the current study, it could be hypothesized that greater improvements occurred in the EXP group because team sports games were found to be more enjoyable compared to physical education classes, which could have an impact on participants' motivation during the program (35, 36).

The results for the vertical jump are contradictory. The CMJ was improved by +7.5% in the current study, but without significant differences between groups. Similar results were obtained after 8 months of recreational training in small-sided volleyball, in which the CMJ improved by 3.0%. Furthermore, Hammami et al. (36) found small effects on jumping performance in untrained adolescents after 8 weeks of soccer training. This was confirmed by Trajković et al. (34) following a school-based recreational soccer intervention, which showed only small effects (3.5%). In contrast, recreational soccer training in overweight and obese children showed significantly greater effects on CMJ (17.0%) (37). Differences in the duration of the interventions across studies, as well as differences in weight status and other characteristics, could be a possible explanation for this discrepancy between studies. There is also the possibility that different protocols were used to test vertical jump height, which could also contribute to differences in results.

Similar and conflicting results were found for the standing long jump. Sozen (38) found no significant differences in standing long jump after the volleyball school program compared to the control group. However, the regular physical education classes combined with the additional volleyball program promoted positive effects in the standing long jump (39). Similarly, Michailidis et al. (40) found significant improvement in standing long jump after 1 year of soccer training in 8–10 and 10–12 year old school children. In the present study, improvement in standing long jump (+4.1%) was found after 12 weeks of additional game-based activities. Significant changes between the initial and final measurements, as well as between groups, also occurred in explosive strength (medicine ball throw), upper body strength (bent arm hang), and strength endurance (sit-ups). It could be speculated that the significant differences between groups were due to the high number of high intensity activities during the team sports games. In addition, elements such as swings in volleyball and throws in handball and basketball could contribute significantly to the improvement of arm and shoulder muscle strength, thus improving explosive strength during throws. In addition, playing games requires a lot of activities involving changes of direction with the help of the trunk muscles (40), which could be the reason for the better improvement of the abdominal muscles compared to the control group.

Although we found significant improvements in physical fitness, the study has some limitations. We used only adolescent girls in the current study. Further studies should include both genders to show whether boys and girls receive the same benefits from this type of additional training in the school setting. In addition, we did not monitor students' overall physical activity during the intervention period or food intake, which could affect the overall results. Given that this is the age at which a significant decline in moderate-to-vigorous physical activity occurs, the greatest strength of the study is that a game-based after-school intervention provides an adequate incentive to improve physical fitness in adolescent girls compared to regular physical education.

CONCLUSION

The results of this study show that the after-school game-based intervention significantly improves the physical fitness of adolescent girls compared to regular physical education. The most important finding is the improvement in aerobic fitness following game-based activities after a relatively short program. Significant improvement was also found in musculoskeletal

fitness. The overall conclusion suggests that as few as two additional sessions per week are sufficient to produce significant changes in physical fitness in adolescent girls. Therefore, these results support the proposal to include additional forms of physical activity in school curricula.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethical Committee of Faculty of Sport and Physical Education Novi Sad (Ref. No. 11/2019). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

NT designed the research and recruited participants. ŠB conducted the data analysis and interpreted the results. TP drafted the manuscript. All authors read and approved the final version of the manuscript.

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SYSTEMATIC REVIEW
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Does Learning Through Movement Improve Academic Performance in Primary Schoolchildren? A Systematic Review

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Physically active children have greater motor competence and a faster maturation compared with their sedentary peers. Recent research also suggests that physical activity during childhood may also promote cognitive development and therefore improve academic performance. The aim of this study was to understand if physically active academic lessons may improve academic achievement in primary schoolchildren. A systematic review following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines was conducted. The search was performed on the following database: PubMed, Web of Science, Scopus, Education Resources Information Center (ERIC), and PsycINFO (APA). Studies evaluating schoolchildren aged between 3 and 11 years taking part in educational contexts that include physical activity and natural environments evaluating physical fitness and/or educational outcomes were included. A total of 54 studies (for a total sample of 29,460 schoolchildren) were considered eligible and included in the qualitative synthesis. The Effective Public Health Practice Project risk-of-bias assessment revealed a moderate quality of the included studies with only two considered weeks. Despite differences in the retrieved protocols, physically active academic lessons improve the total time engaged in physical activity, motor skills, and/or academic performance. The results of this review suggest that learning through movement is an effective, low-cost, and enjoyable strategy for elementary schoolchildren.

Keywords: preschool, infant, kindergarten, outdoor learning, nature, academic achievement, primary school

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INTRODUCTION

Children spend an ever-increasing time in sedentary behaviors such as the ∼2 h (children aged 3 years) or 3 h (children aged between 3 and 5 years) per day in television view (1). Sedentary behaviors are also in school settings during which ∼80% of the time children are seated (2), and only 5% of the time is spent in moderate to vigorous activities in European schoolchildren (3). Consequently, considering the classroom as a place where students spend the majority of their waking time, the school setting can be considered as an ideal setting to improve physical activity

and academic achievement and also because it has positive results inside and outside the school (4, 5).

The key point to limit sedentary behaviors is to propose health promotion programs to promote physical activity since early childhood (6). Physical activity interventions for children should improve physical fitness, promote health-related behaviors, and facilitate mental development (7, 8). Physical activity, especially during development, has positive effects on the measures of adiposity, motor skill, bone and skeletal health, psychosocial health, cardiometabolic health indicators, and cognitive development (9–11). Gross and motor skill practice has also positive effects on cognitive development (12) and functions (such as perceptual skills, intelligence quotient, academic achievement and readiness, verbal and mathematics tests, developmental level) (13, 14), non-executive cognitive functions, core executive functions, and higher-level executive functions (15). It seems that aerobic training has the largest effects (16). Its performance during early childhood could become a lifelong habit, improving cognitive and physical health (17), making the physical movement even more important in this phase of life. Consequently, states need to monitor and evaluate strategies to increase physical activity during school time, adopting a policy specific to prevent potential loopholes (18). On the other side, elementary schools could be a platform for early intervention to improve daily physical activity, but further investigations are required to secure the successful assimilation of movement integration into routine practices (19). Especially in children, physical activity practice during school days can be incorporated, and it increases moderate to vigorous physical activity levels (20) and improve aerobic fitness (4) and also has positive learning outcomes and consequently academic achievement (21). It can integrate physical activity in the academic curriculum and consequently propose a classroom-based physical activity program, increase children's cognition (15) and energy expenditure (22), develop social skills, improve mental health, and reduce risk-taking behaviors, but it also has short-term cognitive benefits (23). A physical education program could be a decisive education strategy to enhance motor and cognitive learning in preschool children and to achieve successful academic outcomes (24). Physically active lessons can be proposed with different contents such as math, language, arts, and social sciences, and this has also positive effects on physical activity level and learning and attention (25). The inclusion of physical activity in the curriculum to improve learning outcomes is feasible, and it is suggested in elementary schoolchildren (21).

Schools and teachers are culturally changing, adopting active learning and other kinds of learning methods, but further improvement is required (26). Unfortunately, individuals and schools limit the application of these kinds of programs (27). In 2012, Erwin et al. (21) suggested that more research is required to study integrated physical activity interventions, both on the learning outcome and physical activity levels. Consequently, the objective of this systematic review was to analyze the protocols adopted and the effects of outdoor learning on schoolchildren.

MATERIALS AND METHODS

The systematic review was conducted following the principles outlined by PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (28).

Eligibility Criteria

The selection criteria of this review were of the PICO-S (Population, Intervention, Comparison, Outcomes, and Study) design.

The population was composed of young children aged between 3 and 11 years of primary/elementary schools. Studies that investigated only a special population such as people with disabilities were excluded because of the possible disability-specific outcomes.

The intervention of interest had to be the use of movement and natural environment with educational elements integrated to improve physical fitness and/or educational outcomes. Curriculum physical education, physical activity breaks without educational elements, recess, and after-school interventions were excluded.

The comparison and the outcomes of interest comprised physical fitness parameters and education outcomes.

About the study design, only English-written original and peer-reviewed studies were considered because of the limitations of the authors with the languages. Intervention, cross-sectional, longitudinal, correlational (randomized and non-randomized controlled, and quasi-randomized studies) studies were also included. Reviews, meta-analyses, abstracts and scientific conference abstracts, citations, opinion articles, books and book reviews, letters, editorials, statements, and commentaries were excluded.

Data Collection

The systematic search was performed through the electronic databases PubMed, Web of Science, Scopus, Education Resources Information Center (ERIC), and PsycINFO (APA).

The following keyword groups were adopted and matched with the Boolean operators AND/OR:

Group 1: *child*, *preschool*, *infant*, *toddler*, *pupil, kindergarten*;
Group 2: *primary school*, *elementary school*, *student*, *education*;
Group 3: *psychomotor education*, *physical education*, *kinesiology education*, *active play*, *motor play*, *active learning*, *nature play*, *whole school*, *movement integration*, *comprehensive school*, *physical activity break*.

This is a string example:

(Child* OR preschool* OR infant* OR toddler* OR pupil* OR kindergarten) AND ("primary school" OR "elementary school" OR student* OR education) AND (psychomotor education OR physical education OR kinesiology education OR active play OR motor play OR nature play OR whole school OR movement integration OR comprehensive school OR physical activity break OR active learning).

Study Record

The selected articles were included in EndNote software (EndNote version X8; Thompson Reuters, NY, USA). In the first step, duplicates were detected. After this step, two investigators, who worked independently, performed a selection process based on the inclusion and exclusion criteria on the title, abstract, and full-length articles. If the two investigators were in disagreement in categorizing an article, the coordinator of the study was involved and, independently, provided the tie-breaking decision. All investigators were not blinded to the authors or associated institutions of the articles during the selection process.

Information related to the sample (age, gender, and sample size) and intervention (type, duration, frequency) characteristics, and on physical fitness and educational outcomes was collected. The data were discussed narratively and represented through tables.

Risk-of-Bias Assessment

To detect the risk of bias and the quality of the study, the Effective Public Health Practice Project tool (29) was adopted. This tool is composed of three scores (weak, moderate, or strong) that were assigned to the following: (1) selection bias assessment, (2) study design evaluation, (3) confounder factors, (4) blinding, (5) data collection methods, (6) withdrawals, and (7) dropouts, to provide an overall rating. A "strong" scoring was provided to a study if at least four strong ratings and no weak rating were provided to each sub-domain. A "moderate" scoring was provided to a study if it had less than four strong ratings and one weak rating provided to the subdomains. A "weak" scoring was provided to a study if two or more weak ratings were provided to the subdomains. In order to numerically quantify the subdomains, a score of 3 was attributed to a strong evaluation, a score of 2 was attributed to a moderate evaluation, and a score of 1 was attributed to a weak evaluation.

RESULTS

A total of 17,862 studies were found in the electronic databases searched, and 6,820 of the articles were immediately removed because they were duplicates. The final number of included studies after the eligibility criteria screening has been of 54 (three studies were included in a second moment after the reference checking of the included studies). A summary of the search process is provided in **Figure 1**.

Risk of Bias

The quality of the studies was overall moderate, with only two studies deemed weak. The mean score for selection bias was 3/3, for the study design 2.5/3, for the confounder 2.4/3, for the blinding of 1.3/3, for the data collection of 2.2/3, and for the dropout of 2.9/3, reaching an overall mean total score of 1.8 out of 3.

Study Characteristics

A summary of the study's characteristics is proposed in **Table 1**. The number of participants included in the studies was 29,460; one study did not specify the number of students, but the number of classrooms included was 4. A total of 11,392 were composed of girls (39%), 11,021 were boys (38%), whereas in 6,486, the gender was not specified (23%). The mean age (standard deviation) of the included participants was 8.2 (0.7) years, and it ranged from 3.9 to 11.2 years.

The studies were performed in different countries. The majority of the studies were performed in the United States ($n = 22$). In Australia, a total of nine studies were conducted. Five studies were conducted in the United Kingdom and Norway. More than one study was conducted in Denmark ($n = 4$), in the Netherlands ($n = 3$), in Greece ($n = 2$), and in Ireland ($n = 2$). Only one study was conducted in Italy, New Zealand, and Vietnam.

The majority of the studies were randomized controlled trials ($n = 25$). They were followed by quasi-experimental design ($n = 13$), observational studies ($n = 5$), intervention studies ($n = 4$), and pilot studies ($n = 3$). Other study designs such as mixed factorial, mixed experimental, within subject, and pedagogical experiments were adopted only one time.

Seven interventions provided negative feedback on the effect of integrated lessons on physical activity and/or academic outcomes, and there are no aspects between the studies that could suggest excluding some aspects of the intervention such as the duration of the program or session, or the kind of intervention, or the subject considered.

Intervention Characteristics

Different studies were based on national or international intervention programs. The Comprehensive School Physical Activity Programs was the intervention program adopted majority of times ($n = 4$). Adopted in three different studies is the Active Smarter Kids intervention. Less adopted assessment methods are provided in **Table 2**.

Most of the interventions wanted to improve mathematics ($n = 30$) and language ($n = 14$) learning. Language arts was proposed as integrated lessons in five studies, social studies in only three studies, and two times for geography and history. Other subjects such as reading, handicrafts, science, general health, statistics, biology, and religion were studied only one time. In different studies, no information related to the curriculum subjects studied has been provided ($n = 22$).

The mean length of the intervention was 153.5 days, with a range from 5 to 1,095 days. The mean duration of the integrated physical activity was of 28.5 min, with interventions that were of 10 and others arrived to 60 min. Different studies proposed three interventions a week ($n = 10$), but other studies proposed only 2 days a week of curriculum-integrated physical activity ($n = 7$). Five studies proposed more than 3 days a week of intervention ($n = 5$). Unfortunately, the majority of the studies ($n = 32$) have not provided this information.

The majority of the 29 studies (**Table 2**) that included data related to the physical activity level collected with accelerometers or pedometers had positive results, with a percentage range of improvement from 1.8 to 96.2. Only one study reported no improvement with the integrated movement program. Unfortunately, the data are not heterogeneous; indeed, studies compared different groups or the same group before and after

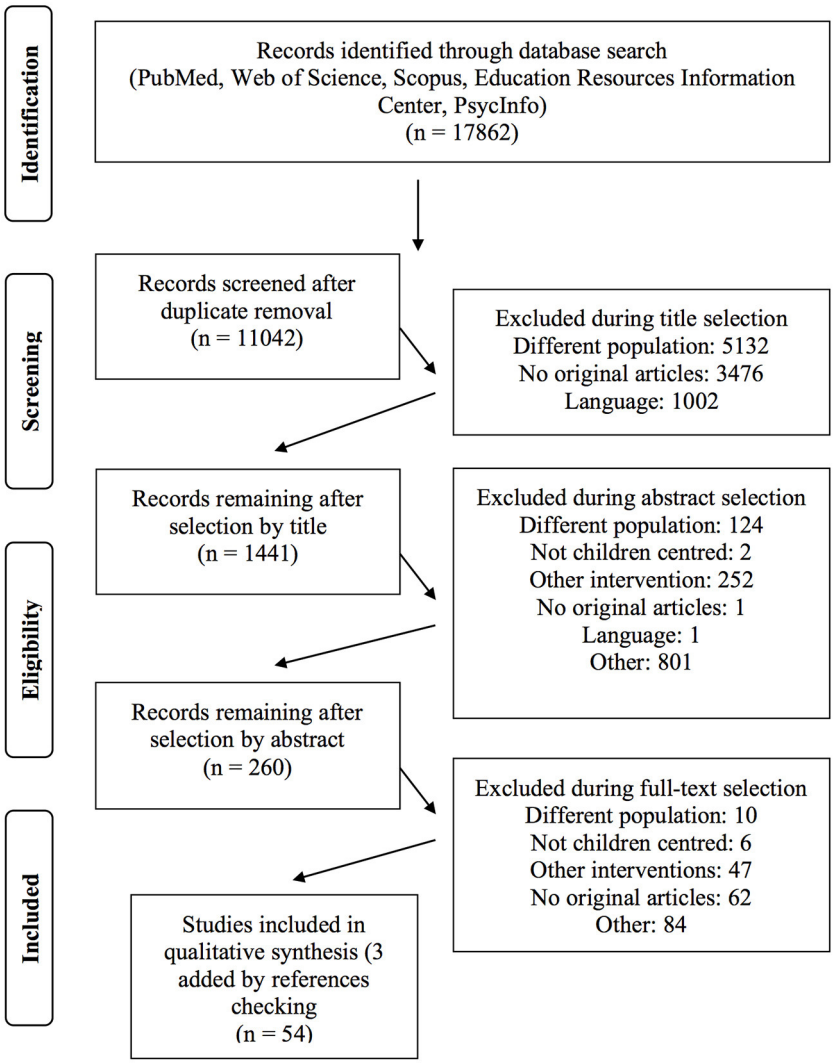

FIGURE 1 | PRISMA flow chart illustrating the systematic process.

the intervention. Studies reported the time in which the children were engaged in moderate to the vigorous physical activity or the number of steps. Studies collected data during the school hours or during the week or the day.

Academic achievements or cognitive functions were assessed majority of times through the academic outcomes and the time on task ($n = 3$). In three studies, the authors evaluated them through the "on-task" behavior. Less adopted assessment methods are provided in **Table 2**.

Related to physical activity assessment, 29 studies evaluated it through an accelerometer or a pedometer. Some studies evaluated health-related physical fitness characteristics through physical tests such as the Test of Gross Motor Development 2 ($n = 4$), Andersen test ($n = 2$), 20-m shuttle run test ($n = 3$), and Progressive Aerobic Cardiovascular Endurance Run ($n = 2$). Less adopted evaluation methods are provided in **Table 2**. Skill-related physical fitness was evaluated through test to evaluate executive functions and motor skills ($n = 1$). Studies adopted also batteries to evaluate physical fitness such as the FITNESSGRAM ($n = 2$). The most interesting subjective physical activity evaluation methods were the System for Observing Student Movement in Academic Routines and Transitions ($n = 3$), Physical Activity Questionnaire for Older Children ($n = 1$), interviews, and observations.

Intervention Proposal

Some studies reported the intervention in detail or examples of intervention, and the following are proposals of the included studies. Some studies proposed outdoor structured nature-based play (33, 71) or adopted the outdoor environment to learn math, language, history, or religion (70). Games-centered interventions (34, 35) or games related the pedometer with mathematics (36) or free play or semistructured physical activity have been proposed (39). Always through play was the intervention

TABLE 1 | Main descriptive characteristics of the included studies.

References	Nationality	Study design	Sample size (female) [male]	Mean age (standard deviation)	Intervention	Length (days)	Duration (min)/times a week
Aadland et al. (30)	Norway	RCT	1,129 (541) [588]	10.2 (0.3)	Active learning	12	30/3
Alhassan et al. (31)	USA	RCT	67 (29) [38]	4 (0.7)	Active school	28	30/3
Bacon and Lord (32)	United Kingdom	RCT	36 (15) [21]	9.5	Active learning	14	10/5
Bai et al. (33)	Australia	Observational	1,596	3.5	Play and learning	1,095	No info
Bartholomew et al. (34)	USA	RCT	2,716 (1,467) [1,249]	9.5	Active learning	5	15/5
Bartholomew et al. (35)	USA	RCT	2,493 (1,349) [1,144]	9	Active learning	No info	15
Braun et al. (36)	USA	Observational	3,479	9.5	Active learning	365	No info
Brusseau et al. (37)	USA	Quasi-experimental	1,460 (730) [730]	8.4 (1.8)	Active classroom	84	50
Bugge et al. (38)	Denmark	Quasi-experimental	1,181 (629) [552]	8.4 (1.4)	Active classroom	No info	60/6
Burns et al. (39)	USA	Quasi-experimental	327 (162) [165]	9.6 (1.7)	Integrated PA	84	No info
Burns et al. (40)	USA	RCT	1,460 (730) [730]	8.4 (1.8)	Integrated PA	No info	No info
Christodoulos et al. (41)	Greece	RCT	68 (36) [42]	11.2 (0.3)	Active classrooms	No info	45/2
Cradock et al. (42)	USA	Quasi-experimental	393 (206) [187]	10.2 (0.8)	Active classrooms	150	No info
Dyrstad et al. (43)	Norway	RCT	483	9.5	Active school	238	45/2
Egan et al. (44)	USA	Quasi-experimental	161 (78) [83]	7.3 (0.9)	Active learning	120	No info
Goh et al. (45)	USA	Observational	210 (118) [92]	9.1 (0.1)	Active classroom	28	10
Grieco et al. (46)	USA	Mixed factorial	320 (164) [156]	8	Physically active lessons	No info	15
Invernizzi et al. (47)	Italy	RCT	121 (64) [57]	10.5 (0.5)	Active classroom	84	60/2
Konijnenberg and Fredriksen (48)	Norway	Quasi-experimental	1,173 (595) [578]	10.2 (1.5)	Active classroom	210	45/6
Martin and Murtagh (20)	Ireland	Pilot study	28 (14) [14]	8.5	Integrated PA	No info	No info
Martin and Murtagh (49)	Ireland	RCT	248	10	Integrated PA	5	No info
Mattson et al. (50)	USA	Observation	789 (355) [434]	10	Active classroom	No info	No info
Mavilidi et al. (51)	Australia	Mixed experimental	125 (61) [64]	4.9 (0.6)	Integrated PA	28	15/2
Mavilidi et al. (52)	Australia	Intervention	90 (45) [45]	4.9 (0.6)	Integrated PA	28	15/2
Mavilidi et al. (53)	Australia	RCT	120 (57) [63]	4.7 (0.5)	Integrated PA	28	15/2
Miller et al. (54)	Australia	RCT	168	11.2 (1)	Game intervention	49	No info
Mullender-Wijnsma et al. (55)	Netherlands	Within subject	81 (41) [40]	8.2 (0.6)	Active learning	154	30
Mullender-Wijnsma et al. (56)	Netherlands	Quasi-experimental	228 (106) [122]	8.1	Active learning	154	30
Norris et al. (57)	United Kingdom	RCT	264	8.5	Active classroom	42	10/3

(Continued)

TABLE 1 | Continued

References	Nationality	Study design	Sample size (female) [male]	Mean age (standard deviation)	Intervention	Length (days)	Duration (min)/times a week
Norris et al. (58)	United Kingdom	RCT	219 (108) [111]	8.6 (0.5)	Active classroom	42	10/3
Oliver et al. (59)	New Zealand	Intervention	78 (41) [37]	9	Integrated PA	28	No info
Pham et al. (60)	Vietnam	Pedagogical experiments	55 (32) [23]	7	Active school	150	35/2
Powell et al. (61)	United Kingdom	Quasi-experimental	485	8	Active learning	No info	No info
Powell et al. (62)	United Kingdom	Quasi- experimental	84	8.5	Active learning	No info	No info
Reed et al. (63)	USA	RCT	155 (67) [88]	9.5	Active learning	120	30/3
Resaland et al. (64)	Norway	RCT	1,129 (542) [587]	10.2 (0.3)	Active learning	310	No info
Resaland et al. (65)	Norway	RCT	1,129 (542) [587]	10.2 (0.3)	Active learning	310	No info
Riley et al. (66)	Australia	Pilot study	54 (26) [28]	10.5 (0.7)	Active learning	42	60/3
Robinson et al. (67)	USA	RCT	72 (37) [35]	3.9 (0.2)	Active classroom	63	30/2
Ruiter et al. (68)	Netherlands	RCT	118 (71) [47]	7.1 (0.4)		No info	No info
Schneller et al. (69)	Denmark	Quasi-experimental	361 (140) [221]	10.9 (1)	Movement integration	No info	45
Schneller et al. (70)	Denmark	Quasi-experimental	663 (317) [346]	10.8 (1)		No info	45
Seljebotn et al. (71)	Norway	RCT	447 (219) [228]	9.5	Games intervention	300	No info
Trawick-Smith et al. (72)	USA	Intervention	47 (27) [20]	3.9 (0.6)	Play to learn	No info	No info
Vazou et al. (73)	USA	RCT	77 (36) [41]	9.4 (0.5)	Active learning	56	10
Vazou et al. (74)	USA	Quasi-experimental	245 (105) [140]	5.7 (1.4)	Active learning	49	No info
Vetter et al. (75)	Australia	RCT	172 (89) [83]	8.4 (0.3)	Active learning	42	30/3
Vetter et al. (76)	Australia	RCT	85 (38) [47]	9.8 (0.3)		42	30/3
Weaver et al. (77)	USA	Quasi-experimental	1,826 (1,029) [797]	7.5	Integrated PA	730	No info
Weaver et al. (78)	USA	Intervention	229 (104) [125]	7.3 (0.8)	Active classroom	No info	10
Webster et al. (79)	USA	Mixed methods	4 Classrooms	7	Active learning	730	No info
Williams et al. (80)	USA	Pilot observational	207	4.6	Movement integration	10	10
Zachopoulou et al. (81)	Greece	RCT	251 (121) [130]	4.3 (0.5)	Active learning	70	40
Zippert et al. (82)	USA	Observational	251 (121) [130]	4.3 (0.5)	Play intervention	No info	20

of Pham and colleagues, which adopted balls with numbers, letters, and mathematical symbols on the surface (60). Complex, independent, and symbolic play (72) and playing with math-related materials to examine children's verbal and non-verbal mathematics exploration without adult guidance (82) were also proposed. Other proposals that comprised cooperative activities integrate health education into several school subjects (41). An intervention proposed as language activity "Scrabble relay," where children worked in groups, or "Bingo" to improve mathematics (43). In another study, one teacher read a story while students perform the movements in the story (45). Mavilidi and colleagues proposed different interventions for

TABLE 2 | Synthetic description of the interventions included.

References	Intervention	Subjects	Academic evaluation	Physical assessment	Conclusion	Effect on PA
Aadland et al. (30)	ASK	Norwegian, math, English	Executive functions	Acc; executive functions; Andersen test; motor skills	Small effects on executive functions, cognitive flexibility	0% (MVPA)
Alhassan et al. (31)	SPARK	No info	No info	Acc	Improvements in PA	+22.8% (MVPA)
Bacon and Lord (32)	No info	Math	No info	Acc	Improve PA and academic outcomes	+22-5% (steps)
Bai et al. (33)	PLAYCE	No info	No info	No info	Improve educators' self-efficacy to engage in PA	ND
Bartholomew et al. (34)	I-CAN!	Math, language arts	Time on task	Acc	Significantly increased time on task	+43.6% (MVPA)
Bartholomew et al. (35)	I-CAN!	Math, language arts	No info	Fitnessgram	Increases PA within elementary students	ND
Braun et al. (36)	CSPAP	Math	No info	PACER	Need for more prospective research	+19% (min/week)
Brusseau et al. (37)	CSPAP	No info	No info	Acc, Fitnessgram; PACER	Improve PA	+17.9% (MVPA)
Bugge et al. (38)	CHAMPS	Math, Danish	Academic achievement	Andersen test	No negative effects of additional PA on scholastic outcomes	ND
Burns et al. (39)	CSPAP	No info	No info	Acc	Increase PA	+26.2% (steps)
Burns et al. (40)	CSPAP	No info	No info	TGMD-2	Motor skills improved	ND
Christodoulos et al. (41)	No info	Math, reading, handicraft	No info	20-m shuttle run; sit and reach, sit-up test	Slow the age-related decline in PA	ND
Cradock et al. (42)	SPARK	No info	No info	Acc	Increase moderate to vigorous PA	+45.7% (MVPA)
Dyrstad et al. (43)	No info	Language, math	No info	No info	Appropriate pedagogical method	ND
Egan et al. (44)	PACES	Math	No info	SOFIT	Effectiveness of the research	ND
Goh et al. (45)	TAKE 10!®	Language arts, math, science, social studies, general health	No info	Pedom	Improvement of children's PA	+15% (steps)
Grieco et al. (46)	No info	No info	Time on task	Acc	PA increases time on task	+96.9%(MVPA)
Invernizzi et al. (47)	No info	No info	No info	PAQ-C; MFT; TGMD-2; PACES	Positive effects on physical literacy development	ND
Konijnenberg and Fredriksen (48)	HOOP	Language, math	Stroop/Eriksen, flanker tasks	No info	No positive effect of the PA intervention	ND
Martin and Murtagh (20)	No info	English, math	No info	Acc	Improve PA	+96.2% (MVPA)
Martin and Murtagh (49)	No info	No info	No info	Acc	Improve PA	+4.2% (MVPA)
Mattson et al. (50)	CSPAP	English, math	No info	No info	Increase PA	ND
Mavilidi et al. (51)	No info	No info	Recall words, free recall, cued recall	Acc	Highest learning outcomes	+54.5% (MVPA)
Mavilidi et al. (52)	No info	Geography	No info	Acc	Positive way to increase learning	+41.9% (MVPA)
Mavilidi et al. (53)	No info	Math	Cognitive task	Acc	Improve math learning	+55.4% (MVPA)
Miller et al. (54)	PLUNGE	No info	Time on task	Pedom; TGMD-2	Improve object control motor skills proficiency and PA	+95.9% (steps/min)
Mullender-Wijnsma et al. (55)	F&V	Math, language	Time on task	20-m shuttle run test	Positively influence time on task	ND
Mullender-Wijnsma et al. (56)	F&V	Math, language	Time on task, Tempo-Test- Rekenen, Eén-Minuut-Test	No info	The lessons contributed to the academic outcomes	ND
Norris et al. (57)	Virtual Traveler	Math, English	No info	No info	Low- cost PA intervention	+7.7% (MVPA)
Norris et al. (58)	Virtual Traveler	No info	No info	Acc	Integrated PA has no negative effects on education	ND
Oliver et al. (59)	No	English, social studies, math, statistics	No info	Pedom	Significant increases in step counts	ND

(Continued)

TABLE 2 | Continued

References	Intervention	Subjects	Academic evaluation	Physical assessment	Conclusion	Effect on PA
Pham et al. (60)	BRAINball	Language, math, history, geography, biology	No info	TGMD-2	Positive effect on children's motor performances	ND
Powell et al. (61)	SHARP	No info	No info	SOFIT	Significant increases in PA	+4.1% (MVPA)
Powell et al. (62)	SHARP	No info	No info	SOFIT	Effective teaching strategy	+37% (MVPA)
Reed et al. (63)	No info	Language arts, math, and social studies	Fluid intelligence Academic performance	Pedom	Movement can influence fluid intelligence	ND
Resaland et al. (64)	ASK	Norwegian, math, English	Academic performance	Acc	No evidence to affirm the correlation	+3.4% (MVPA)
Resaland et al. (65)	ASK	Norwegian, math, English	Academic performance	Acc	Increase in academic performance	ND
Riley et al. (66)	EASY Minds	Math	On-task behavior	Acc	Improve on-task behavior in mathematics lessons	+3% (MVPA)
Robinson et al. (67)	CHAMP	No info	No info	SOFIT	Increase in PA	+9.1% (MVPA)
Ruiter et al. (68)	No info	Math	Math test, Evaluation Questions	No info	Movement conditions increase test results	ND
Schneller et al. (69)	EOtC	Math, history, language, religion	No info	Acc	Time- and cost-neutral increase time spent in PA for boys	+7.5% (MVPA)
Schneller et al. (70)	EOtC	No info	No info	Acc	Opportunity to accumulate PA	+8.4% (MVPA)
Seljebotn et al. (71)	Active school	Several subjects	No info	Acc	Increased PA	+13% (MVPA)
Trawick-Smith et al. (72)	No info	Math	TEMA-3, Communication about math	Food-fit play interactions	Teacher interactions in children's play help academic results	ND
Vazou et al. (73)	Move 4 Thought	Math	No info	Acc	Contribute to increasing PA levels	+60.6% (MVPA)
Vazou et al. (74)	Walkabouts	Math, language arts	No info	SOSMART	Academic does not impact PA	ND
Vetter et al. (75)	Maths on the move	Math	NAPLAN	Acc; shuttle run test	Improve of learning and PA	+92.7% (MVPA)
Vetter et al. (76)	No info	No info	Numeracy	Aerobic fitness	Positive combination of PA with learning	ND
Weaver et al. (78)	PACES	No info	No info	Acc	Routine practice increase PA	+5.6% (MVPA)
Weaver et al. (79)	PACES	No info	No info	Acc	Increase PA	+1.8% (MVPA)
Webster et al. (79)	PACES	No info	No info	No info	No impact	ND
Williams et al. (80)	Animal Trackers	No info	No info	No info	Increased structured PA	ND
Zachopoulou et al. (81)	Active learning	Math	TCAM test	No info	Improve creative fluency, imagination	ND
Zippert et al. (82)	Play	Math	TEMA-3, PPVT-IV	No info	Play improve math	ND

Acc, Accelerometer; ASK, Active Smarter Kids; CHAMPS, Childhood Health, Activity, and Motor Performance School Study; CSPAP, Comprehensive School Physical Activity Program; EASY, Encouraging Activity to Stimulate Young; EOtC, education outside the classroom; F&V, Fit and Academically Proficient at School; HOPP, Health Oriented Pedagogical Project; MVPA, moderate to vigorous physical activity; MFT, Multistage Fitness Test; PACER, Progressive Aerobic Cardiovascular Endurance Run; PACES, Partnerships for Active Children in Elementary Schools; PA, physical activity; PAQ-C, Physical Activity Questionnaire for Older Children; Pedom, pedometer; PLAYCE, Play Spaces and Environments for Children's Physical Activity; ND, no data; SPARK, Sports, Play, and Active Recreation for Kids; I-CAN!, Texas Initiatives for Children's Activity and Nutrition; SOFIT, System for Observing Student Movement in Academic Routines and Transitions; SOSMART, System for Observing Student Movement in Academic Routines and Transitions; TGMD-2, Test of Gross Motor Development 2.

different subjects. To learn language, children enacted the actions indicated by the words to be learned by physically exercising (i.e., for the word "fly," children ran and moved their hands as if they were flying) (51). To learn geography, children "traveled" from one continent to the other, imitating the movements of the animal representing the continent (52). To learn math, foam blocks of numbers were placed on the floor, shaping a straight line, and the children ran, jumped, and stepped each time on one number while counting or walked or ran backward, sideward, or forward (53). A similar intervention to learn geography was the one proposed by Oliver et al. (59). Norris et al. (57) proposed in their intervention presentation sessions known as Virtual Field Trips, designed to be delivered using existing classroom interactive whiteboards. Similarly, children autonomously navigated through two skill stations with at least three levels of difficulty at each station (67). Other language and mathematics interventions consisted in the performance of a spell by jumping in place for every mentioned letter or to jump

to solve multiplications. Similar academic tasks with different words or sums were exercised during one lesson (55, 56). Other interventions consisted in building two-digit numbers by making and simultaneously verbalizing out loud different-sized steps (68). Students stand on their self-space and jump the answer to a problem the teacher provided and the second by moving around the classroom, picking a card with a problem working as a group or with a partner (73). Locomotor skills of running, skipping, hopping, and galloping (75) integrating structured movement and motor skill practice with preschool learning concepts and integrating auditory, visual, and kinesthetic learning methods (80) were also proposed. Use and modification of movement elements, development of creative thinking during movement activities through exploration, use of movement for experienced learning of concepts of different teaching thematic areas such as mathematics, and development of critical thinking during movement activities were also adopted (81).

DISCUSSION

The findings of the review highlighted that different interventions were proposed to teach different curriculum subjects through movement with a lack of standardization in the protocols adopted by the authors (**Table 2**).

Similar to the findings of Erwin and colleagues, physical activity integrated in the academic curriculum is proposed with other interventions (such as breaks), and the details on the effect on children's learning and physical fitness are not always provided (21). It is important to propose a structured intervention; only in this way that it is possible to contextualize and generalize the finding and make the procedure safer (83), and the teachers have a crucial role in following the procedures proposed (22). Differences were also detected in the length, duration, and week frequency, making impossible a comparison among the studies. These findings are similar to the study by Daly-Smith and colleagues, where differences in the design, interventions, duration and intensity, and outcomes were detected (84). The intervention duration in this study started from 5 days arriving to more 1,000 days, differently from other studies in which the intervention ranged from 13 to 300 days (21). Even if the literature suggests that the length of the intervention did not influence the effect of the intervention (21), a short-duration program is not useful to have a long-term improvement on academic performance (85). Furthermore, it is important to propose the integrated programs in daily or weekly schedule because it increases also the physical activity during the school day, and it is feasible (86). Ideally, the physical activity interventions should be three times per week to obtain the best results on children's cognitive and achievement outcomes (16).

Differences were detected also in the interventions. The movement integration program wants to teach students through the movement. It is well-known that physical activity interventions have a positive effect on cognitive performance and academic performance in children (87, 88). Integrated physical activity in the classroom can increase children's academic intrinsic motivation, perceived competence, and effort without influencing academic lessons (89).

For those studies that proposed play as an intervention, positive outcomes have been detected. Learning through play forces children to make choices and assuming responsibility having fun at the same time, working on the internal cognitive transactions and intrinsic motivation, determine life habits (90). Play should have to be enjoyable, freely chosen, non-literal safe, and actively engaged; only in this way that learning is through intrinsic motivation (90).

Other interventions, instead, were based outdoors. This way of learning can be incorporated within conventional teaching methods (91); it increases physical activity and reduces sedentary behaviors (92). Open learning environments want to educate the students with own initiative, planning, experimentation, elaboration, and self-evaluation, which is an interesting way (26).

The interventions showed improvements in the academic outcomes, motor skills, or amount of physical activity (through step count), but an important point is that they are cost-effective, teachers are not required to prepare them, and they are enjoyable both for teachers and children (5), making them ideal for primary schools. The advantage of a classroom-based physical activity program integrated in the school curriculum is that it takes time from other subjects, but improves physical activity and on-task behavior without sacrificing or influencing academic performance (93, 94). Furthermore, physical education in elementary school children has no negative effects on standardized academic achievement test scores (95). Indeed, physical activity improves mathematics-related skills, reading, and composite scores such as the classroom behaviors, suggesting physical exercise lessons in the curriculum and physical activity integration in classroom lessons (96). Even brief bouts (1 h long) of outdoor active play can improve on-task behavior (97). The level of physical activity enjoyed outdoors on the playground is higher, and the increase in on-task classroom behavior is greater; simple play outdoors seems to be not sufficient (97). Physical activity incorporated into the school day improves attention to task (98). Physical, active academic lessons have several benefits for schools and students; indeed, they are cost-effective. Children and teachers enjoy them. They do not require additional teacher preparation time and improve academic achievement scores (5).

Limitations and Future Studies

Data obtained from accelerometers were not analyzed because of the limitation of this tool in detecting activities performed with the upper body (30). Furthermore, the studies included in the review present a wide variety of testing conditions and interventions, making the performance of a meta-analysis impossible. The sample background (physical activity participation outside the school, social status, or other influencing factors) was not detected, making the comparison even harder.

The study has been focused only on a specific population. It has been suggested by the literature (16) that children with learning disabilities also present improvements in academic abilities when physical activity interventions are adopted, making the study of these interventions also in this population even

more important. There is a lack of heterogeneity among the study interventions, with differences not only in the length of the program, duration of the session, and frequency but also in the intervention methodology and in the subjects included in the programs. Differences were also in the outcome studies, both for physical activity and academic performance evaluation. Future studies should focus their attention on review of the literature about physical activity breaks during classroom time to improve physical fitness and academic performance. Attention should be focused also on interventions performed in nature, for two reasons: first, the intervention moves the children outside, and second, this intervention can help the children to understand the importance of nature.

CONCLUSION

All the interventions, despite differences in the protocols, have a common aspect: they improve physical activity and/or academic performance, making this kind of approach ideal in elementary schools.

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

GC and MB: conceptualization. CG: methodology. JB and FR: investigation. DLV: resources. LP: writing—original draft. ET and AS: writing—review and editing. MB: supervision. All authors contributed to the article and approved the submitted version.

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frontiers in Public Health

ORIGINAL RESEARCH
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Consequences of COVID-19 Lockdown Restrictions on Children Physical Activity—A Slovenian Study

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During the COVID-19 pandemic, countries took several restrictions to contain the spread of coronavirus. In the second wave of the COVID-19 pandemic, primary schools in Slovenia were closed for a period long time (from October 19th 2020 until January 18th 2021 when they were partially reopened for 6–9 year olds until February 15th 2021 when they were reopened for all children) and organized sport activities for children and adolescents under the age of 15 was not allowed during this period. The aim of the study was to examine how these restrictions were reflected in the amount of different forms of physical activity (PA) of 6–12-year old children ($N = 3{,}936$). Data were collected using an online questionnaire (International Physical Activity Questionnaire Short Form) comparing different forms of PA before (BEFORE) and during (DURING) remote schooling. The results show that there has been a decline in children's PA DURING, specifically, only 4.3% of children had their physical education $\geq$ 45 min (or 77.7% $\leq$ 30 min), as is the usual duration in Slovenia. There was also a remarkable decline in extracurricular sports activities ($p < 0.001$), which BEFORE had been participated by 72.2% of children, while DURING remote schooling, as many as 83.5% of children did not participate these activities. 69.7% of children participated in organized sports in clubs at least once a week, while DURING remote schooling, as many as 88.1% ($p < 0.001$) did not participate in such form of activities. Furthermore, the time spent exercising in moderate to vigorous PA also decreased (BEFORE 8.2% vs. DURING 24.9%; $p < 0.001$). We found that during lockdown there has been an alarming decrease in the frequency and duration of organized PA at school and at sports clubs. These findings are a good starting point for designing (developing) an effective strategy for promoting health-enhancing PA of children in the event of a future lockdown or similar situations. The strategy should focus on the appropriate implementation of PA curriculum and motivate young people to participate regularly in extracurricular organized and non-organized activities.

Keywords: COVID-19 pandemic, physical activity, children, remote schooling, physical education

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INTRODUCTION

The COVID-19 pandemic, public health recommendations and governmental measures have enforced lockdowns and restrictions. While these restrictions help to abate the rate of infection, such limitations result in negative effects by limiting participation in normal daily activities, physical activity (PA), travel and access to many forms of exercise (e.g., closed gyms, no group gatherings, increased social distancing). Even more, several countries imposed long-lasting curfews, one of the longest (174 days) in Slovenia, limiting or eliminating time for outdoor activities. Although the restrictions help to limit the spread of the virus, they also impose a direct and indirect burden on public health.

Globally, a multicentric 22-country study revealed that the COVID-19 home confinement has had a medium to large (23–43%) negative effect on all levels of PA (vigorous, moderate, walking and overall) and a large increase in daily sitting time by more than 28% in adults (1). However, effects of COVID-19 lockdown on children were even greater than on adolescents and adults or seniors (2) where authors reported a 42% decreased in PA, a 36% increase in sitting time and a 62% increase in screen time for children.

PA (in combination with sedentary behavior) is associated with numerous health benefits for children and adolescents, including cardiometabolic health, motor skill development, bone density, and emotional regulation/psychological health (3, 4). However, even prior to the COVID-19 pandemic, <10% of school aged (5–17 years) children achieved recommended amounts of physical PA (5). Since the onset of the COVID-19 pandemic only 4.8% of Canadian children were meeting PA guidelines (6). Furthermore, there are limited data investigating changes in children's PA levels during COVID-19 pandemic compared to before pandemic. Among children PA levels decreased, and screen time increased by 52 and 145% in Spain (7), by 32 and 54% in Germany (8) by 64 and 175% in Italian children (9), respectively.

During 2020 an estimated 1.5 billion children (age 5–12 years old) and adolescents (age 13–17 years old) transitioned to remote schooling following school closures or partially closures (10). During the 2nd wave of the COVID-19 pandemic, Slovenian primary schools were closed from October 19th 2020, until January 18th 2021 when they were partially opened for 6–9 year olds and from February 15th 2021 for all children. In total, Slovenian children did not attend school for 89 calendar days or 60 working days. In parallel, all curricular and extracurricular sports programs were completely closed for the same period, while most of sport programs were closed for the entire 2020/21 school year.

Despite the benefits of PA on child health and wellbeing, new data suggest that during COVID-19 pandemic, access to health-promoting PA has been largely disrupted, whereas use of screen-based media for education and recreation has increased (11–14) when compared to studies from before the COVID-19 pandemic (15, 16). Important here is to know that short-term changes in PA and sedentary behavior in reaction to COVID-19 may become permanently entrenched, leading to increased risk of obesity, diabetes, and cardiovascular disease in children (11). During the COVID-19 restrictions, USA children spent 90 min in school-related sitting with over 8 h of leisure time sitting, where greater decrease in PA and increase in sitting time was reported in adolescents when compared to younger children (11). Additionally, school physical education (PE) represents the largest youth PA intervention worldwide. And school closures due to COVID-19 created a new set of obstacles as PE shifted from playgrounds and gyms to virtual learning platforms (17). Despite the considerable amount of research, especially on general effects on children's PA, physical inactivity and sedentary behavior associated with screen time, the little is known about the implementation of PE (on-line)clasess in the period of COVID-19 restrictions. Compering PE implementation time with a comprehensive analysis of school-based and extracurricular physical/sport activity in children before and during the COVID-19 restriction is still a missing gap in the field of study.

Increased physical inactivity level is not only regularly associated with increased risk of severe health outcomes in adults, but also with adiposity, lipid profile, insulin and glucose levels, blood pressure and other cardiovascular risks in children (18). Furthermore, it is also associated with serious COVID-19 outcomes in adults (19). Therefore, it would be of great interest to limit the level of physical inactivity already in children, especially if it occurs regularly in secular trends and during COVID-19 pandemics.

The aim of the study is to evaluate the changes in curricular physical education (PE) and leisure PA during COVID-19 restrictions compared to period before. Specifically, we focused on the implementation of PE in schools, extracurricular sports activities organized by schools, organized activities in sports clubs, and non-organized PA with friends, family or individually.

MATERIALS AND METHODS

Data Collection From the Questionnaire Survey

An on-line survey was created about PA, quality of life, and eating habits of primary school students. The survey was intended for parents of second to fifth grade students aged 6 to 12 years (mean = 8.81, SD = 1.46) in Slovenia. The time frame of the survey refers to the period before (BEFORE) the outbreak of the epidemic (March 12, 2020) and the imposed measures to contain the COVID-19 epidemic as well as to the period when the transition to remote schooling was ordered at the state level (DURING). The survey was conducted in the period from 23 December 2020 to 15 January 2021, i.e., for a total duration of 24 days. An invitation to participate in the survey with a detailed explanation for school principals and parents, was sent to all primary school in Slovenia by the Director-General of the Directorate for Preschool and Primary Education of the Ministry of Education, Science and Sport. The research group also sent the invitation directly to primary schools. Parents as the target group were invited through a circular letter from the of Slovenian primary school principals, while it was also the task of classroom teachers to invite parents to participate.

TABLE 1 | Demographic characteristics of the participants.

Variable	Demographic characteristics	Frequency	%
Gender	Boys	2,070	52.6
	Girls	1,866	47.4
Age (years)	6	79	2.0
	7	781	19.8
	8	939	23.9
	9	829	21.1
	10	870	22.1
	11	191	4.9
	12	247	6.3
Number of household members	2	111	2.8
	3	668	17.0
	4	2,108	53.6
	5	753	19.1
	6	219	5.6
	>6	77	2.0
Region	1. Upper Carniola region	259	6.6
	2. Gorizia region	276	7.0
	3. Southeast Slovenia region	354	9.0
	4. Carinthia region	146	3.5
	5. Coastal-Karst region	210	5.3
	6. Central Slovenia region	895	22.7
	7. Drava region	489	12.4
	8. Mura region	343	8.7
	9. Lower Sava region	153	3.9
	10. Littoral-Inner Carniola region	216	5.5
	11. Savinja region	433	11.0
	12. Central Sava region	162	4.1

TABLE 2 | Duration of an individual session of PE during lockdown.

Duration of exercise session	Frequency	%
<15 min	1,520	38.6
16–30 min	1,538	39.1
31–44 min	708	18.0
≥45 min	170	4.3
Total	3,936	100

During the period up to 15 January 2021, 5,282 clicks were received in response to the invitation and 4,737 (90%) parents and guardians chose to complete the survey, representing a high response rate. Three thousand nine hundred and thirty-six (74%) questionnaires completed for PA domain, were accepted for further analysis.

Participation in the online survey was voluntary and respondents could opt out at any time before the survey was completed. By clicking on survey, parents and guardians agreed to participate and additionally received additional instructions on how to complete the survey.

Survey Questionnaires

The questionnaire entitled "CHILDREN AND MEASURES DURING THE COVID-19 EPIDEMIC" comprises of 58 variables and 29 questions divided in four sets, i.e.,:

- The socio-demographic section to collect basic demographic data of children, related to the current status of the child and the family;
- The standardized International Physical Activity Questionnaire—Short form (IPAQ-SF) (20). For the needs of the survey, the IPAQ-SF questionnaire was translated by a certified translator and slightly amended for the needs of the survey to collect parents' assessments of the child's PA. Specifically, we added questions to collect data on the child's inclusion and implementation of physical education (PE); extracurricular, school- and sport club-organized sport activities; and non-organized PA (with friends, family or individually). All questions were referred to BEFORE and DURING lockdown, meaning that every question required two answers. Responses related to the duration of PA were defined in terms of categorical ordinal variables as labeled in row/column labels in **Tables 2–10**. Such formulation of answers facilitated parents' responses regarding the duration of PA, as parents are not with their children all day and therefore it is difficult to estimate the duration in minutes. Therefore, only frequencies were reported and analyzed for each variable.
- Standardized KINDL–R (Questionnaire for Measuring Health-Related Quality of Life in Children and Adolescents), (21). The parents' version of the questionnaire was selected to meet the needs of the project (1.2.2 Parents' versions KINDL). This standardized questionnaire was also translated from English into Slovenian by a certified translator. Back translation was also done to ensure the validity of the translation. Data on these are not included in this report.
- Questionnaire on the child's eating habits, with questions on frequency of consumption of unhealthy and healthy food and beverages as well as eating habits and regular meals, again for the period before and during remote schooling. Data on these are not included in this report.

Data Privacy

Parents and guardians who responded to the survey, were informed in the introductory section that all data would be processed and managed in compliance with the provisions of the applicable legislation on the protection of personal data and the General Data Protection Regulation (GDPR). Respondents' answers were anonymous and confidential and are kept for research purposes in the archives of the survey providers, the Faculty of Education of the University of Maribor and the Science and Research Centre Koper. The survey questionnaire does not contain any personal data (name, date of birth or other contact information) that would allow the respondents identification. It also does not contain any ethically or morally disputable questions.

TABLE 3 | Contingency table for comparison of frequency (category percentages for during; category percentages for before) of participation in school extracurricular sports activities before and during lockdown.

		DURING						
		Never	**1 session**	**2 sessions**	**3 sessions**	**>3 sessions**	**Total ≥1 sessions**	**Total**
BEFORE	Never	1,078 (32.8; 98.6)	4 (1.3; 0.4)	8 (5.0; 0.7)	3 (2.6; 0.3)	0 (0; 0)	15 (2.3; 1.4)	1,093 (27.8; 100)
	1 session	721 (21.9; 83.8)	115 (37.3; 13.4)	12 (7.5; 1.4)	6 (5.2; 0.7)	6 (9.2; 0.7)	139 (21.4; 16.2)	860 (21.8; 100)
	2 sessions	846 (25.7; 82.5)	85 (27.6; 8.3)	75 (46.6; 7.3)	12 (10.3; 1.2)	7 (10.8; 0.7)	179 (27.5; 17.5)	1,025 (26.0; 100)
	3 sessions	401 (12.2; 70.0)	63 (20.5; 11.0)	40 (24.8; 7.0)	59 (50.9; 10.3)	10 (15.4; 1.7)	172 (26.5; 30.0)	573 (14.6; 100)
	>3 sessions	240 (7.3; 62.3)	41 (13.3; 10.6)	26 (16.1; 6.8)	36 (31.0; 9.4)	42 (64.6; 10.9)	145 (22.3; 37.7)	385 (9.8; 100)
	Total	3,286 (100; 83.5)	308 (100; 7.8)	161 (100; 4.1)	116 (100; 2.9)	65 (100; 1.7)	650 (100; 16.5)	3,936 (100; 100)

$\chi^2 = 383.2$; $p < 0.001$.

TABLE 4 | Contingency table for comparison of frequency (category percentages for during; category percentages for before) of duration of an individual session of extracurricular sport activities before and during lockdown.

		DURING			
		≤45 min	**46–60 min**	**>60 min**	**Total >0 min**
BEFORE	≤45 min	445 (79.7; 92.7)	24 (23.1; 5.0)	11 (25.0; 2.3)	480 (68.0; 100)
	46–60 min	74 (13.3; 53.2)	61 (58.7; 43.9)	4 (9.1; 2.9)	139 (19.7; 100)
	>60 min	39 (7.0; 44.8)	19 (18.3; 21.8)	29 (65.9; 33.3)	87 (12.3; 100)
	Total	558 (100; 79.0)	104 (100; 14.7)	44 (100; 6.2)	706 (100; 100)

$\chi^2 = 267.0$; $p < 0.001$.

Statistical Analysis

The data from the questionnaire were processed with SPSS, version 21. Descriptive statistics were calculated (mean, standard deviation, frequency). The χ^2 test was carried out to analyse differences in all PA variables BEFORE and DURING lockdown. The level of significance was set at $p < 0.05$.

RESULTS

Sample Description

The questionnaire on PA was completed in full by parents and guardians of 3,936 children; of these 2,070 (52.6%) were boys and 1,866 (47.4%) were girls. The age range of children was from 6 to 12 years (mean = 8.81 years, SD = 1.46). Respondents came from all 12 Slovenian regions. The detailed data are presented in **Table 1**.

Physical Activity

In Slovenia, PE takes place three times a week in primary school, for the age group of children in the selected sample. The duration of a single PE session is 45 min and one of its objectives is to encourage children to engage/to achieve moderate to vigorous physical activity (MVPA). DURING lockdown, PE was implemented in a variety of ways. Teachers provided online instructions to students via text or videos, while PE sessions were also delivered live, via video call. The results in **Table 2** show that 38.6% of PE session lasted < 15 min, 39.1% lasted from 16 to 30 min, 18% from 31 to 44 min, and only 4.3% of students exercised ≥45 min, which is also the learning objective. This means that overall, of 95.7% of the students had a substantially shorter duration of PE sessions DURING lockdown than in the period BEFORE lockdown.

Table 3 shows a decline in participation in school extracurricular sports activities BEFORE and DURING lockdown ($\chi^2 = 383.2$; $p < 0.001$) after grouping DURING data in two categories: never and ≥1 session (grouping categories: 1 session, 2 sessions, 3 sessions, >3 sessions). In particular, 72.2% of children participated in at least one school extracurricular sports activity BEFORE, while DURING 83.5% of them did not. BEFORE, 21.8% of children participated in one session per week and DURING lockdown this proportion decreased to 7.8%. BEFORE lockdown, 26% of children participated two sessions, while DURING lockdown only 4.1% had two sessions per week. BEFORE lockdown, 14.6% of children participated in three sessions a week and DURING lockdown only 2.9% continued this practice. 9.8% of children had more than three weekly sessions BEFORE lockdown and DURING lockdown only 1.7% remained included/persisted.

Table 4 shows the differences in duration of an individual/single session in extracurricular sport activities between BEFORE and DURING lockdown ($\chi^2 = 267.0$; $p < 0.001$). The duration of individual sessions mainly decreased. BEFORE lockdown, 68% of children engaged in sessions of duration ≤45 min and DURING lockdown this proportion increased to 79.0%. BEFORE, 19.7% of children participated in sessions 46–60 min long and DURING lockdown this percentage fell to 14.7%. Sessions longer than 60 min BEFORE lockdown were reported by 12.3% of the respondents, while

TABLE 5 | Contingency table for comparison of frequency (category percentages for during; category percentages for before) of participation in sports clubs before and during lockdown.

		DURING						
		Never	**1 session**	**2 sessions**	**3 sessions**	**>3 sessions**	**Total ≥1 sessions**	**Total**
BEFORE	Never	1,183 (34.1; 99.3)	5 (3.3; 0.4)	0 (0; 0)	1 (1.4; 0.1)	2 (4.0; 0.2)	8 (1.7; 0.7)	1,191 (30.3; 100)
	1 session	558 (16.1; 90.6)	50 (37.3; 13.4)	5 (7.5; 1.4)	2 (5.2; 0.7)	1 (9.2; 0.7)	58 (12.3; 9.4)	616 (15.7; 100)
	2 sessions	948 (27.4; 84.8)	49 (32.0; 4.4)	109 (55.9; 9.7)	8 (11.1; 0.7)	4 (8.0; 0.4)	170 (36.2; 15.2)	1,118 (28.4; 100)
	3 sessions	509 (12.2; 70.0)	30 (20.5; 11.0)	49 (24.8; 7.0)	35 (50.9; 10.3)	8 (15.4; 1.7)	122 (19.3; 26.0)	631 (14.6; 100)
	>3 sessions	268 (7.7; 70.5)	19 (12.4; 5.0)	32 (16.4; 8.4)	26 (36.1; 6.8)	35 (70.0; 9.2)	112 (23.8; 29.5)	380 (9.8; 100)
	Total	3,466 (100; 88.1)	153 (100; 3.9)	195 (100; 5.0)	72 (100; 1.8)	50 (100; 1.3)	650 (100; 12.0)	3,936 (100; 100)

$\chi^2 = 302.8$; $p < 0.001$.

TABLE 6 | Contingency table for comparison of frequency (category percentages for during; category percentages for before) of duration of an individual session in sports clubs before and during lockdown.

		DURING				
		≤30 min	**31–45 min**	**46–60 min**	**>60 min**	**Total**
BEFORE	≤30 min	15 (22.1; 93.8)	1 (1.1; 6.3)	0 (0)	0 (0)	16 (3.4; 100)
	31–45 min	9 (13.2; 22.5)	29 (30.5; 72.5)	2 (1.1; 5.0)	0 (0)	40 (8.5; 100)
	46–60 min	18 (26.5; 10.6)	30 (31.6; 17.6)	117 (63.9; 68.8)	5 (4.1; 2.9)	170 (36.2; 100)
	>60 min	26 (38.2; 10.7)	35 (36.8; 14.4)	64 (35.0; 26.3)	118 (95.9; 48.6)	243 (51.8; 100)
	Total	68 (100; 14.5)	95 (100; 20.3)	183 (100; 39.0)	123 (100; 26.2)	469 (100; 100)

χ^2 *(Likelihood Ratio)* $= 274.0$; $p < 0.001$.

for the period DURING lockdown this percentage fell to only 6.2%.

Table 5 shows a major decline in the participation in MVPA in sports clubs BEFORE and DURING lockdown ($\chi^2 = 302.8$; $p < 0.001$) after grouping DURING data in two categories: never and ≥1 session (grouping categories: 1 session, 2 sessions, 3 sessions, >3 sessions). We found that BEFORE lockdown, 69.7% of children participated in at least one session weekly. In the period DURING, this changed substantially, as 88.1% did not engage in such activities at all. BEFORE, 15.7% of children had one session and in the period DURING this percentage fell to 3.9%. BEFORE lockdown, 28.4% of children participated in two sessions, while DURING lockdown only 5% had two sessions a week. In the period BEFORE, 14.6% of children participated in three sessions a week and in the period DURING, this percentage stood at 1.8%. BEFORE lockdown, 9.8% of children participated in more than three sessions, while DURING lockdown only 1.3% had three sessions a week.

The results in **Table 6** show the difference in duration of an individual/single session in sports clubs BEFORE and DURING lockdown ($\chi^2 = 274.0$; $p < 0.001$; due to the low values of individual frequencies, the χ^2 Likelihood Ratio has been used in some cases). BEFORE lockdown, 3.4% of children engaged in sessions of duration ≤ 30 min and DURING lockdown this proportion increased to 14.5%. BEFORE 8.5% of children participated in sessions lasting 31–45 min and DURING lockdown this percentage stood at 20.3% of children. Sessions lasting 40–60 min BEFORE lockdown were reported by 36.2% of the respondents, while for the period DURING lockdown this percentage stood at 39%. Sessions lasting longer than 60 min BEFORE lockdown were reported by 51.8% of respondents, while this percentage for the period DURING lockdown was only 26.2%. To summarize, the longer the duration of the session, the smaller the proportion of the children DURING compared to BEFORE.

Table 7 shows differences in the participation in non-organized MVPA between BEFORE and DURING lockdown ($\chi^2 = 967.0$; $p < 0.001$) after grouping DURING data in two categories: never and ≥ 1 session (grouping categories: 1 session, 2 sessions, 3 sessions, >3 sessions). BEFORE lockdown, 8.2% of children did not participate in such sessions, while in the period DURING lockdown this proportion increased to 24.9%. BEFORE, 18.6% of children participated in one session per week and DURING lockdown this proportion increased to 20.2%. BEFORE lockdown, 23.6% of children participated in two sessions, while DURING lockdown this proportion decreased to 17.8%. In the period BEFORE, 17.4% of children participated in three sessions per week and in the period DURING, this percentage stood at 12.1%. BEFORE lockdown, 32.3% of children participated in more than three sessions and DURING lockdown this proportion fell to 24.8%. The results show that the proportion of active children in non-organized MVPA BEFORE and DURING slightly decreased, however significantly less than in organized sports activities.

Table 8 shows difference in the duration of an individual session in non-organized MVPA between BEFORE and DURING

TABLE 7 | Contingency table for comparison of frequency (category percentages for during; category percentages for before) of participation in non-organized moderate-to-vigorous physical activity before and during lockdown.

		DURING						
		Never	**1 session**	**2 sessions**	**3 sessions**	**>3 sessions**	**Total ≥ 1 sessions**	**Total**
BEFORE	Never	296 (30.1; 91.9)	13 (1.6; 4.0)	8 (1.1; 2.5)	1 (0.2; 0.3)	4 (0.4; 1.2)	26 (0.9; 8.1)	322 (8.2; 100)
	1 session	212 (21.6; 29.0)	316 (39.6; 43.2)	107 (15.3; 14.6)	64 (13.4; 8.8)	32 (3.3; 4.4)	519 (17.6; 71.0)	731 (18.6; 100)
	2 sessions	236 (24.0; 25.4)	198 (24.8; 21.3)	276 (39.4; 29.7)	88 (18.4; 9.5)	131 (13.4; 14.1)	693 (23.5; 74.6)	929 (23.6; 100)
	3 sessions	123 (12.5; 18.0)	136 (17.1; 19.9)	117 (16.7; 17.1)	219 (45.8; 32.0)	89 (9.1; 13.0)	561 (19.0; 82.0)	684 (17.4; 100)
	>3 sessions	115 (11.7; 9.1)	134 (16.8; 10.6)	193 (27.5; 15.2)	106 (22.2; 8.3)	722 (73.8; 56.9)	1,155 (39.1; 90.9)	1,270 (32.3; 100)
	Total	982 (100; 24.9)	797 (100; 20.2)	701 (100; 17.8)	478 (100; 12.1)	978 (100; 24.8)	2,954 (100; 74.9)	3,936 (100; 100)

$\chi^2 = 967.0; p < 0.001.$

TABLE 8 | Contingency table for comparison of frequency (category percentages for during; category percentages for before) of duration of an individual session of non-organized moderate-to-vigorous physical activity before and during lockdown.

		DURING				
		≤30 min	**31–45 min**	**46–60 min**	**>60 min**	**Total**
BEFORE	≤30 min	249 (38.5; 75.5)	48 (6.4; 14.5)	24 (2.8; 7.3)	9 (1.1; 2.7)	330 (10.8; 100)
	31–45 min	174 (26.9; 22.7)	449 (59.7; 58.7)	108 (12.7; 14.1	34 (4.3; 4.4)	765 (25.1; 100)
	46–60 min	136 (21.0; 13.7)	157 (20.9; 15.8)	574 (67.5; 57.6	129 (16.2; 13.0)	996 (32.7; 100)
	>60 min	88 (13.6; 9.2)	98 (13.0; 10.3)	145 (17.0; 15.2)	625 (78.4; 65.4)	956 (31.4; 100)
	Total	647 (100; 21.2)	752 (100; 24.7)	851 (100; 27.9)	797 (100; 26.2)	3,047 (100; 100)

$\chi^2 = 2,343.6; p < 0.001.$

lockdown ($\chi^2 = 2343.6$; $p < 0.001$). In general, the duration of individual sessions slightly decreased. BEFORE lockdown, 10.8% of children engaged in sessions of duration ≤30 min and DURING lockdown this proportion increased to 21.2%. Sessions in duration of 31–45 min BEFORE lockdown were reported by 25.1% of the respondents, while this percentage for the period DURING lockdown stood at 24.7%. BEFORE, 32.7% of children participated in sessions lasting 46–60 min and DURING lockdown this percentage stood at 27.9%. Sessions lasting longer than 60 min BEFORE lockdown were reported by 31.4% of the respondents, while this percentage for the period DURING lockdown was at 26.2%.

Table 9 shows differences in the participation in non-organized light physical activity (LPA) between BEFORE and DURING lockdown ($\chi^2 = 689.7$; $p < 0.001$) after grouping DURING data in two categories: never and ≥1 session (grouping categories: 1 session, 2 sessions, 3 sessions, >3 sessions). We found that BEFORE lockdown, 95.2% of children participated in at least one session a week. DURING lockdown, the percentage of such children stood at 87%. BEFORE, 16.7% of children participated in one session a week and in the period DURING, this percentage stood at 16.1%. BEFORE lockdown, 24.5% of children participated in two sessions and DURING lockdown only 19.1% had two sessions a week. BEFORE, 17.7% of children had three sessions a week and in the period DURING this percentage stood at 16.4%. BEFORE lockdown, 36.3% of children participated in more than three sessions, while DURING lockdown this percentage stood at 35.4%.

The results in **Table 10** show difference in the duration of non-organized LPA between BEFORE and DURING lockdown ($\chi^2 = 3145.9$; $p < 0.001$). BEFORE lockdown, 12.3% of children engaged in sessions of duration ≤ 30 min and DURING lockdown this proportion increased to 17.9%. BEFORE, 26.2% of children participated in sessions lasting 31–45 min and DURING lockdown this percentage stood at 24.7%. Sessions lasting 40–60 min BEFORE lockdown were reported by 31.2% of respondents, while this percentage for the period DURING lockdown was at 27.9 %. Sessions lasting longer than 60 min BEFORE lockdown were reported by 30.4% of the respondents, while this percentage for the period DURING lockdown stood at 29.5%.

DISCUSSION

The purpose of this study was to examine how the restrictions, which were imposed due to COVID-19 pandemic, have been reflected in the implementation of the different forms of PA of children aged 6–12 years. We found that DURING lockdown, PE was implemented by teachers providing students with online instructions, in the form of text or videos, while PE sessions were also held live, via video call. The fact is that shift to remote schooling was a major challenge for teachers. At the same time, it was also unclear which strategies were the most effective for the remote implementation of PE. The results of our study show that a total of 95.7% of students had a substantially shorter implementation of

TABLE 9 | Contingency table for comparison of frequency (category percentages for during; category percentages for before) of participation in non-organized light physical activity before and during lockdown.

		DURING						
		Never	**1 session**	**2 sessions**	**3 sessions**	**>3 sessions**	**Total ≥1 sessions**	**Total**
BEFORE	Never	137 (26.9; 73.3)	17 (2.7; 9.1)	14 (1.9; 7.5)	9 (1.4; 4.8)	10 (0.7; 5.3)	50 (1.5; 26.7)	187 (4.8; 100)
	1 session	97 (19.0; 14.8)	257 (40.5; 39.2)	110 (14.6; 16.8)	94 (14.6; 14.3)	98 (7.0; 14.9)	559 (16.3; 85.2)	656 (16.7; 100)
	2 sessions	137 (26.9; 14.2)	150 (23.7; 15.5)	371 (49.3; 38.4)	116 (18.0; 12.0)	192 (13.8; 19.9)	829 (24.2; 85.8)	966 (24.5; 100)
	3 sessions	63 (12.4; 9.0)	101 (15.9; 14.5)	110 (14.6; 15.8)	289 (44.8; 41.4)	135 (9.7; 19.3)	635 (18.5; 91.0)	698 (17.7; 100)
	>3 sessions	76 (14.9; 5.3)	109 (17.2; 7.6)	147 (19.5; 10.3)	137 (21.2; 9.6)	960 (68.8; 67.2)	1,353 (39.5; 94.7)	1,429 (36.3; 100)
	Total	510 (100; 13.0)	634 (100; 16.1)	752 (100; 19.1)	645 (100; 16.4)	1,395 (100; 35.4)	3,426 (100; 100)	3,936 (100; 100)

$\chi^2 = 689.7; p < 0.001.$

TABLE 10 | Contingency table for comparison of frequency (category percentages for during; category percentages for before) of duration of an individual session of non-organized light physical activity before and during lockdown.

		DURING				
		≤ 30 min	**31-45 min**	**46-60 min**	**>60 min**	**Total**
BEFORE	≤30 min	304 (50.2; 73.3)	56 (6.7; 13.5)	38 (4.0; 9.2)	17 (1.7; 4.1)	415 (12.3; 100)
	31–45 min	129 (21.3; 14.6)	553 (66.4; 62.2)	136 (14.4; 15.4)	66 (6.6; 7.5)	884 (26.2; 100)
	46–60 min	105 (17.4; 10.0)	134 (16.1; 12.7)	653 (69.2; 62.0)	161 (16.2; 15.3)	1,053 (31.2; 100)
	>60 min	67 (11.1; 6.5)	90 (10.8; 8.8)	116 (12.3; 11.3)	752 (75.5; 73.4)	1,025 (30.4; 100)
	Total	605 (100; 17.9)	833 (100; 24.7)	943 (100; 27.9)	996 (100; 29.5)	3,377 (100; 100)

$\chi^2 = 3,145.9; p < 0.001.$

PE sessions DURING lockdown than in the period BEFORE lockdown. Worryingly, 38.6% of students engaged in PE sessions of <15 min and as many as 77.7 % of children performed PE sessions of lasting ≤30 min DURING lockdown. This was much less than required by school curriculum (45 min).

A significant decline was also noted in children's participation in school extracurricular sports activities. In the period BEFORE lockdown, 72.2% of children participated in at least one school extracurricular sports activity a week. In the period DURING lockdown, 83.5% of children did not participate in any such activity. There was a decrease in the weekly number of sessions in school extracurricular sports activities as well as a decline in the duration of individual sessions. A decrease of children' participation in sports sessions held in sports clubs was noted. BEFORE lockdown, 69.7% of children attended at least one session weekly. In the period DURING, as many as 88.1% of children did not participate in such activities at all. The weekly number of these sessions per child and the duration of a single session also decreased. The situation is similar, though slightly better, in non-organized MVPA. We found that BEFORE lockdown, 8.2% of children did not engage in this type of activity, while this percentage DURING lockdown stood at 24.9%. The duration of individual sessions in non-organized MVPA also declined slightly in the period DURING compared to the period BEFORE lockdown. The results show that the proportion/percentage of active children in non-organized MVPA BEFORE slightly decreased, however much less than in organized sports activities. The same also applies to the duration of individual/single sessions. We found that BEFORE lockdown, 95.2% of children participated in at least one session of non-organized LPA a week. DURING lockdown, the percentage of such children was 87%. The duration of individual sessions was slightly longer BEFORE compared to the DURING lockdown period. Again, it was found that there were no major differences between the period BEFORE and DURING lockdown.

To date, no research has been observed which address the frequency and duration of PE in schools, extracurricular sports activities organized by schools, organized activities in sports clubs, and non-organized PA for the COVID-19 lockdown period. However, the results of our study are consistent with other individual studies that found that COVID-19 lockdown had a major negative effect on all PA intensity levels, while also increasing daily sitting time (1, 22). Genin et al. (2) found that the effects of COVID-19 lockdown on children were even greater than those on adolescents and adults. In Canada, an international survey (6) showed that during lockdown a very small proportion of children met PA recommendations. At the same time, the decrease in PA was paralleled to increased sitting and screen time (9). Ding et al. (23) report on the COVID-19 lockdown which led to a substantial decline of PA levels in 11 countries across the globe. The authors thus recommend that countries implement PA promotion interventions. Another study found a substantial decrease in PA levels during leisure time, PE, and recess of Czech children during the COVID-19 lockdown (24). During the

COVID-19 lockdown, older students in Norway recorded higher PA levels compared to younger students (25). The authors raise the questions of whether older students were given too much responsibility for their own PA during this period and whether teachers should offer students more remote workout sessions using digital technologies.

An increase in physical inactivity, or a decrease in PA, during the COVID-19 epidemic was also reported by Bu et al. (26). The authors believe that given the well-established relationship between PA and health, an increase in physical inactivity will have both immediate and long-term implications for people's physical and mental health and general wellbeing. In this respect, the authors state that more efforts are needed to promote PA during the pandemic and beyond. In their systematic review, Stockwell et al. (27) noted that a majority of studies report a decrease in PA and an increases in sedentary behaviors during lockdown across several populations, including children. The authors believe that public health strategies should include the development and implementation of interventions that promote safe PA and reduce sedentary behavior if further lockdowns occur.

Future intervention measures to contain the COVID-19 epidemic should take in to account the findings that lockdowns have negative effects, by drastically limiting the participation in non-organized and organized PA and access to numerous types of activities (e.g., closed gyms, no group meetings, social distancing). In addition to all the known negative consequences of low PA, recent studies also show that physical inactivity in adults is associated with a higher risk of severe COVID-19 outcomes (19). As great effort has been made in the last 20 years to reduce obesity and increase the fitness level of children and adolescents, a drastic decline in all fitness dimensions (SLOfit test battery) was observed after COVID-19 restrictions (28). The decline was so severe, that the average Slovenian child's overall locomotor efficiency decrease by more than 13% after only 2-months COVID-19 restrictions. Therefore, our findings allow us to suggest that incentives for regular PA and reduction of physical inactivity (sedentarism) during COVID-19 restricted period should be classified as one of the most effective strategies for short- and long-term prevention of public health.

These findings are a good starting point for shaping an effective strategy to promote a health-enhancing children's PA in the event of repeated pandemic restrictions, or otherwise for the implementation of organized forms of in-person sports activities. The strategy should predominantly/primarily focus on motivating children to participate in organized and non-organized regular PA for an average of at least of 60 min per day and limiting sedentary time (especially screen time), in line with the WHO guidelines from 2020. Motivation is even more important, as teachers in remote education have no face-to-face contact with students, limited possibility for interaction, difficulty in corrective work of movement techniques. It is particularly important to motivate groups of children who are otherwise already not physically active enough. In the light of the obtained results, it can be recommended that, much more emphasis should be placed on organized sport activities in schools and sports clubs in the event of another lockdown. Practical experience has shown that sport activities can be carried out successfully implemented remotely if is not possible to carried them face-to-face. All in all, organized sport activities could also be implemented face-to-face, considering professional recommendations (29). In any event, it is necessary to take a different approach to the implementation of organized sport activities than during the second wave of the epidemic which lasted from autumn 2020 to spring 2021. The strategy should primarily focus on motivating young people and on providing organized activities that are professionally run, sufficiently frequent, and appropriate in terms of time. The smallest decline was observed in non-organized PA, which, in the case of children, usually takes place within the family. However, here too, the strategy should be geared toward promoting PA, especially in nature, to replace screen time and especially recreational screen time (30).

STRENGTHS AND LIMITATIONS

The most important strength of this study is the large sample of respondents, covering parents and guardians of children from all Slovenian regions. This allows us to generalize the obtained results to the entire population of Slovenian children. The limitations of the study mainly refer to the fact that the questionnaire was answered only by parents and guardians, although this was the only way, as they are not with children all day, so it is difficult for them to exactly define the duration and the intensity of their child's PA.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethical Committee of the Science and Research Centre Koper, Slovenia (No. 0624-13/21). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JP, ČM, SP, RP, and BŠ contributed to the study design and execution, writing the manuscript, and provided critical feedback. ČM and SP carried out all primary data collection. All authors reviewed the results and approved the final version of the manuscript.

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To Create a Safe and Healthy Place for Children: The Associations of Green Open Space Characteristics With Children's Use

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Green open space (GOS) is an important outdoor resource for the well-being of children by providing places for physical activity (PA), especially in the highly urbanized environment. The COVID-19 lockdowns have made children have more sedentary time than before due to less access to public places. This article aims to examine the associations of GOS characteristics (environmental and surrounding) and children's use (visitation and PA pattern) to provide evidence for promoting their PA during the pandemic. This study employed the method of GPS positioner, accelerometer, and survey to measure the children's actual use in GOS. A total of 179 children participated in the study and 10 GOSs were selected. The children were provided with the accelerometers and GPS positioners to track their walking steps, duration, and locations. The environmental characteristics and 1 km buffer of the selected GOSs were explored as extended study area. Results showed that 49.16% of children reported more visitations than before the pandemic, and 48.60% of them preferred to go on weekdays during the pandemic. Both environmental and surrounding characteristics could affect the visitation pattern. The size ($p < 0.000$), residential ratio ($p < 0.000$), and intersection density ($p < 0.000$) were found as the factors significantly associated with visitation pattern. The children's PA pattern was mainly associated with the environmental characteristics of size ($p < 0.000$), sports, and playground proportion ($p < 0.000$). The locations of children's PA were mainly around square, playground, sheltered place, and waterside areas. COVID-19 has transformed the children's use of GOS, as well as their relationship with GOS. The large GOS was more likely to promote PA and its use by the children. The environmental and surrounding characteristics of GOS could affect their use pattern, whereas their PA pattern was mainly associated with the environmental characteristics. The findings suggest that GOS characteristics could be an effective solution to respond the challenge from the pandemic, and promote their visitation and PA.

Keywords: green open space, children, physical activity, design, planning, landscape, environmental characteristics

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INTRODUCTION

COVID-19 has substantially changed the relationship of the human life and urban environment since its first outbreak in Wuhan, China, in December 2019. People had to follow the practice of social distancing and "self-quarantine," and one half of the global population was required to stay at home, resulting in a negative influence to their health (1). One of these consequences is the decrease in physical activity (PA) among children, which is a major cause of overweight and obesity (2). PA is a health-prompting behavior, which is important for children's physical and mental growth, especially when it comes to moderate to vigorous physical activity (MVPA) (3). Before COVID-19, reports showed that less children meet the recommended level of PA (4, 5). The pandemic aggravated this trend due to the closures of school, gyms, parks, and other public places. The outdoor play and walking decreased significantly after pandemic restrictions were posed (6, 7). Children living in the higher dwelling density and closer to the roads were more likely to be impacted (8). Children were reported to have low PA level, less outdoor time, and higher sedentary lifestyle during the lockdown (9). According to a report from Canada, <3% of children could reach the PA guidelines due to the closure of common indoor and outdoor places (10). Some studies suggested the importance of green open space (GOS) in the pandemic, which could alleviate residents' negative effect of lockdowns by providing places for exercising and relaxing while ensuring the safety (1, 11, 12). Some GOSs were reported with increasing visitation because staying outdoors was thought be safer and healthier than indoors during the pandemic (13, 14). Some studies showed that GOS could be essential to the low-income population or those living in the highly dense urban environment because they are not likely to have private green space to mitigate the influence from the pandemic (13). It is necessary to reconsider the relationship of GOS and people, whereas few of the studies have explored the actual effect of GOS on the PA of children.

Green open space is a public place and an open space with abundance of natural and green features including park, greenway, green infrastructure, etc. Except for the green attribute, it is also featured with environmental components and recreational functions that can contribute to human health for various dimensions (15–17). For children population, studies have revealed the positive relationship between GOS and PA (18, 19). GOS was assumed as the primary outdoors setting for children on encouraging PA and producing positive health outcomes (20, 21). Understanding how children use and play in different GOS could support effective interventions to promote PA for health benefit on various layout, size, and location (22). In highly urbanized areas, GOS is the one of the most important environmental solutions for improving PA because they offer facilities and programming specifically for children from low socioeconomic status (23, 24). Longitudinal studies proved the health potential of GOS for children by promoting physical activities and reducing their BMI (25, 26). Moreover, the green and natural settings could alleviate children's negative moods and restore their direct attention when using GOS (27). The social engagement would also be promoted by the active exposure to GOS (28). Overall, there is abundance of evidence showing the importance of GOS to promote the PA and well-being of children. Nonetheless, how to respond to the challenges from COVID-19 by understanding the effect of GOS on children's use is still unclear.

The availability and characteristics of GOS are associated with children's use, meanwhile its built environment features are related to children's PA (29). The GOS characteristics consists of the physical design and planning of the urban environment, such as land use pattern and transportation system. The environmental characteristics of GOS were found to be influential on children's use such as the landscape features, shade cover, and environmental quality (30–32). Their use of GOS was associated with the presence and a variety of active recreation facilities, size of fields, and level of maintenance (33). Their perceptions of the GOS availability and environmental quality were reported to affect their use and PA level (34). Some studies examined the GOS-based PA regarding the surrounding neighborhood environment (35), showing that neighborhood with high walkability, high level of land use mixture, transit density, and destinations of parks and recreation facilities, had a great potential to promote PA among children. In another side, parents' perception of safety and access to mixed land use (36, 37), residential density, recreational facilities, and open space could make a great impact on the children's PA (31, 38). The street density could affect children's PA by perceiving the traffic as a safety barrier to hinder the GOS visitation of children (39, 40). The accessibility, sidewalk condition, connectivity of street around GOS were all reported to associate with children's PA (41, 42). However, few studies examined the effect of GOS on children's PA using multilevel factors from the environmental and neighborhood characteristics.

In spite of the recognition that the GOS characteristics are important for the children's well-being, by affecting their PA, the knowledge is still limited about assessing the children's actual use of GOS and its relationship with GOS during the pandemic. Specifically, there is also a lack of studies focusing on the specific information of children's use (such as locations, steps, and duration), which makes the evidence of promoting PA *via* GOS less practical. Moreover, studies on GOS characteristics usually just examined a few of factors on a certain aspect, which is difficult to draw a comprehensive conclusion. Given the accumulating evidence and imperious demand from the pandemic, it is critical to understand the relationship of GOS characteristics and children's use. This work aims to investigate the associations of GOS characteristics (environmental and surrounding), and children's use (visitation and PA pattern) to provide evidence for promoting their PA during the pandemic. Specific aims were: (1) Examine children's visitation and PA pattern of GOS during COVID-19; (2) Examine the extent to which GOS characteristics are associated with children's PA; (3) Identify the key factors of GOS characteristics affecting children's use. Eventually the findings would provide evidence and insights for the decision making and planning process of GOS.

METHODS

Study Setting

Data in this work comes from a crosssectional study of children's use in 10 GOSs and their surrounding neighborhoods, in Suzhou city, China. All the GOSs are located in the highly dense urban environment, where the GOS is crucial for outdoor activity of children during COVID-19, because most of resident over there don not have private green space. The GOSs include parks, affiliated green space, and greenway, which allows residents to use without any cost. To better understand the specific effect, the children's use would be divided into two parts: (1) use visitation pattern (frequency, time, comparison), measured by site-based survey; (2) PA pattern (waking steps, duration and locations), measured by GPS positioner and accelerometer. To comprehensively understand the built environmental features, GOS characteristics consist of environmental and surrounding characteristics. The research design is trying to provide a holistic understanding of the relationship between GOS characteristics and children's use.

Measurement

Children's Use

Children's use consists of visitation and PA pattern. The visitation pattern refers to how children perceive to visit and use GOS. It includes:(1) frequency they visit the studied GOS; (2) comparison with the visitation prior to COVID-19; (3) the day they prefer to visit (weekday or weekend). The visitation pattern is collected by site-based survey.

Regarding the PA pattern in GOS, a combination method of GPS positioner and accelerometer is employed. Accelerometer is used to measure the walking steps and duration, whereas GPS positioner is used to record the locations of the participants. This approach is proved the validity to track geo-data of children's PA in a given setting (43). Intensity of PA is usually measured by computing the metabolic equivalents (44), but it was not considered in this work because it was difficult to objectively calculate the intensity with high accuracy for a short period. The accelerometer (ActiGraph GT3X+) could track the walking steps and duration with high accuracy, and is widely applied in the studies of sports and physical activities for children and adolescents (45). The GPS positioner (Newman K2A) is adopted for its high accuracy (error was <5 m, outdoors) and could be initiated in a minute. It could collect the geo-data of users every 10 min and last for 8 h per full charge, which could cover the physical activities of all the children. Both of the devices could be belted in the waist of participants, without hampering their activities.

GOS Characteristics

The GOS characteristics consist of environmental and surrounding characteristics, which are used to describe the built environmental features inside and outside GOS. Based on the previous study and polit survey, the environmental characteristics could be summarized as size, greenery (grassland, woods, and other natural features), facilities, and amenities (square, seating, shelter, restroom, picnic area, etc.), sports and playground (sports courts and field, swing sets, splashpads, playground equipment, and other recreational places). To mediate the impact of size of GOS, all these variables are measured by the proportion instead of actual areas. These factors could be objectively measured by calculating the area of the polygon enclosing the areas, then merged and processed with geo-data of children's PA. Regarding the surrounding characteristics, four parameters are selected as residential ratio, intersection density, transit density, and land use mixture, which are proved to be constantly related to the PA of children (46). The scope of surroundings was defined as the area within 1 Km along the street network and includes all the parcels with access to the GOS boundary within 1 km. This distance was reported to be the threshold for children's walking range as well as parents would allow due to the safety concern (47, 48). The residential ratio, land use mixture, and transit density are calculated and drawn based on the official documents of zoning and planning from the Bureau of Natural Resources and Planning in Suzhou. The intersection density is measured by the number of street and road intersections, which indicate the connectivity around the studied GOS.

Participants and Site

A total of 10 GOSs from Suzhou city are selected, which are located either along the river or lake, indicting the decent environmental qualities and view (**Figure 1**). The GOSs are represented in the form of parks, afflicted green space, and urban forest. They consist of different areas such as playground, square, shelter seating, jogging trail, or pathway, etc., which are attractive to both adults and children. These GOS could be divided into three categories: (1) community level (1–5 ha), (2) district level (6–10 ha), (3) subcity level (>10 ha). The category criteria come from the official guideline for the GOS planning and design. All the GOSs are located in urban area of the city with high density. Suzhou is a large and typical city in China known for its urban development and planning, with a combination of old towns and new districts. All the studied GOS were distributed around river or lake in the old towns and new districts. The data of these GOSs is drawn from the official documents and input into GOS to make the basic dataset.

Regarding the participants, all of them are recruited on the site after obtaining consent. The recruiting criteria includes: (1) they are attending primary school and are affected by the lockdowns due to pandemic, (2) they are able to wear the devices on the waist, (3) they are planning to play and stay in the GOS, instead of just traveling through, (4) they need to stay in the GOS more than 10 min and <180 min. The investigators conduct the survey in the main entrance of the GOS, and need to screen off unqualified children. After obtaining the verbal consent from their guardians, the qualified children would be invited to join the study. If their guardians were not with them, the investigators would call to ensure their consent and full recognition. All the participants or their guardians would answer a web-based questionnaire for their demographic background and visitation pattern. The qualified participants would be provided with the GPS positioner and accelerometer, and are required to return these devices when they leave the GOSs. For each GOS, we prepare 15–25 sets of

FIGURE 1 | Site locations.

TABLE 1 | Description of children and visitation pattern.

Individual information	Items	Number	Percent
Age	<6	2	1.12%
	7–9	75	41.90%
	10–12	91	50.84%
	>12	11	6.15%
Gender	Male	96	53.63%
	Female	83	46.37%
Presence of guardians	Yes	112	62.57%
	No	67	37.43%
The way come to the GOS	On foot	75	41.90%
	Public transit	62	34.64%
	Private car	42	23.46%
Distance from home	≤1 km	123	68.72%
	>1 km	56	31.28%
Visitation pattern			
Visitation comparison (with prior Covid-19)	More visitations	88	49.16%
	Almost the same	42	23.46%
	Less visitations	49	27.37%
Visitation time	Weekday	87	48.60%
	Weekend	65	36.31%
	Both	27	15.08%
Visitation frequency	Less than once a week	21	11.73%
	Once to third time a week	123	68.72%
	More than third time a week	35	19.55%

devices, depending on how many qualified children there are. The surveys were conducted during the last 2 weeks of April 2020, and the collection period was set up at 9:00–12:00 and 14:30–17:30. Eventually, a total of 179 children participated in the study with valid records.

Statistical Analysis

Descriptive statistics was used to analyze the children's demographic information, use, and GOS characteristics. To compare the differences of visitation and PA patterns across GOS, one-way ANOVA and chi square tests are utilized. Two regression models are established to explain the associations of the use and GOS characteristics. To examine the effect of GOS on PA pattern of children, multivariate regression is performed with the environmental and surrounding characteristics. Multinomial logistic regression is conducted to explore the relationship of GOS characteristics and visitation pattern of children, which included their visitation frequency, visitation comparison with prior COVID-19 situation, and visitation time. The collinearity diagnostics among the independent and control variables are performed before modeling, and the result showed there was no high correlation among the variables (VIF < 10). The significance level was set up at 0.05, and the statistical analysis was performed on the platform SPSS 26 (IBM, Armonk, NY, USA).

RESULTS

Visiation Pattern of Children During COVID-19

A total of 179 valid records were obtained (**Table 1**). The average age of participants was 10.11 years old (min = 6, max = 14), and the majority was ranging from 9 to 12 years old (50.84%), following by group of 10 to 12 years old (41.90%). There were more boys (53.63%) than girls (46.37%) among the participants. More than a half of the children (62.6%) were accompanied by their guardians (parents or other legal adults). Most of them came to visit the GOS on foot (41.90%) and 34.64% of them traveled by public transit, indicating that most of them were living nearby or in the normal economic condition. The majority of participants was living within 1 km (68.72%), which was in accordance with the results above. Regarding the visitation pattern, 48.6% of children preferred to visit GOS on weekdays, while those prone to visit on weekends only accounted for 36.31%. Nearly a half of

the participants reported higher frequency of visits (49.16%) than before the pandemic, and only a small amount of them showed less visits (27.37%). The majority of children reported to visit the GOS for 1–3 times per week (68.72%), and only 11.73% of them visit less than a week.

Phsycial Activity Pattern of Children in GOS

Generally, the mean value of walking steps was 2,930.13, with the maximum steps (9,913) and minimum steps (461). The maximum of duration was 129.14 mins, whereas the minimum was 17.13 mins, and the mean value of stay length was 46.70 min. Since we set up a visitation threshold (15–25), the average counts of visiting were 17.90, with a maximum and minimum of 25 and 10, respectively. Regarding the type of GOS, the average walking steps (2,786.52) and duration (46.31 mins) was found in the GOS of subcity level, and then they were followed by district level and community level (**Table 2**). Regarding the location of PA, the distribution was not even as some places were crowded, and some places showed few records. Generally, children's PA was mainly around a square, playground, sheltered place, and waterside areas (**Figure 2**). The speed of each records was also categorized into sedentary (<0 m/s), (moderate) 0–1.5 m/s, (vigorous) >1.5 m/s to distinguish different level of PA (**Table 3**). It was found the proportion of intensive PA go up as the GOS becomes larger.

Environmental and Surrounding Characteristics of GOS

Regarding the environmental characteristics of GOS, the size ranged from 1.91 to 14.89 ha, with a mean value of 7.64 ha (**Table 4**). The greenery proportion was all above 60%, which was a baseline for GOS according to official guideline. The average proportion of sports and playground was 13.88%, and it was higher in the subcity level than in the community level. The proportion of facilities and amenities area ranged from 14.23 to 17.87%, with a mean value of 16.27%, which was slightly higher than the proportion of sports and playground. As for the surrounding characteristic, the residential ratio ranged from 30.21 to 42.15%, with a mean value of 36.83%. The intersection density ranged from 43.15 to 22.24/km^2, with a mean value of 32.64/km^2. It was evident that the GOS located in the old town showed a higher residential and intersection ratio than that in the new district. The transit density varied with a mean value of 20.20/km^2, ranging from 25.02 to 12.54/km^2. Similar with the residential ratio, GOS located in the old town showed a higher transit density than that in the new district. The mixture of land use was calculated by means of entropy index of land uses (49). The mean value was 0.46, and ranged from 0.81 to 0.17, indicating a large variation.

The Effect of GOS Characteristics on PA Pattern

The results of one-way ANOVA showed that children in different GOS had significant differences in their average walking steps ($p < 0.001$) and duration ($p = 0.011$). Obviously, the mean value of the two variables was the highest in the city level GOS whereas it was the lowest in the community level (**Table 2**).

Multivariate regression was performed to further examine the relationship between GOS characteristic and PA pattern of children (**Table 5**). Walking duration of children was positively associated with the size of GOS ($p < 0.000$), indicating that larger GOS could be more likely attract children to stay longer. Sports and playground proportion was also positively associated with the use duration ($p = 0.006$). It meant that these areas could increase the duration of children's physical activities as well. As for the model of walking steps, it was also positively associated with the size as well as sports and playground proportion.

As for the location of the PA, the geo-data of all the participants were categorized into: (1) Speed = 0, representing that the participants were in the secondary status, (2) Speed > 0, representing that the participants were moving and physically active. In the large GOS, there were more active records, whereas less active records in the small GOS (**Table 3**). According to the mapping of these records, the locations of PA were not evenly distributed in the GOS (**Figure 2**). Some places were heavily used whereas some others were seldom occupied. Specifically, places with playing facilities and amenities, landscape, water features, and shaded area were spot with more records. The linear space was long and showed a significantly high percentage of records, such as jogging trail and waterside pathway. Since some children were companied by parents, their locations of PA were usually distributed around squares, water features, and status.

Associations of GOS Characteristics With Visitation Pattern of Children

The results of Chi-square test showed that participants from different sites showed significant differences in their visitation pattern of frequency ($p < 0.000$) and comparison with prior to COVID-19 ($p < 0.000$). It was clear that the children would like to visit larger GOS more frequently than smaller ones. Similarly, larger GOS could attract more visitation than smaller ones.

Multinomial logistic regression model was used to examine the association of children's visitation pattern and GOS characteristics (**Table 6**). Results showed that size was significantly associated with visitation frequency ($p < 0.000$) and comparison with prior COVID-19 ($p < 0.000$). The residential ratio was closely associated with visitation comparison with prior COVID-19 ($p < 0.000$) and visitation time ($p < 0.000$). Intersection density was significantly associated with visitation frequency ($p < 0.000$).

DISCUSSION

This study examines the associations of GOS characteristics with children's use during COVID-19 using site-based survey, GPS, and accelerometer. In particular, it is to explore how the neighborhood and environmental characteristic affect the visitation and PA pattern of children in the GOS in a highly dense urban setting. The results show that the pandemic has posed some changes on children's use, and it could be affected by GOS characteristics. The findings suggest the importance of GOS characteristics from both environmental and surrounding. Necessary environmental internecions of design and planning are

TABLE 2 | The description of visitation and PA pattern by different GOS.

Children use	**Community level (1–5 ha)**		**District level (6–10 ha)**		**Sub-City level (>10 ha)**			**Total**
Visitation pattern	***n***	**%**	***n***	**%**	***n***	**%**	***p***	**179**
Visitation frequency							0.001**	
Less than once a week	6	3.35%	8	4.47%	7	3.91%		21
Once to third time a week	28	15.64%	39	21.79%	56	31.28%		123
More than third time a week	13	7.26%	10	5.59%	12	6.70%		35
Visitation comparison with Prior to COVID-19							0.001**	
More visitations	21	11.73%	26	14.53%	41	22.91%		88
Almost the same	10	5.59%	13	7.26%	19	10.61%		42
Less visitations	15	8.38%	16	8.94%	18	10.06%		49
Visitation time							0.082	
Weekday	29	16.20%	36	20.11%	22	12.29%		87
Weekend	9	5.03%	11	6.15%	45	25.14%		65
Both	14	7.82%	7	3.91%	6	3.35%		27
PA pattern	Mean	SD	Mean	SD	Mean	SD		Mean
Duration (mins)	42.12		46.31		51.22		0.001**	46.70
Walking steps	2,786.52		2,982.74		3,010.81		0.011**	2,901.13

One-way ANOVA is employed to examine the differences of visitation pattern between different GOS.
Chi square test is employed to examine the differences of PA pattern between different GOS.
**p < 0.05, **p < 0.01. *Indicates the significance level.*

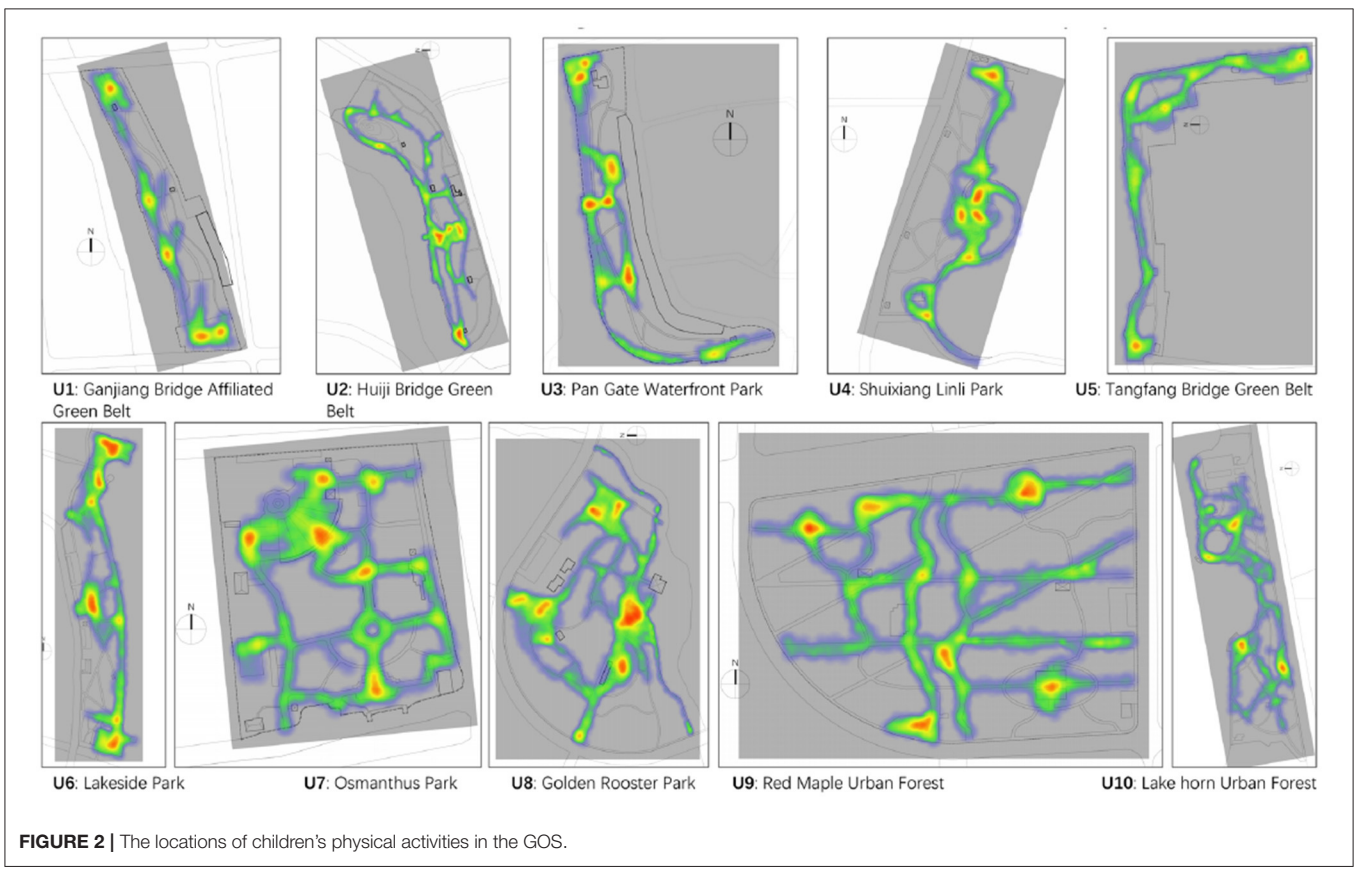

FIGURE 2 | The locations of children's physical activities in the GOS.

TABLE 3 | Description of GOSs.

Category	Item	Participants	GPS records						
			Speed = 0		Speed (0–1.5 m/s)		Speed (>1.5 m/s)		Total counts
Community level	U1	10	3,611	61.95%	1,707	29.28%	511	8.77%	5,829
1–5 ha	U2	13	3,715	60.46%	1,863	30.32%	567	9.23%	6,145
	U3	12	3,901	58.04%	2,039	30.34%	781	11.62%	6,721
	U4	22	6,871	64.45%	2,759	25.88%	1,031	9.67%	10,661
District level	U5	15	4,861	63.85%	1,938	25.46%	814	10.69%	7,613
6-10 ha	U6	21	6,788	58.80%	3,247	28.13%	1,509	13.07%	11,544
	U7	23	1,1414	66.24%	3,367	19.54%	2,451	14.22%	17,232
City level	U8	16	4,851	53.95%	2,799	31.13%	1,341	14.91%	8,991
>10 ha	U9	22	6,919	57.89%	3,190	26.69%	1,844	15.43%	11,953
	U10	25	6,797	56.08%	3,415	28.18%	1,908	15.74%	12,120

TABLE 4 | The GOS environmental and surrounding characteristics.

	Community GOS				District GOS				City GOS		Total	
Environmental characteristics	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	Mean	(SD)
Size (ha)	1.91	3.22	3.41	4.71	6.72	7.94	8.92	11.21	13.45	14.89	7.64	4.48
Greenery proportion (%)	61.15	65.14	67.21	69.24	61.34	62.89	67.51	62.31	67.34	66.84	65.10	2.94
Sports and play ground proportion (%)	12.51	14.11	13.64	12.89	13.75	14.12	13.99	14.24	15.34	14.21	13.88	0.78
Facilities and amenities area proportion (%)	17.87	15.32	15.44	14.23	18.15	17.24	15.21	17.54	15.42	16.24	16.27	1.34
Surrounding characteristics												
Residential ratio (%)	42.15	39.21	41.11	38.74	39.52	36.21	35.32	34.56	30.21	31.25	36.83	4.03
Intersection density (n/km^2)	36.84	42.12	43.15	31.25	39.32	32.15	26.53	22.24	24.61	28.14	32.64	7.42
Transit density (n/km^2)	20.01	24.52	25.02	25.32	24.21	19.62	19.21	17.21	12.54	14.33	20.20	4.57
Mixture of land use	0.45	0.69	0.77	0.81	0.67	0.32	0.33	0.24	0.17	0.19	0.46	0.25

needed to promote the children's use for their well-being during and after the pandemic.

Children Visitations Pattern During COVID-19

The pandemic exerted a great impact on the children's visitation pattern on GOS. Nearly half of the children showed more visitation than before, whereas only a small amount of them showed less visitation. This trend was particularly clear among the groups visiting subcity GOS. This finding might contradict with some previous assumptions that the usage of GOS could be compromised due to the implementation of policies such as social distancing and closure of some public places (8, 10). Actually, some studies asserted the importance of GOS to human health during the pandemic, and observed increasing visitation in certain settings (50). The possible reasons could be that children had more free time due to the lockdown of schools. Many adults had to work at home, which allowed them more time to accompany their children to visit GOS. Moreover, the study was conducted in a highly dense urbanized city, where GOS was a scarce outdoor recreational resource because the majority of urban dwellers lived in a flat or apartment, and they did not have private green space. Another finding was that participants preferred to visit GOS on weekdays than on weekends. It could be different from that before COVID-19, when most of children would go to GOS at the weekend and stay at school at the weekdays. The possible reason could be the lockdown policy which allowed more free time for both children and parents during the weekdays. Besides, the fear of the crowdedness and contact could also discourage children to use GOS during the weekend. In the survey, many of the parents would instruct their children to go on the weekday to avid crowds. Overall, the visitation pattern of children has been profoundly affected by the pandemic, which could be producing negative influence on their physical fitness, especially for boys (51). It is hence necessary to reflect the relationship of GOS characteristic and children visitation pattern during the pandemic.

The GOS Charatoristics Associated With Children's Visitation Pattern

Regarding the visitation pattern, the study found that both of the neighborhood and environmental Characteristics could affect the frequency, time, and comparison with prior COVID-19 of visitation. For the neighborhood characteristics, residential ratio and intersection density were identified as the main variables associated with visitation comparison, frequency, and time. It indicated that children's visitation pattern was dramatically affected by the surrounding neighborhood environment, which aligned with previous studies. The residential ratio/proportion of neighborhood would affect the importance children perceived with GOS. In this study, all the GOS were located in the highly dense urban areas, indicating that there were could be an abundance of children living around the GOS. During the pandemic, since the high residential ratio means more possibility of crowdedness in the neighborhood, children were prone to seek more visitations to GOS than before, and avoid going on weekends. Intersection density was an indicator of street connectivity, and was reported to negatively associate with visitation frequency (52, 53). Some studies reported that it was positively associated with children's use of open space and parks because increasing connectivity could make these destinations more accessible (46). The possible reason for the differences could be the sense of transportation safety. Since the outbreak of COVID-19, many children and parents would prefer to visit parks near their homes and travel on foot or bikes. High intersection density was always associated with the high road density as well as the amount of street crossings, which could become a barrier to prevent children from traveling. Regarding the environmental characteristics, only size was associated with visitation frequency and comparison. It indicated that children preferred to use larger GOS, which was consistent with previous studies (50). Larger GOS could be safer and more attractive to children during the pandemic because social distancing is more likely to be implemented. This study further proved that, in a highly dense urban environment, large GOS could be more beneficial to promote children's use. Overall, the findings suggested that the GOS located in the high residential density and less road intersections could be of great significance for children's use.

TABLE 5 | Regression of GOS characteristics with PA.

Dependent variables	Walking steps		Duration	
	B	*p*	B	*p*
Interior characteristics of UGOS				
Size	1.215	0.000**	1.233	0.000**
Greenery proportion	0.022	0.652	0.042	0.182
Sports and play GROUND proportion	1.475	0.000**	0.697	0.006**
Facilities and amenities area proportion	−0.028	0.404	−0.022	0.642
Surrounding characteristics of UGOS				
Residential ratio	−0.065	0.091	−0.157	2.631
Intersection density	−0.044	0.182	0.031	0.753
Transit density	0.028	0.718	0.107	0.089
Mixture of land use	−0.037	0.324	−0.427	0.954
Constant	0.877	0.000	0.813	0.000
R-square	0.321		0.284	
N	179		179	

*$p < 0.05$, **$p < 0.01$. *Indicates the significance level.*

TABLE 6 | Regression of GOS characteristics with visitation pattern.

Dependent variables	Visitation frequency		Visitation comparison with prior COVID-19		Visitation time	
	B	*p*	B	*p*	B	*p*
Environmental characteristics						
Size	9.441	0.000**	5.125	0.000**	0.205	0.221
Greenery proportion	1.309	0.157	0.816	0.462	0.812	0.057
Sports and play ground proportion	0.779	0.431	0.698	0.783	0.003	0.701
Facilities and amenities area proportion	1.127	0.557	0.902	0.664	0.312	0.375
Surrounding characteristics						
Residential ratio	0.874	0.750	3.481	0.000**	7.221	0.000**
Intersection density	4.175	0.000**	0.789	0.574	−0.126	0.082
Transit density	1.342	0.203	0.561	0.978	−0.496	0.061
Mixture of land use	1.351	0.083	0.747	0.127	0.002	0.407
Constant	−6.411	0.002	−6.111	0.003	−5.876	0.003
Cox and snell R square	0.214		0.257		0.311	

*$p < 0.05$, **$p < 0.01$. *Indicates the significance level.*

The GOS Charatoristics Associated With Children's PA Pattern

The study found that only the GOS environmental characteristics were significantly associated with the PA pattern of children. The variable size was both associated with walking steps and duration of children, indicating the positive impact of large GOS on their walking activity. Studies showed that large park was more likely to stimulate children's PA, especially MVPA, by providing more places, trails, and amenities to encourage children to play for a long time as well as more vigorous PA (54). The findings suggested that larger GOS with much ground for sports and play could make children walk more distance and stay there longer. During the pandemic, large GOS was recommended as places for outdoor activity because of its capacity to practice social distancing and avoid crowdedness (50). In another side, the small GOS was found to limit the space for running fields, and features such as slides and swings that were relevant to children's PA (47). Small GOSs were always simpler and of less diversity, which were less exciting and stimulating than larger ones (55). Accordingly, this work found that children in the subcity level GOS reported 224.29 more steps on average than that in the community level. It was clear that walking steps and duration were mainly associated with environmental characteristics of GOS. The findings suggest that it is necessary to fully explore the potential of the large GOS and expand the existing small ones.

Similarly, the variable of sports and playground proportion was positively associated with the walking steps and duration. Adequate places for recreational activity could be an essential asset for the GOS to attract children. The availability of sports grounds such as football fields and basketball courts were closely reported to closely associate with the PA, especially MVPA. During COVID-19, children were encouraged by the authority to do exercises, sports, and recreational activities outdoors, which were believed to protect the body and limit damage by improving their immunity (50). Hence, it was suggested to enlarge the sports and playground by converting hard-covered places and grasslands to recreational places, on the condition of ensuring safety. Designers should create more spaces for individualized activity in place of group and organized sports. The size of field, courts, and trails might be enlarged. New and expanded recreational infrastructures need the reassessment of capacity to ensure the safety when children were playing (50, 55).

The GOS Layout and Locations of Children's PA

The study found that the layout of GOS was obviously related to the spatial distribution of children's PA. Children often stayed and played around the sports field, playground, squares, and grassland with cover, according to their location records. The findings aligned with previous studies showing that these areas were the most attractive part of GOS (56, 57). The areas with recreational facilities and natural features could always facilitate more outdoor play for children because they provided abundant attractive places to promote enthusiastic and diverse activities.

Notably, the linear elements of the GOS such as pathway, trails, and waterside were also marked with dense records. Walking would be the most common type of PA for children, and the abundance of walkway or trails in the GOS could stimulate children to walk more. Particularly, the walkway of waterside was significantly marked with dense records, underlining the importance of water features for attracting PA. Previous study shows that water features could stimulate the positive emotion of park users, leading to the possibility of increasing PA (58). The findings suggested the advantages of planning the walkway and jogging trails along the waterside, and connecting the different sports and playground to create network for PA. Overall, except for the quantitative characteristics, the layout of GOS could affect the PA as well, and it could be effective to improve PA by providing a combination of quantitive and qualitive interventions.

Limitations

This study is based on an Asian city with high urban density, and the results could be limited due to its urban context. Another limitation of this article is the crosssectional study design, which could limit its capacity to fully explore the dynamics of the effect of children's use during COVID-19. The scope is limited to only highly urbanized areas, and the finding may not apply to the suburban and rural areas, which are believed to be more attractive to children for outdoor recreation than urban areas for its low density and rich natural features. Another limitation is the interferential approach, which equipped the participants with the GPS and accelerometer, which could produce the possibility of impacting their vigorous PA by reducing their active engagement in the activity. These influences could be mitigated by just measuring their walking steps and locations. Nonetheless, this bias should be addressed by more comprehensive research methods, such as smart wearable devices. The last limitation is that the visitation outcomes are self-reported instead of objective, which could be vulnerable to a social desirability error. Children's responses to survey and PA status might be influenced by the presence of their guardians because of the importance of parent–child relationship in supporting their activity during the pandemic (59). In the future, studies should be designed to control the influence of their parents by distinguishing the group without parents from those with.

CONCLUSIONS

The pandemic has already transformed the relationship of children and GOS. It may force us to reflect our existing GOS practice as well as the design and management measures to ensure its safety and resilience in these special times. Since many children and parents have to move away from crowded public venues, GOS becomes an important outdoor setting for children's well-being by providing a relatively safe and an attractive place for PA. Understanding the effect and characteristics of GOS on children's use could facilitate decision makers and planners to explore the potential of GOS better in the special time. This study examined the associations of GOS characteristics with children's use during the pandemic. The results show that children's visitation pattern of GOS has been deeply impacted by the pandemic. More children prefer to visit large GOS during the weekdays due to the fear of infection. Their visitation pattern is associated with both environmental and

surrounding characteristics of GOS, and the most prominent factors are size, residential ratio, and intersection density. Children's PA pattern is mainly affected by the environmental characteristics including size, sports and playground proportion, and layout. The findings suggest that both the environmental and surrounding characteristics of GOS could be considered into the decision-making and managing process of GOS. The large GOS located with high residential density and street connectivity should be given more priority for PA promotion. Moreover, it suggests enlarging the sports and playground area in the large GOS on condition of ensuring the safety. The walkway, trail, and waterside walk could be utilized to connect the grounds to a composite network for stimulating high-level PA. Overall, GOS is an effective solution to respond to the challenge of children's health from the pandemic by promote the use. This findings could provide evidence for the design guidance and recommendations of health and resilient GOS, which could be beneficial for children's well-being during and post COVID-19 era.

DATA AVAILABILITY STATEMENT

The data could be available upon reasonable requirements through corresponding author due to the agreement with participants.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

MM: conceptualization, funding acquisition, and writing—original draft. MM and WC: data curation. MM, MA, and ST: methodology. ST, MA, and DD: resources. MA: software. MM and MA: writing—review and editing. All authors contributed to the article and approved the submitted version.

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A Tale of Two Cities: Understanding Children's Cycling Behavior From the Socio-Ecological Perspective

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The childhood obesity epidemic has persisted for over three decades, which has presented serious social, economic and health consequences worldwide. For researchers and policy makers alike, cycling has been a promising focus over recent years for developing long-term physically active lifestyles in urban environments, in addition to contributing to the global quest to combat climate change. Promoting cycling thus presents a win-win situation not just for individuals' well-being, but for multiple involved sectors such as public health, transport ministry and environmental agencies. For children, cycling promotes exercise engagement, active transport opportunities, motor skill development and social interaction. However, across European cities, there are considerable discrepancies in the uptake of cycling amongst children. To understand and subsequently promote children's cycling behavior, it is crucial that the complex social, physical and policy environment, and their interrelationships, are considered. Therefore, in this perspective article, we adopt the socio-ecological model to gain insight into how children's cycling behavior is shaped at the interpersonal, organizational and community level embedded within city policies, relevant to increase future cycling participation in children. Our perspective is based on a review of cycling policies of two European cities, Amsterdam (Netherlands) and Newcastle (UK), where stark contrasts in children's cycling participation can be observed. Our findings show that cycling policies in Amsterdam have mainly contributed to comprehensive organizational level changes, for example, cycling infrastructure development within the city, whereby these initiatives have made significant progress at the community level where cycling has become part of the "Dutch culture". Hence, cycling is a more common transportation mode among children in Amsterdam than in Newcastle. In Newcastle, policies primarily focus on organizational or community level changes, and progress has recently been accelerated in response to COVID-19. In addition to differences, we have also identified similar challenges in the two cities, such as the urgency to support uptake of cycling for children with low socio-economic background or challenges related to cultural differences. We also propose a "shared (cycle-)path" for policy makers and researchers as working together is crucial in producing multi-component interventions at a policy level that recognize individual, as well as interpersonal, community and organizational factors.

Keywords: health, built environment, physical activity, youth, cycling, social ecological model, active lifestyle, urban environments

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INTRODUCTION

The global rise in childhood obesity is partly due to the alarmingly low rates of children's physical activity (PA) participation. In 2012, the Lancet, one of the most respected medical and health journals, stated that physical inactivity has become a pandemic (1). In Europe alone only one in four 11-year-olds and only one in seven 15-year-olds took part in at least 1 h moderate-to-vigorous exercise daily in 2018 (2). In all countries, girls were less physically active than boys at both ages. With more than 80% of Europeans projected to reside in cities by 2030, the WHO has a strong agenda to promote physical activity in urban environments (3). Due to COVID-19, physical inactivity increased even more, and children's (especially children aged between 4 and 6) motor skill development was affected (4). Hence, increasing children's physical activity has become more urgent than ever. Increasing physical activity in children requires a wide range of interventions and strategies incorporating knowledge and experience at several different levels and settings. One aspect to explore for instance is active transport, which can provide children 15 min of extra movement per day (5). Therefore, cycling can be one of the pieces of the large physical inactivity puzzle. In recent years, cycling has gained popularity as a recreational activity and sustainable "greener" means of active transport. To increase cycling opportunities at first instance, an appropriate infra-structure is needed. Actions to increase cycling opportunities thus primarily occurred at a policy level within urban environments, e.g., providing infrastructure such as cycle ways or shared bicycle schemes. At the same time, at the individual behavioral level, the mental and physical benefits (6) of cycling (particularly improved motor skill development in children) (7) have become more evident. From the health and behavior change perspective, the alignment of policy and individual level changes must occur in tandem for the successful development and roll-out of public health initiatives to promote PA through cycling in children. The share of total trips that are completed by bicycle is high in Europe (for example it is around 9% in Germany or 19% in Denmark) compared to other westernized countries including Australia or North America (all 1%) (8). Cities have their own cultures, needs and geographical or urban characteristics to create safe and integrated cycling systems (9). These characteristics shape the cycling culture and thus, if we want to increase cycling participation, it is important to understand the current situation in different urban areas and the decisions that have been adopted by governments or local authorities. In this perspective, we will focus on two cities, Newcastle and Amsterdam, in Europe where the cycling rates are higher than many other continents. Amongst the European countries, the Netherlands has the highest cycling percentages (27%) while the percentage is much lower (2%) in the UK (10). This perspective article is oriented at understanding policies. Hence, we first describe current cycling policies in Newcastle and Amsterdam incorporating physical (e.g., infrastructure) and social (e.g., cycle training) factors relevant to promoting cycling in children and secondly apply the socio-ecological model to compare progress of cycling initiatives, in the two different cities. Policy interventions have been placed the context of a theoretical framework, the socio-ecological model, to be able to analyze and make recommendations. We highlight shared challenges of cycling initiatives in urban environments, that can be applicable to other cities, and provide recommendations for the development of effective, sustainable, and long-lasting public health interventions to promote PA through cycling in children.

URBAN ENVIRONMENTS WITH LOW CYCLING PARTICIPATION: NEWCASTLE (UK)

In England, less than half of children walk or cycle to school despite nearly half of the population (42% of people) aged above 5 years owning or having access to a bicycle (10). In fact, bicycle ownership is much more likely among children aged 5–10 years old than other age groups (10). In 2019, 41% of all children (aged 5–16 years) usually walked to school, however, only 3% of all children cycled to school (11). Road safety concerns and traffic are common reasons for people not cycling more (11).

For Newcastle, there is a lack of city-wide cycling user data available. However, in a large-scale survey of primary school children ($n = 4{,}775$), 81% of students reported enjoying physical activities, yet when traveling to school, only 3% of students cycled compared to 54% of students taking passive transport (i.e., traveled by car, bus, taxi/minibus or public transport) (12). Considering the surprisingly low level of PA participation outside of school (only 9% of all children), the opportunity to cycle to school (and therefore increase daily PA) was not popular for reasons not reported. However, a previous dataset indicated that despite bicycle ownership between boys and girls being similar in participating Newcastle Schools (87 and 85%, respectively), the percentage of boys cycling to school was around 30% compared to around 25% for girls (13). Within the city of Newcastle, there are diverse socio-demographic characteristics (much like other urban environments), however, there are relatively little data available on specific factors (e.g., cultural and socio-economic status) which may impact cycling engagement and opportunities for different groups of children.

URBAN ENVIRONMENTS WITH HIGH CYCLING PARTICIPATION: AMSTERDAM (NL)

The Netherlands is well-known as a cycling country. According to the latest estimate, each person in the Netherlands owns more than 1.3 bicycles, which is unique in the world (14). In 2018, more than 25% of all movements in the Netherlands were completed using bicycles (15). The Netherlands has the highest percentage of movements using bicycles relative to the world population (16).

In the Netherlands, children cycle more than adults in terms of percentage of trips they complete by bike. Almost half of all movements (48%) by children aged under 18 years are cycling related (17). Of all age groups, young people aged 12–18 years use their bicycles the most. With an average of 6.2 kilometers per day, youngsters also cover the longest distance (18). However, in recent years, the number of cycling children has declined,

partly because only half of children aged 4–12 years have learnt to cycle in urban areas (19). In Amsterdam, more than 16,000 primary school children cannot cycle (20). Most of these children are from families with a low economic status. Furthermore, among families with a low economic status, bicycle ownership and cycling skills are more limited which further hinders cycling opportunities (20).

APPLYING THE SOCIO-ECOLOGICAL MODEL TO COMPARE CYCLING INITIATIVES IN URBAN ENVIRONMENTS

In this perspective article, we compare the impact of cycling policies in Newcastle and Amsterdam on children's cycling behaviors using the socio-ecological model (21, 22). The socio-ecological model (SEM) considers how the broad political and environmental factors shape individual and interpersonal characteristics (23). The model is comprised of individual (e.g., knowledge and attitude), interpersonal (e.g., immediate physical environment and social unit), organizational (larger environments and (in)formal organizations), and community (e.g., demographic, ethnic, religious characteristics) level changes that are embedded within the policy environment (**Figure 1**) (24). Various preceding studies used the socio-ecological model in physical activity studies as it helps health professionals plan, implement, and/or evaluate physical activity interventions (25). In addition, it helps to focus not only on individual characteristics but also the social and physical environment context that can include family, friends, or formal and informal organizations and facilities that promote or prevent physical activity (26) and allows to provide a holistic understanding of how policy interventions interact with a range of personal/social factors, which is needed to be able to understand what are appropriate interventions at what time, in which city and targeting who. Increasing cycling behaviors among children is complex since many factors, including personal factors such as cycling skills and environmental factors such as infrastructure, affect it. Hence, we use the socio-ecological model to capture the factors influencing cycling behavior in children at five levels: individual, interpersonal, organizational, community and policy. Within the context of cycling in children, policy makers and researchers usually focus on physical environment and individual level factors. The socio-ecological model suggests that the combination of individual, social, and physical environmental factors explain PA participation best and hence, the SEM is particularly appropriate for studying PA (27). This model allows us to explore policy interventions at different levels, and provide insights and understanding into the differences in children's cycling participation in different cities, as well as in promotion policies targeting an increase in children's cycling participation. These insights can inform future intervention strategies. Hence, during analyzing the reports and decisions for Amsterdam and Newcastle, we aimed to understand the levels targeted in SEM.

FIGURE 1 | The socio-ecological model (24).

Newcastle: Getting Wheels on the Road

Policies in Newcastle have mostly focused on getting people (not just children specifically) to cycle more. At the organizational level, policies aimed to create continuous, safe, direct routes where cyclists can travel separated from the vehicles (28), and "school streets": closing streets to through traffic and having parking restrictions at school pick-up and drop-off times (29), or closing bridges to traffic in order to create safer routes for children (30, 31). Community level activities were supported, such as, "walk to school week" (32), whereby parents and children were invited to actively commute to school. In addition, Newcastle Healthy School program promoted health and well-being of children and staff, whereby schools provided evidence of their health promoting practice or undertook a 2-year program of activity on a public health issue (26).

Interpersonal or individual level changes have also been targeted, such as through the "Active Newcastle" program to promote physical activity and reduce health inequalities for different age or gender groups (33), nationwide cycling festivals (34), a "Fix your bike" voucher scheme launched by the Department of Transport (35) as well as free cycling trainings for schools offered by the Newcastle city council (36). However, few policies targeting individual and interpersonal level changes in Newcastle have been implemented.

Amsterdam: Keeping the Wheels Turning

In Amsterdam, organizational level changes are ongoing and are far more advanced than in Newcastle. While safe cycling routes are already present throughout the city, further improvements to current infrastructure to better connect different parts of the city have been proposed, so that new routes will be

added and existing routes will be modified (37). At the community level, a main goal is to strengthen the cycling culture amongst the low socio-economic groups and non-western background people (38) due to their low cycling uptake. In addition, to promote cycling, there are specific schemes at schools. For example, parents can declare costs for cycling or parents from lower income groups can buy bikes with discounts (28).

At the individual and interpersonal level changes, the aim is to increase children's and their parents' cycling skills so that the parents can be role models to encourage cycling with their children. All equipment such as bicycles and helmets are provided by the executive party "Verkeersplein Amsterdam" and the cycling activities target children who cannot learn cycling from home (39).

SHARED CHALLENGES: RIDING TOWARDS PROMOTING CHILDREN'S PA THROUGH CYCLING IN URBAN ENVIRONMENTS

The policies in each city target different levels of the social ecological model (see **Figure 2**). Amsterdam city already has a high number of cyclists (children included), and the infrastructure is already well-developed to support cycling. Hence, policies mostly focus on individual and interpersonal level changes. On the other hand, in Newcastle, cycling infrastructure is yet to be developed in order to support cycling behavior. Hence, policies focus on organizational and community level changes yet interpersonal and individual level changes are warranted. In addition to generating a sound cycling infrastructure, policies that are based on knowledge of the factors that impact cycling behavior in children (with or without disabilities) from low socio-economic groups, ethnic minorities and different gender groups are critical. Despite that Amsterdam has already got the wheels turning, more concerted strategies from the government in both cities are called for to help improve the cycling culture amongst their children to promote PA through cycling. To target children specifically, both cities appear to have (to some extent) collaborations with schools to promote cycling initiatives acknowledging the need to implement individual and/or community level changes.

Additionally, policies should target the most influential and the most modifiable factors that impact cycling behavior, such as bike parking, schemes to promote cycling and parental perception of safety. It is crucial to identify such factors that are meaningful to policy makers. Until recently, cycling and walking have not been priorities of transport plans for some time in the two cities. This has recently changed, especially in Amsterdam (38); however, there is still a lot that can be done. Rather than having plans focused on reducing vehicles on the road [to become more "green" and reduce CO_2 emissions (40, 41)], the focus of plans should be shifted toward making cycling (and walking) more appealing and encouraging PA, particularly for children and young people. Recent attempts show that it is possible to create large car-free areas to create safe and healthier environments for pedestrians and cyclists (42). This shift from car-dominated cities to car-free areas/regions can be adapted to any country/city in the world (organizational level change), which can help improve interpersonal and individual level changes.

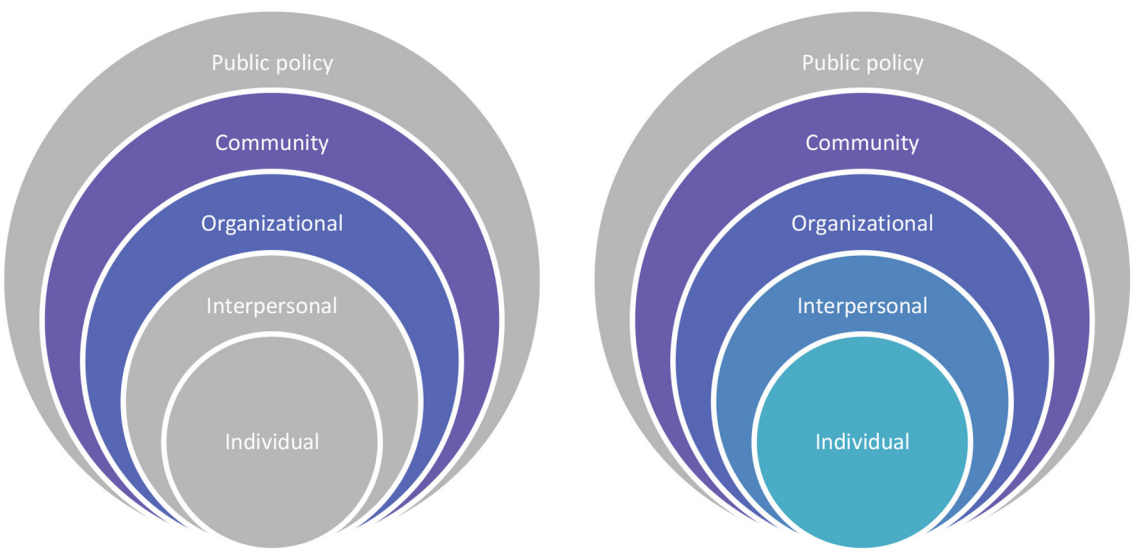

FIGURE 2 | Socio-ecological model and the levels covered by the policies (on the left, policies in Newcastle and on the right, policies in Amsterdam). Colored parts of the figure show the targeted levels and gray parts show the levels that are not (fully) targeted.

DISCUSSION: A SHARED "CYCLE-PATH" FOR POLICY MAKERS AND RESEARCHERS TO DEVELOP AND IMPLEMENT EFFECTIVE CYCLING INITIATIVES TO PROMOTE LIFE-LONG PHYSICAL ACTIVITY IN CHILDREN

Seldom do the "cycle-paths" of policy-makers, who implement public health initiatives, and researchers, who devise behavior change initiatives, co-create PA interventions and design implementation studies, run in parallel. It is a common practice for government to implement strategies before consultations are sought from the targeted population or from researchers, while an evidence-based approach, involving stakeholder's input, would likely increase effectiveness. At the moment, the policy regarding promoting cycling seems to be limited as it does not cover all determinants as proposed in SEM. Public policies mainly focus on external conditions relevant to cycling policy (e.g., infrastructure, parking spots or shared bikes). Though this is very important, particularly in the UK where cycling infrastructure is less developed than in the Netherlands, policies should also target the social factors that impact cycling behavior, self-efficacy or skills. As stated before, policies focus on keeping the wheels turning, rather than promoting cycling among citizens who are not yet able to, or unwilling to cycle. For example, there is not much effort to promote cycling among children from low socio-economic groups in both cities. Currently, there are cycling promotion events mostly at school level to learn more about cycling and schools can participate these events voluntarily. But this is not embedded in policies yet. This requires more cooperation between departments that work on cycling and other active travel modes (e.g., department of health, planning). Besides, more research is needed to identify the barriers or motivations for children who do not cycle. This can help us determine the effectiveness of current interventions.

In health research, evidence-based practice is a key term for decision-making in medicine (43). It involves considering 1. target population/patient perspectives, 2. expertise of professionals, and 3. available scientific evidence, to make adequate decisions about healthcare. For successful uptake of behavior change strategies (at the crux of successful policy implementation), it is imperative that policy-makers and other stakeholders, such as children, parents and schools, are involved from the outset (44) and available scientific evidence is used as input for interventions (43). Working together is crucial in producing and evaluating multi-component interventions at a policy level that recognize individual, as well as interpersonal, community and organizational needs that can lead to positive behavior change at a societal level, and, in this case, promote PA through cycling in children. For both Amsterdam and Newcastle, it is time to focus on both the external conditions as well as the social aspects to promote cycling.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

DY and RP collected the data and completed the analysis. DY, RP, FL, GT, SM, MJ, and FH provided critical input to the manuscript. All authors contributed to the conceptualization of the study. All authors contributed to the article and approved the submitted version.

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The Influence of a School Social Network Intervention on Adolescent's Health Behaviors: A Gender-Specific Agent-Based Model

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Introduction: Adolescence is a crucial stage for health behavior development, which is associated with health in adulthood. School closures caused by the coronavirus disease 2019 (COVID-19) pandemic have exposed adolescents to an increased risk of obesity due to a lack of physical activity. Although social network interventions provide an effective approach for promoting health-related behavior, current practices neglect gender differences in adolescent behavioral patterns and emotional preferences. The aim of this study was to examine the effectiveness of centrality-based methods integrated with of gender contexts in a social network intervention to improve adolescent's health behavior.

Methods: We developed an agent-based model (ABM) that supports the small-world characteristics of adolescent social networks. Health-related data for junior middle school students (n = 234, 48% girls) were collected in November 2018, 2019 and 2020 in Tianjin, China. We simulated multiple network-based interventions with different criteria for influential agents (i.e., betweenness centrality, closeness centrality, eigenvector centrality, and PageRank) and a random condition. The rules for generating peer influence and accelerating behavioral changes were based on the diffusion of innovations theory, with gender specifications.

Results: After the school closures, there was a significant increase in the prevalence of overweight and obesity among adolescents, with a greater increase in girls than in boys (+8.85% vs. +1.65%, $p < 0.001$). Simulations showed that centrality-based network interventions were more effective than the random condition (average 6.17% per tick vs. 5.22% per tick, $p < 0.05$), with a higher efficiency in girls than boys (average 3.68% vs. 2.99% per tick, $p < 0.05$). PageRank outperformed other centrality conditions at the population level (6.37% per tick, $p < 0.05$). In girls, betweenness centrality was the best method (3.85% per tick, $p < 0.05$), while in boys, PageRank still had the greatest efficiency (3.21% per tick, $p < 0.05$).

Conclusions: We found evidence for gender differences in the negative impact of COVID-19-related school closures and the potential for centrality-based social

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network interventions to affect adolescent health behavior. Therefore, we emphasize the importance of gender-specific targeting strategies to further promote health-related school programs in the post-pandemic era.

Keywords: gender differences, agent-based model (ABM), obesity, peer influence, small-world networks, centrality measurement

INTRODUCTION

Adolescent's patterns of health behavior, especially physical activity (PA), are associated with academic achievement (1) and lifelong health in adulthood, including obesity and related diseases (2). The World Health Organization (WHO) recommends that schoolchildren aged 5–17 years accumulate at least 60 min of moderate-to-vigorous physical activity (MVPA) daily (3). However, nearly 80% of adolescents aged 13–15 worldwide do not meet these guidelines (4), resulting in increasing rates of overweight and obesity in adolescents (5, 6). Recently, temporary school closures due to the coronavirus disease 2019 (COVID-19) pandemic have exacerbated physical inactivity and obesity problems (7) and have raised broad social concern about the promotion of positive adolescent health behavior.

Schools offer an appropriate environment for adolescents to shape and sustain health-related behaviors. These behaviors may arise and be reinforced through observing and imitating peers (8). Peer influence, which emphasizes the friendship ties in social relationships (9), plays a crucial role in increasing PA. Evidence suggests that adolescents behave more actively when together with their peers (10), and they influence the PA level of their friends (11). As peer influence is often recognized as a social network phenomenon (12), studies have used social network interventions for various health behavior issues, such as smoking prevention (13), PA promotion (14), and water consumption (15). The results of these studies indicate the efficiency of social network interventions in accelerating individual behavioral change and improving collective health performance by a shared physical environment.

Social network intervention is based on the diffusion of innovations theory (16). Using social network data, interventions are developed with multiple tactical alternatives, including individuals, segmentation, induction, and alteration. The selection of these alternatives is based on data availability, the perceived characteristics of the behavior, the existing prevalence, and the social context (17). Studies of social networks have highlighted the value of network structure, indicating that a highly centralized network may benefit from using leadership strategies (18, 19) to inform leader selection criteria or by targeting the most influential individual, which can be provisionally determined by different concepts of centrality (i.e., in-degree centrality, closeness centrality, and betweenness centrality) (20). Van Woudenberg et al. (21) found that a network-based intervention that used closeness centrality to select influential individuals outperformed the betweenness centrality condition in promoting PA in a school setting. However, there is limited guidance on gender contexts in health behavior strategies, which may have contributed to the unpredictable process and analysis results of previous interventions (22).

There is increasing evidence for gender differences in PA participation and changes in weight among adolescents during the COVID-19 pandemic (23, 24). Girls who previously had a low level of PA showed less of a tendency than boys to further decrease their level of PA, revealing a greater resilience in girls (25). It is plausible that boys who used to actively engage in organized outdoor team sports had many of their activities canceled due to the pandemic (26) and turned to more recreational screen time and sedentary behavior (27). Paradoxically, some studies of obesity have reported a higher prevalence of overweight and obesity in boys than in girls (28, 29), whereas others have demonstrated the opposite (30, 31). Furthermore, gender disparities have also been observed in weight perception and the motivation for weight management, which may influence the role of peer relationships in social networking. Compared with boys, girls have been reported to more frequently experience weight problems and have a stronger incentive to meet appearance-related goals (32), resulting in a higher proportion of same-gender network members in the promotion of PA (33). Jacob Miguel Vigil suggested that gender-specific contexts in relationship functioning and attraction preference may translate into differences in perceptions, initiation, engagement, and maintenance and, consequently, affect the process of behavior dissemination within a social network (34). Therefore, gender-related attributes and traits are particularly necessary when implementing social network interventions for adolescents. However, real-world networks often present a challenge in terms of directly understanding the mechanism of peer influence underlying such a gender context due to the great expense and effort involved in network data collection (35). It remains unclear how social networks may be exploited in a gender-specific manner to promote positive adolescent health behaviors.

Agent-based models (ABMs) have been used in social network interventions to explore promising approaches to addressing public health challenges (36, 37). These models are useful as they simulate dynamic patterns of adaptive behavior and identify the key criteria of influential agents (38). To understand the complex process of social interaction, ABMs allow agents to have a specific influence on others who connect with themselves while maintaining the attributes and characteristics of each agent in the production of population health disparities (i.e., gender differences). Moreover, as the social influence of environmental exposure on health can occur over time (39), ABMs provide a

heterogeneous environment for simulating temporal variability, which enables vertical causality tests and long-term assessments of public health policies.

Objective of this study was to examine the effectiveness of centrality-based methods integrated with of gender contexts in a social network intervention to improve adolescent's health behavior. We developed an ABM to support network-based targeting methods and generate gender-specific health behavioral change. The social network structure used typical features with short average distances and a high degree of clustering to represent the small-world characteristics often found among adolescents (40). The network intervention focused on different selection criteria for the initial influential agents, as measured by four centrality indicators (i.e., betweenness centrality, closeness centrality, eigenvector centrality, and PageRank). To parameterize the model, we included adolescent health information, including gender, body mass index (BMI), and physical fitness (PF) test status, from both real-world datasets and other evidence from the literature for propagation details.

In regarding to the spread of health behavior, we sought to gain a greater understanding of how gender disparities in health performance and social interaction differentially determine the efficacy of school social network interventions. Specifically, we addressed the following research questions: Q1. what is the most effective centrality method in the general population? Q2. Do girls have a higher efficiency than boys? Q3. What is the most effective centrality method in girl's and boy's groups, respectively?

Following our conceptual framing and extant research, we hypothesized that the general spread of health behavior is expected to be faster under eigenvector-like centrality conditions than under betweenness or closeness centrality conditions (H1), with a higher efficiency in girls than boys (H2). In boys, an intervention based on the eigenvector centrality method is expected to be more effective than interventions based on other centrality-based methods (H3-a). Meanwhile, in girls, an intervention based on the page rank centrality method is expected to be more effective than interventions based on other centrality-based methods (H3-b).

METHODS

This section introduces the details of the social network simulation and analysis using our ABM. The demographic characteristics used to derive the parameter estimates are first illustrated intuitively, and then the social diffusion dynamics that are assumed for the propagation of health behavioral change in social networks are presented. We then discuss the construction and implementation of a synthetic network. Finally, we define the centrality measures used for the comparison of gender-specific effectiveness by networking.

Population for Model Design

Data were collected in November 2018, November 2019 and November 2020, from three rounds of a national student physical fitness test for junior middle school students at one school in downtown Tianjin, China. Two hundred and thirty-four participants (113 girls, aged 13–14 years) completed both rounds of the test and had complete health-related information of height and weight, which were used to assess the BMI (i.e., underweight, normal weight, overweight, or obese) and physical fitness test status (i.e., excellent, good, fair, or fail). The BMI and physical fitness status were defined according to national student physical health standards for Chinese school-age children based on gender- and age-specific criteria (41). Participants were classified as overweight and obese according to the 85 and 95th percentiles of BMI, respectively. The results of multiple physical tests were used to determine student's physical fitness (e.g., 50-meter run, standing long jump, vital capacity, pull-ups for boys, and 1-min sit-ups for girls). Descriptive and correlational analyses were performed using SPSS software (IBM, Armonk, NY, USA). Z-tests were used to examine statistical significance of proportional differences. Chi-square tests were used to examine the difference in mean BMI change, overweight/obesity prevalence, and PF test performance by gender. All statistical tests were two-sided, and the statistical significance was set at a P-value < 0.05.

Recognizing Gender Context in Behavior Patterns and Peer Network Formation

A higher prevalence of overweight/obesity in boys has been found consistently in previous studies of school-aged children in China (23, 28) and other Asian countries (42, 43). The reasons for this gender difference have been attributed to behavioral determinants, including diet (30, 44), PA (29, 45), weight perception (46, 47), motivation, and peer interaction (48), all of which may be key factors affecting the process of peer networking for health-related behavior promotion. Generally, boys are reported to consume more unhealthy food (e.g., high-energy fast food, sugar-sweetened food, and high-carbohydrate drinks) and show less preference for vegetables than girls. However, boys have more motivation and greater self-efficacy for PA improvement, especially in rigorous competitive PA and team sports, and are less likely than girls to be dissatisfied with their weight, which is a vital starting point to overcome perceived barriers to health behavioral change (49). Nevertheless, some studies have shown that girls place a higher value on adapting to social standards in the context of motivation for weight loss or physical appearance (32), indicating that adolescent girls may show greater adherence to school-based interventions.

Evidence shows that the effects of within-gender interactions are stronger than those of between-gender interactions (50, 51). A recent study of the heterogeneity of peer effects according to gender showed that girls are more sensitive to peer influence and are more influential than boys (52), implying that peer networks comprising only girls may be more likely to promote positive health behavior than those of boys. Moreover, girls may favor smaller group sizes (53, 54) for peer friendships and affiliations related to internalizing behaviors than do boys. However, an investigation of middle-aged adult PA reported no significant gender differences in the average network size (33).

Based on the distinctive social demands and relational constraints on behavioral patterns described above, we translated these gender features into probabilities for behavior in the ABM. Consequently, each gender was considered as an independent

target in the follow-up intervention. This approach explicitly indicates disparate parameters of the network structure (i.e., gender rewiring proportion), the diffusion rate of health behavioral change (i.e., spread chance) and the perseverance likelihood of health behavior after the intervention (i.e., resistance chance) within our simulation model.

Building the Agent-Based Model

An agent-based social network model was built using the Netlogo platform (55) to explore the efficiency of different network-based intervention strategies and determine which strategy is superior in terms of the functionality and flexibility of its implementation (35). For this model, a key assumption was that influential agents could spread their health behavior to their connected neighbors with a gender-specific probability. Thus, the number of influenced agents increased, and the positive effect spread through the social network. Meanwhile, all influenced agents had a gender-specific chance of persistence, which implied that once an influenced agent failed to persevere (relatively small chance), they would reenter the process of diffusion. Ultimately, our goal was to influence as many agents as possible, resulting in influenced agents maintaining a stable standard.

The social network was composed of a certain number of nodes (i.e., 234 agents equal to the number of participants) and links between them, with an appropriate structure indicating how these agents were connected. Different sets of initial influential agents contributed to a diverse range of propagation patterns based on the network structure. As the small-world property is often found in the social networks of adolescents (40), we relied on the well-known Watts and Strogatz (WS) (56) small-world model to generate the social network, assuming that small-world properties were always expressed in our simulation. These networks with short average distances between nodes (average path length, APL) and high clustering coefficient (CC) were created by a signature rewiring conduction (17), which maximized the optimal opportunities for influential nodes to propagate the desired influence among other nodes. The algorithm was first constructed by creating a ring of nodes, in which each node linked to two neighboring nodes on either side (four links in total). Then, each link was rewired with a certain probability. In our model, the principle of the rewiring process rewired the endpoint of a link with a small probability p ($0.01 \leq p \leq 0.1$) and considered the gender attributes of connected agents (**Figure 1**). The final proportion of links had a certain gender-specific probability (i.e., 41% for male-male, 38% for female-female, and 21% for male-female links), and the global social network satisfied the small-world properties ($CC = 0.43$, $APL = 4.8$). We used some parameters reported in previous studies to construct the network. For instance, according to the study of Rahmatollah et al. (57), the reciprocity rate was set at 0.54, with the degree of nodes set at $\sim$12 and the clustering coefficient set at 0.42. In Framingham Heart's Study (58), the clustering coefficient was set at 0.66, and the reciprocity rate was 0.57 for males and 0.71 for females, respectively, based on data from the Add Health study (59).

Four centrality-based conditions were tested in the social network intervention (i.e., betweenness centrality, closeness centrality, eigenvector centrality, and PageRank), and the agents in the top 15% of centrality were assigned as influential agents initially, equal to the scale reported in other studies (27). Due to the uncertainty in selecting influential agents, we simulated the spread dynamics of each conditional scenario via hundreds of independently repeated experiments that used the same parameters and then averaged the outcomes to provide a single value for each condition.

Based on data from previous studies, the within-gender spread chance was higher than the between-gender spread chance, whereas the spread chance was relatively greater for females than males (i.e., 0.2 for male-male link, 0.25 for female-female link, and 0.1 for male-female link). Furthermore, regarding the perceived barriers and PA preference, the chance of resistance after being influenced was lower for males than for females (i.e., 0.1 for males, 0.2 for females). Therefore, in these experiments, we emphasized the general qualitative features of the results rather than the precise measures of diffusion rate to facilitate network intervention refinement and adolescent health improvements in future practice (40). An overview of the model parameters is presented in **Table 1**.

Definitions for Centrality Measure

Certain types of centrality parameters traditionally have been considered in social network predictions (60). It is widely accepted that different applications require different centrality measure definitions (61). Thus, we briefly introduced these four centrality measures to further determine the effective centrality-based strategies for social network interventions.

Betweenness centrality is calculated as the number of the shortest paths between the members of each pair that pass through the current agent in sum (20). It depends on the extent to which an agent participates in information flow conducive to dissemination within the network intervention. In our experiment, a higher betweenness centrality agent implied a mediating role of social relationships between other indirectly linked agents, groups or subgroups. Once this agent is removed from a network, the diffusion of information may be disrupted, as the entire subgroup would be isolated from the intervention.

Closeness centrality is defined as the inverse of the average of the distances to all other agents (62). It indicates the reach of the desired influence of the diffusion speed and accessibility within a network-based intervention. It may be effective when selecting an agent with high closeness centrality as the initial influencing agent, as it disseminates the message through the fewest paths to reach all social network members.

Eigenvector centrality, devised by Phillip Bonacich (63), describes the amount of influence an agent has on a network. The importance of this influence depends on the number of linked agents (i.e., the degree of the node) and the value of the linked agents (i.e., the weight of the node), indicating that agents connected to other agents who are more well-connected will have a higher eigenvector centrality score. In our implementation, we distributed the initial influential values to each agent and designed rules to update the influential values iteratively until stable influential values were obtained (64).

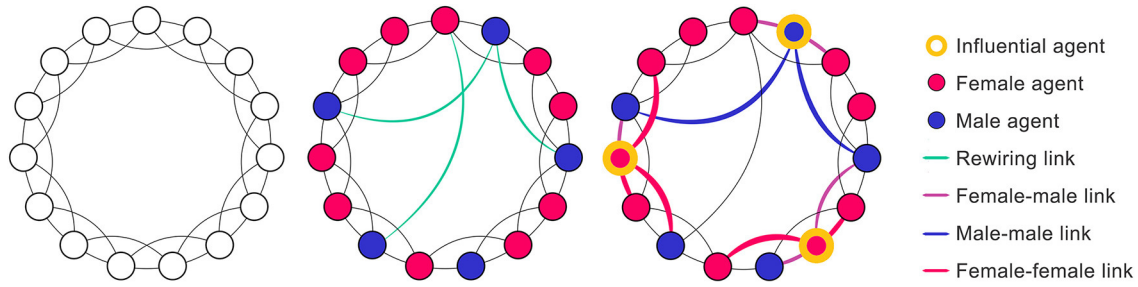

FIGURE 1 | The building process of the Watts–Strogatz small-world model with gender contexts.

TABLE 1 | Overview of parameters used for the social network ABM.

Feature	Variable name	Value
Small-world property	Clustering coefficient	0.43
	Average path length	4.81
Link proportion	Male-male	0.41
	Female-female	0.38
	Male-female	0.21
Influence agent	Initial influence proportion	0.15
Spread chance	Male-male	0.20
	Female-female	0.25
	Male-female	0.10
Resistance chance	Male	0.10
	Female	0.20

Eigenvector centrality was normalized so that a value of 1 was the highest eigenvector centrality an agent could take.

PageRank, a variant of eigenvector centrality, is a measure of the proportion of time that a message transferred randomly through the network spends at an agent (65). The message has an equal chance of taking any of the link edges and moves around the network completely randomly 15% of the time. The agent has a higher PageRank when connected to a small number of agents that are more important than themselves than when connected to a large number of agents that are less important than themselves. However, PageRank was defined for all networks, regardless of connectivity, which distinguished it from eigenvector centrality. We treated all links as undirected links in our simulation, and the sum of all PageRank values should be ∼1.

RESULTS

In this section, statistical analyses of the empirical data are first presented. We added an additional condition to validate our model by randomly selecting influential agents. In the main analyses, we created a centrality-based factorial design to investigate the contribution of various network features to the change in the average diffusion speed of a synthetic population.

Preliminary Analyses

The results of the statistical analyses indicated a marked change in the prevalence of overweight and obesity in Chinese adolescents due to COVID-19-related school closures. As shown in **Table 2**, there were significant increases among all participants in both the mean BMI (pre vs. post-lockdown: +0.52 vs. +1.39 kg/m^2, $p < 0.001$), and the overall overweight/obesity prevalence (pre vs. post-lockdown: +0.43 vs. +5.13%, $p < 0.001$). It is worth noting that gender differences included a greater increase in BMI in boys than in girls (+1.48 vs. +1.29 kg/m^2, $p = 0.036$), and a higher total prevalence of overweight/obesity in boys than in girls (47.11 vs. 40.71%, $p = 0.047$). Approximately 55.34% of boys were overweight or obese, indicating higher odds of an unhealthy BMI status, which may be associated with the difference in hormone biology as well as certain social and cultural factors (66). However, the increase in the prevalence of overweight/obesity was markedly higher in girls (pre vs. post-lockdown: +0.00 vs. +8.85%, $p < 0.001$) than in boys (pre vs. post-lockdown: +0.83 vs. +1.65%, $p < 0.001$). In addition, correlation analysis demonstrated that BMI and physical fitness scores were negatively correlated (-0.589, $p < 0.05$), which may partly explain the unsatisfactory outcomes of the increased number of physical fitness test failures. In conclusion, the many adverse effects of COVID-19-related lockdowns on BMI and obesity in adolescents confirmed the urgent need for health behavior promotion strategies in school settings aimed at increasing adolescent's fitness to pre-pandemic levels.

Model Validation

For model validation, an extra experiment was performed in which the initial influential agents were selected at random using the same model parameters and compared with the centrality-based network methods. We focused more on the diffusion speeds of various targeting interventions at the population level than the success rate of each condition. The statistical analysis revealed (**Table 3**) that, on average, the diffusion speed was lower under the random condition (5.22 % per tick, $p < 0.05$) than under the centrality-based conditions (6.17% per tick, $p < 0.05$), and there were no significant differences in the average final success rate between the random condition (98.72%, $p < 0.05$) and the centrality-based conditions (98.89%, $p < 0.05$). These

TABLE 2 | Descriptive and correlational analyses of the study population.

		Total	Girls	Boys	*P*-value[a]
Age		13.35	13.35	13.36	0.878
Number (*n*, %)		234	113 (48.29%)	121 (51.71%)	0.274
Mean BMI (kg/m^2)	2018.11	21.42	20.62	22.17	0.012
	2019.11	21.94	21.30	22.54	0.048
	2020.11	23.32	22.59	24.01	0.036
Overweight/obesity prevalence (%)	2018.11	38.46	31.86	44.62	0.023
	2019.11	38.89	31.86	45.45	0.005
	2020.11	44.02	40.71	47.11	0.047
Unhealthy weight in PF test failure (%)	2018.11	66.67	32.60	67.40	0.001
	2019.11	75.00	40.00	84.21	0.929
	2020.11	81.25	50.00	88.46	0.008
BMI and PF test failure Pearson Correlation	2018.11	−0.494***	–	–	< 0.05
	2019.11	−0.540***	–	–	< 0.05
	2020.11	−0.589***	–	–	< 0.05

[a]*Difference between boys and girls; ***Significant at P-value < 0.05.*

TABLE 3 | Descriptive statistics for the social network interventions.

Variables	Random	Betweenness	Closeness	Eigenvector	PageRank
Mean	–	0.04	0.21	0.33	0.43
Maximum	–	0.15	0.25	1.00	0.70
Minimum	–	0.00	0.17	0.07	0.01
Success rate (%)	98.91	98.92	98.71	98.96	98.97
Diffusion speed (% per tick)	5.22	6.16	5.98	6.16	6.37
Female (% per tick)	2.85	3.85	3.57	3.54	3.76
Male (% per tick)	2.81	2.96	2.86	2.92	3.21

findings indicate the credibility of the simulated centrality-based interventions based on the ABM approach.

Model Analyses

To test the effectiveness of a hypothetical social network intervention for all adolescents (H1), the four centrality-based simulated conditions (i.e., betweenness centrality, closeness centrality, eigenvector centrality, PageRank) were compared (**Figure 2**). The average diffusion speed of the PageRank condition (6.37% per tick, $p < 0.05$) was higher than the average diffusion speed of the other targeting conditions, which indicates that an agent who has high prestige among their peers might more efficiently push the entire community toward a change.

To answer the research question on gender performance (H2), the simulation result of each centrality was recorded (**Figure 3**). In contrast to our expectation, the diffusion speed under the random condition showed almost no difference between the genders (male 2.81% vs. female 2.85% per tick, $p < 0.05$). In contrast, based on the centrality-based targeting methods, females always exhibited an advantage over males in the average diffusion speed (male 2.99% vs. female 3.68% per tick, $p < 0.05$). This finding indicates that influential agents selected at random may unconsciously reduce the gender disparities in behavioral change.

To determine a gender-specific network-based strategy (H3-a/b), betweenness centrality was assumed to be the most effective targeting method for girls, with the highest diffusion speed (3.85% per tick, $p < 0.05$), followed by the PageRank method (3.76% per tick, $p < 0.05$). The closeness centrality (3.57% per tick, $p < 0.05$) and eigenvector centrality (3.54% per tick, $p < 0.05$) methods provided a relatively slight advantage for adolescent girls. However, the simulated results by the same targeting strategies showed no coherence in boys. PageRank (3.21% per tick, $p < 0.05$) outperformed other conditions, followed closely by betweenness centrality (2.96% per tick, $p < 0.05$) and eigenvector centrality (2.92% per tick, $p < 0.05$). Closeness centrality method (2.86% per tick, $p < 0.05$) still failed to show potential to propagate health-related behaviors among adolescent boys.

DISCUSSION

This paper provides evidence for the efficiency of centrality-based strategies for adolescent health behavior promotion. To the best of our knowledge, this is the first study to explore a social network

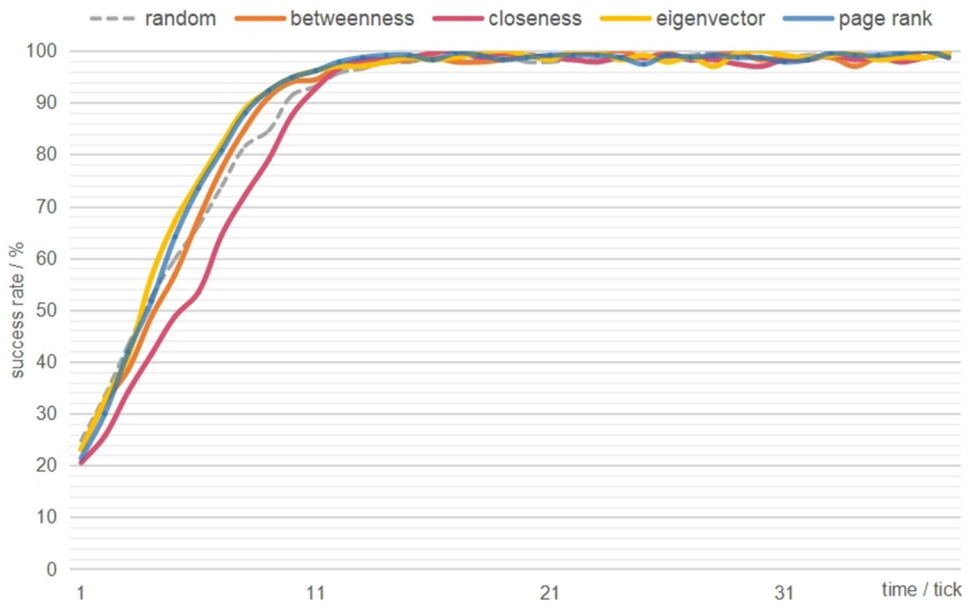

FIGURE 2 | Intervention outcomes of the random and four centrality-based conditions.

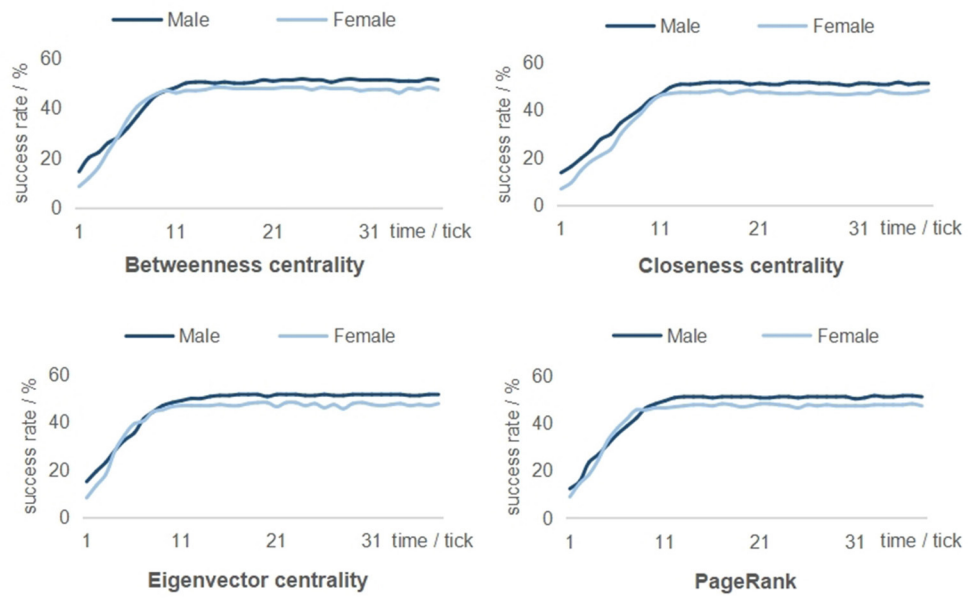

FIGURE 3 | Gender differences under four centrality-based interventions.

ABM that supports the expression of a small-world property and gender-specific attributes. Based on the social network theory, the health behavior modes of adolescents are often determined by massive connections and central positions within the network (67). However, the current practice of network-based interventions does not recognize the gender disparities in behavioral patterns and emotional preferences, exposing girls still lag behind in certain types of health-related performance, such as PA engagement. Therefore, identifying influential spreaders may help enhance the diffusion of positive health behavior in future school social network interventions.

By focusing on the diffusion speeds of different selection criteria for initial influential agents, this study brings insights into two aspects. First, we found that PageRank was the

best method among all centrality conditions at the population level (H1). PageRank is a mathematical algorithm applied by search engines use to determine the importance of a website. It can also be more practically extended to determine social influence (68) and analyze citation networks (69) and other issues (70). Contrastively, the four centrality measures we used can be grouped into two categories of social network prediction. Betweenness and closeness centrality both consider influential agents and depend on their capabilities of controlling information flow in the global network, whereas the eigenvector-like centralities (i.e., eigenvector centrality and PageRank) calculate the importance of an agent based on both the quantity and quality of its neighbors. With a distinctive emphasis on the network structure, these centralities may be regarded as generalizations of the centralities of static networks (71), with potential uses in a wide range of applications. For instance, it has been proposed that betweenness centrality is appropriate to prevent the spread of negative health behavior in a network-based intervention (72). However, the promotion of positive health behavior based on the closeness centrality method might be an efficient strategy (67), as the energetic message or opinion (e.g., PA) would reach the entire network easily without any subgroups being excluded from the intervention (73). Significantly, eigenvector-like centralities that take immediate, mediative, and global effects of social interactions into account (74) have been shown to be successful and effective at assigning centrality weights to the nodes in a network to determine the influence of social peers (71).

Meanwhile, the advantage of closeness centrality was not shown in our simulation, which is similar to the effect reported by Van Woudenberg et al. (75). One explanation for this finding is that closeness centrality agents that closely connect to all members of a network often represent the geometric center of the network. It is possible that such influential agents are not effective in "persuading" when bridging and bonding in a community that is separated into gender subgroups. Children prefer to associate with "same-gender" peers beginning at an early age (76), and this continues through adolescence. A previous study found that adolescents aged 12 to 16 were approximately three times more likely to have "same-gender" friends than "other-gender" friends (77). Building on this conception, the gender-specific subgroups in an adolescent network are more likely to be affected by their central leaders, such as the PageRank agents, rather than closeness centrality agents that lack a high-status despite being close to the entire network. This finding is also consistent with the performance disparity between the closeness and betweenness centrality conditions, as betweenness centrality emphasizes the high level of connectivity of influential agents to multiple subgroups.

Our second finding demonstrated the necessity for gender-specific strategies with different behavioral features and related performance in school social network interventions (H3-a/b). We observed that the PageRank centrality method was more efficient in males, while the betweenness centrality method was superior for network-based interventions in females. Studies have reported gender differences in behavioral patterns such that girls withdraw from boy's more aggressive style of PA engagement (78), which may explain the same-gender preference among girls. However, health promotion programs in most schools have not recognized the gender-related barriers to and opportunities for PA-related behaviors, including a lack of diverse resources and activity categories. Furthermore, emotional preferences enforce the distinctive mechanism of peer influence, as adolescent girls have a stricter definition of health, especially weight status. Those with a higher weight often experience more pressure to be slim and have been identified as a unique cluster, based on homophily and contagion assumptions, in social network studies of obesity (79). Therefore, our simulation result supported that the betweenness centrality agents may play a vital mediating role between different subgroups. This finding creates a positive intention for health-related behaviors associated with weight loss in adolescent girls, especially for those with an unhealthy weight. The betweenness cetrality method may drive subsequent behavioral change when female subgroups remain stable.

In contrast, boys are viewed as stronger and more apt than girls to participate in MVPA, such as cycling and running. It has also been argued that PA may be an additional leisure-time requirement for wellbeing in the daily lives of boys, making them more likely to continue PA behavior after achieving a weight-loss goal (80). A recent survey showed that more boys than girls reported unchanged levels of PA during COVID-19-related lockdowns, which resulted in more stable PA behavior in boys (81). These findings may be due to the originally autotelic purposes for participating in sports and PA-related behaviors among many adolescents. For instance, boys have been shown to participate in sports mainly for competition, whereas girls participate mainly for the social benefits. To some extent, the unique appeal of competitive MVPA to boys gives novel insights into network-based intervention strategies. Therefore, to promote positive health behavior to boys, we recommend that influential agents within male subgroups may be more effective than popular agents outside the subgroups at reaching the overall network with health-related messages, thus highlighting the reliability of eigenvector-like centrality agents in social network interventions. Notably, the idea that the selection criteria of eigenvector-like centralities provide an effective response to the social network intervention at the population level does not necessarily overemphasize that being active with friends is socially desirable (82).

Strengths and Limitations

The present study has several strengths. At the theoretical level, we have provided cross-sectional evidence for the negative effects of school closures and quarantine time on adolescent health outcomes during the COVID-19 pandemic, including changes in BMI and overweight/obesity prevalence and the association between higher BMI and worse physical test performance among Chinese junior middle school students. Second, based on the literature we reviewed, this is the first study to explore gender-specific recommendations for implementing a social network intervention to address adolescent health behavior promotion in the school environment. We considered gender contexts in terms of the effects of multiple behavioral patterns and emotional preference on PA and weight loss using an ABM.

Our investigation explicitly shed light on the roles of different strategies targeting influential agents through the comparison of four centrality-based network measures.

Nevertheless, this study has several limitations. First, there are data shortcomings that limit the applicability of our findings. The health-related data we used to capture a generally negative health impact due to COVID-19-related lockdowns was based on the overall perceptions of a variety of factors, such as family support and the physical environment. However, these data did not specify social cues, such as behavior links and peer interactions. Consequently, we used the WS small-world model to generate a synthetic network with parameters that were mainly based on data from the literature. Future studies assessing social network features in the real world, and the peer selection cues upon which they are based, should seek to unravel these assumed mechanisms. Similarly, we did not assess the extent to which the diffusion process and persistence chance differed according to gender, as these contexts would lead to inescapable effects on the simulation. More empirical data on detailed aspects of gender-specific health behaviors related to social networking are needed to further understand whether the behavior preference due to gender disparities results in the formation of group-related health behaviors, and more specifically, what types of PA-related behavior are preferred in these group settings.

Secondly, based on the mathematical characteristics of the model, the outcome of the ABM showed an initial increase and then reached a state of equilibrium after a certain amount of time in the simulations. Caution may be warranted when interpreting the absolute increase in positive health behavior development in reality. For instance, studies have reported a positive association between health behavior (i.e., PA promotion) and the built environment of the school, which indicates that certain physical factors, such as physical education facilities, playground characteristics, and the presence of green spaces, may affect the adoption of healthier PA behaviors by students (83). In addition, we assessed peer influence from the perspective of network structure, although this structure may also be based on many other social factors (e.g., parents, teacher relationships, and sports interests). Therefore, more extensions are possible to improve the model. For example, the contribution of physical and social environment features may be combined to account for gender-specific contexts, and multi-environmental influence modeling may be explored for adolescent health behavior promotion.

CONCLUSIONS

The COVID-19 pandemic has had an adverse effect on adolescent health globally and has emphasized the urgent need for health behavior promotion when resuming school attendance. Over the last few years, social network interventions have been successfully applied to address adolescent health issues such as obesity and physical inactivity (84, 85) through social influence. This study firstly demonstrated a significant gender difference, in that girls showed a greater increase in the prevalence of overweight and obesity compared with boys. To extend our understanding of social interactions in complex network systems, we confirmed that incorporating gender-related contexts in a social network ABM is a promising approach to disseminating the positive health behavior information. The results suggested that the PageRank centrality method had the highest efficiency in the general and male-only simulation groups, while in female-only groups, betweenness centrality offered potential advantages over the other centralities. As social media has especially become popular in the adolescent age groups nowadays, we reinforced the need to encourage the social influencers and to support peer connectedness via not only real-life but also mobile social network, which might mitigate some of the negative effects of physical distancing (86). These findings indicate that schools and public health organizations should maintain heightened sensitivity to social stimuli, and develop gender-specific strategies and policies to improve adolescent's health behavior in the post-pandemic era.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Medical Research Ethics Committee of Tianjin University (TJUE-2021-174). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

SZ: conceptualization, data curation, methodology, validation, formal analysis, visualization, writing of original draft, and review and editing. TX: methodology, software, visualization, and manuscript review and editing. JH: project administration, resources, supervision, and manuscript review and editing. All authors contributed to the article and approved the submitted version.

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Effectiveness of a Parent-Focused Intervention Targeting 24-H Movement Behaviors in Preschool-Aged Children: Study Protocol for a Randomized Controlled Trial

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Background: Interventions targeting single behaviors of preschool-aged children have been mainstream for some time, but integrated interventions targeting all three 24-h movement behaviors (physical activity [PA], sedentary behavior [SB], and sleep hygiene) are less studied. The aims of this study will be to test the feasibility, acceptability, and effectiveness of a parent-focused intervention for preschool-aged children targeting multiple 24-h movement behaviors.

Methods: This three-arm randomized controlled trial will comprise a 12-week intervention and a 12-week follow-up. A total of 150 parent-child dyads will be recruited and randomly allocated to one of three arms: (1) a PA + SB group (dyadic approach), (2) a PA + SB + sleep group (integrated approach), and (3) a wait-list control group. The theory of planned behavior and behavioral change techniques will guide the development of the intervention via workshops, education materials, interactive questionnaires, and reminders. The intervention strategies for the integrated group will be the same as for the dyadic approach except that the intervention will also target sleep hygiene in addition to PA and SB. The primary outcomes will be preschoolers' 24-h movement behaviors (e.g., activity sleep index, compositional data of PA, SB, screen time, and sleep duration). The secondary outcomes will be preschoolers' sleep quality, weight status, cognitive function, and parents' movement behaviors. The feasibility and acceptability of the intervention will also be evaluated.

Discussion: The proposed study will be a theory-based, parent-focused intervention designed to improve all three 24-h movement behaviors among preschoolers. The trial is expected to improve preschoolers' movement behaviors and health outcomes, as well as their parents' movement behaviors. Given the urgent need to promote active lifestyles, our findings will help to determine best practices for movement behavior change among young children.

Trial Registration: The study is prospectively registered at the Chinese Clinical Trial Registry (ChiCTR2200055958).

Keywords: physical activity, sedentary behavior, sleep, randomized controlled trial, study protocol, preschooler

INTRODUCTION

A healthy lifestyle developed in early childhood is associated with numerous health indicators and tracks into later life (1). Physical activity (PA) (2), sedentary behavior (SB) (3), and sleep (4) in isolation are associated with health in the early years. In addition to their individual effects, the integrated effect of all three movement behaviors in a 24-h day has attracted attention. The World Health Organization (WHO) released 24-h movement guidelines for children under 5 years of age in 2019. Specifically, a healthy day for preschoolers aged between 3 and 4 years should include at least 180 min of PA, of which at least 60 min should be moderate-to-vigorous-intensity PA (MVPA); less than 60 min of sedentary screen time; and 10 to 13 h of good-quality sleep (5). Despite the emerging evidence on 24-h movement behaviors and the promotion of integrated guidelines for the early years, low adherence to the 24-h movement guidelines has been reported in numerous countries (6). In Hong Kong, a recent study found a low compliance rate, with only 2.9% of preschoolers meeting all three 24-h movement guidelines (7). Furthermore, the homeschooling induced by the Coronavirus Disease 2019 (COVID-19) pandemic has led to unfavorable behavior changes. Evidence from several countries indicates that since the outbreak of the pandemic, preschoolers have become more sedentary and had more screen time compared with before the pandemic (8–10). As a result, interventions targeting multiple movement behaviors are warranted and should help to determine best practices for behavior change.

Previous intervention studies have predominantly targeted a single type of movement behavior, particularly PA. Their effectiveness has been summarized in recent systematic reviews (11–13). Interestingly, previous studies have described overflow effects of interventions targeting a single behavior on other non-targeted behaviors. For example, one systematic review reported that interventions aiming to increase PA also reported a decrease in screen time (32 min) for children under 5 years (12). However, given that time is finite and fixed, time spent in PA, SB, and sleep in any 24-h period is not independent and should be viewed as a continuum. In other words, an increase in time spent on one behavior requires an equivalent decrease in time spent on other activities. Studies using statistical models have provided evidence for the effectiveness and flexibility of changing multiple behaviors. Specifically, compositional data analysis found that among adults, similar health outcomes (risk of all-cause mortality) were achieved by different combinations of movement behaviors (14). For example, movement behavior combinations A (light-intensity PA [LPA]: 375 min, MVPA: 3 min, SB: 582 min, sleep: 480 min) and B (LPA: 250 min, MVPA: 55 min, SB: 655 min, sleep: 480 min) during 24 h were associated with a similar risk of all-cause mortality (14). The above evidence suggests that it is necessary to explore whether integrated interventions targeting PA, SB, and sleep simultaneously can generate a larger effect than interventions targeting a single type of behavior. To the best of our knowledge, the only study targeting changes in PA, SB, and sleep simultaneously was conducted in adolescents (15). Compared with the control group, the intervention group had higher PA, lower SB, longer sleep duration, and higher compliance rate to all 24-h movement guidelines after one academic year of intervention (15). However, that study did not evaluate how the 24-h movement behaviors change as a whole, i.e., the composite behavior change. Furthermore, no studies have prospectively targeted changing all 24-h movement behaviors in the early years.

Most behavior change interventions for children under 5 years have been conducted in preschool and childcare settings (11). However, the importance of parental involvement in behavior modifications has been consistently documented (16). A previous systematic review found a greater effect on reducing screen time (−30.6 min/day) for family-based interventions compared to other settings (12). Yoong et al. conducted a study targeting the home routines of preschoolers and found an increase in the sleep of 0.9 h/day after a 3-month intervention (17). Based on the success of family-based interventions targeting single movement behavior, an exploration of the effectiveness of integrated interventions targeting all three 24-h movement behaviors has been recommended (16). Of further note, since the outbreak of the COVID-19 pandemic, preschools have been locked down for a long time and the time that parents spend with their children has significantly increased. A parent-focused intervention to promote 24-h movement behaviors in preschoolers is therefore meaningful and timely.

To fill the research gap and improve understanding of best practices for behavior change in young children, a parent-focused, theory-driven intervention targeting all 24-h movement behaviors for preschool-aged children will be developed. The theory of planned behavior (TPB) will be the theoretical basis for developing this intervention, for several reasons. First, a systematic review found that intention predicted parent-for-child health behaviors, such as reminding and setting limits (18). Second, a study of children in Hong Kong found that parents' perception of the benefits of PA was positively associated with the PA of their children (19). Third, parent-focused TPB-based interventions were effective in improving PA and sleep among preschoolers and children (17, 20). In addition to TPB components, some effective strategies recommended by systematic reviews of interventions in children will be used, such as goal setting, monitoring, and habit development (11, 21, 22). Furthermore, to make the intervention strategies more practical and focused, specific behavior change techniques (BCTs) will be incorporated with the TPB components and strategies (23).

Specifically, the proposed study will (1) test the feasibility and acceptability of a parent-focused intervention targeting multiple 24-h movement behaviors (PA, SB, and sleep hygiene) for preschool-aged children; (2) investigate the effectiveness of a parent-focused intervention to increase PA, reduce SB, and enhance sleep hygiene for preschool-aged children; and (3) examine whether an integrated 24-h movement behavior approach is superior to an intervention targeting daytime behaviors (PA and SB) only. We hypothesize that (1) a parent-focused intervention targeting multiple 24-h movement behaviors for preschool-aged children is feasible and acceptable; (2) both intervention approaches (PA + SB group, PA + SB + sleep group) can effectively change behaviors; and (3) an integrated approach (PA + SB + sleep group) is superior to an intervention targeting daytime behaviors (PA + SB group) only.

MATERIALS AND METHODS

Study Design

The study will be a three-arm randomized controlled trial (RCT) using a 1:1:1 allocation ratio, as shown in **Figure 1**. The intervention will last for 12 weeks and will be followed by a 12-week post-intervention follow-up. After screening and baseline assessments, parent-child dyads will be randomly allocated to one of three groups: (1) PA + SB group (dyadic approach), (2) PA + SB + sleep group (integrated approach), or (3) wait-list control group. Considering the potential impact of the COVID-19 pandemic, the intervention will be delivered predominantly online (Zoom meetings, online survey using Google Forms). The study will follow the Consolidated Standards of Reporting Trials (CONSORT) Statement for randomized trials (http://www.consort-statement.org/).

Participants

Kindergartens that have participated in our previous studies will be contacted (7), and more families will be invited using purposive and snowball sampling. The specific inclusion criteria are as follows: (1) families having at least one 3-to-5.9-year-old child; (2) the child is living with parents; and (3) the child does not have any diseases that prevent them from participating in PA or falling asleep. Children who meet all of the 24-hour movement guidelines will be excluded. In a previous study conducted in Hong Kong, less than 3% of preschoolers met all three guidelines (7). Therefore, over-recruitment will be necessary to ensure an adequate sample size. For screening, children will wear an ActiGraph accelerometer for seven consecutive days to measure their PA, SB, and sleep, and parents will respond to a question regarding their child's screen time. Written consent will be sought from parents. Approval from the Research Ethics Committee, Hong Kong Baptist University has been obtained (Ref. No.: SOSC-SPEH-2021-22-200).

Sample Size

A recent systematic review and meta-analysis found a small but statistically significant effect size for interventions to increase PA in children under 5 years old (11). Intervention studies aiming to reduce SB and improve sleep hygiene among young children reported small to medium effect sizes (17, 24). Based on the above information, a prior analysis was conducted, which indicates that a minimum sample size of 99 (33 per group) is required to detect a small effect size f of 0.15 with a power of 0.90 under the conditions of an alpha level of 0.05, three arms (PA + SB group, PA + SB + sleep group, wait-list control group), and four repeated measures assuming a correlation between repeated measures at 0.50. Considering a potential attrition rate of 20% (25, 26), 119 children are needed. Therefore, using an over-sampling procedure, 150 parent-child dyads will be recruited and screened. The power calculation is conducted using G*Power 3.1.9.7.

Intervention

Procedure

Data collection will be performed during a school visit at baseline (T1), 6 weeks (mid-term; T2), 12 weeks (immediately after the intervention; T3), and 24 weeks (follow-up; T4). Accelerometers and a take-home package will be distributed to parents via the children. The package will include (1) an information sheet about the ActiGraph and instructions on how to wear the device during the 7-day period; (2) online questionnaires to be completed by parents (assessing parents' PA, SB, screen time, and sleep, children's screen time and sleep quality, and demographic information); (3) a log sheet for parents to record when the device is removed and the reasons for removal and their child's nap time. After the baseline and mid-term measurements, a brief report will be provided to parents, including the current movement behaviors of their child and the differences from the recommended durations. After the final measurement (T4), a complete report presenting the changes in the child's movement behaviors will be provided to each parent.

PA + SB Group (Dyadic Approach)

Following the baseline assessment and group allocation, families in the PA + SB group will receive educational materials by email. The materials will include information on the WHO recommendations for preschoolers and materials targeting increasing PA, decreasing SB, and screen time for children. The following materials will be delivered to families biweekly to guide parents to set goals for their child: (1) an individual report on the child's current level of movement behaviors (PA, SB, sleep) and divergence from the guidelines; (2) introduction to setting goals and planning (e.g., specific, progressive, achievable); (3) a schedule for parents to fill in, including biweekly goals for each movement behavior; (4) examples to improve PA and decrease screen time (e.g., games designed for children, including written descriptions and pictures); (5) potential barriers and strategies; and (6) strategies for developing habits.

Three online workshops delivered as Zoom meetings will be held for parents in the intervention groups in weeks 1, 3, and 6. The workshops will aim to explain strategies that can be adopted by parents based on BCTs and TPB to solve problems and to encourage parents to comply with the intervention. Specifically, the first workshop will be a brief lecture for parents about the 24-h movement guidelines and the association between movement behaviors and health outcomes, as well as a general introduction

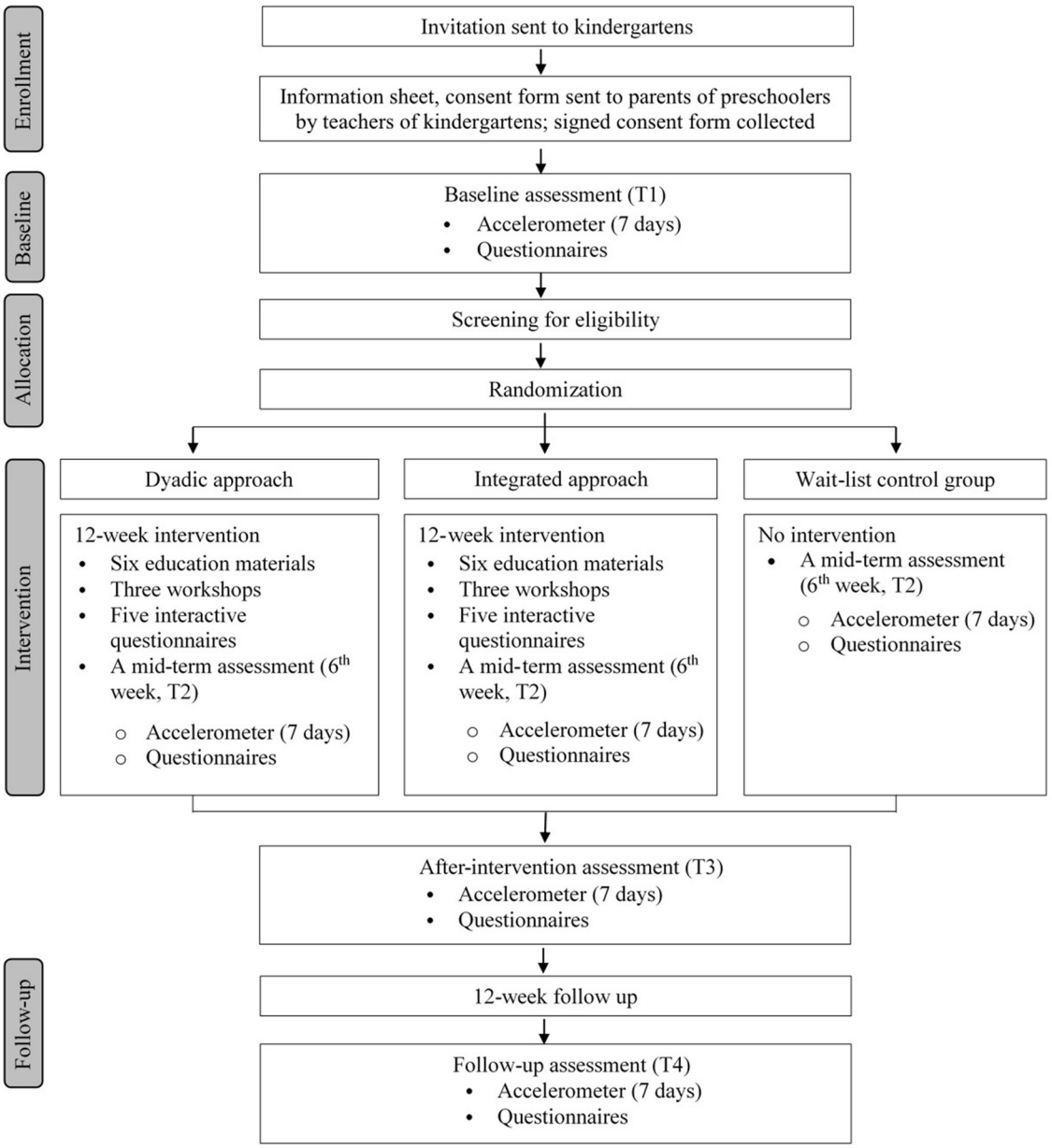

FIGURE 1 | Flow chart of the study.

to the program (e.g., how to set individual goals, how to use the materials). The second and third workshops will focus on discussing and providing strategies to overcome barriers that the parents have experienced during the intervention, as well as strategies to develop habits. Each workshop will be held as a group meeting of approximately 10 parents to ensure manageability and feasibility. Activities such as check-in polls, topic-based Q & A sessions, and breakout rooms for small-group discussions will be designed to facilitate the workshops. Each workshop will last for 30 to 45 min. If any parents do not have time to attend the workshops, a recorded video of the workshop will be sent to them, and a phone call will be made to provide a brief introduction to the workshop, ask whether they have had any challenges, and suggest strategies. Every 2 weeks, the parents will be asked to complete an online questionnaire using Google Forms. The questions will relate to the children's movement behaviors (e.g., average PA, SB, screen time, bedtime, and wakeup time), whether and how they have used the planning materials for each movement behavior, whether they have achieved the goals and schedules for the coming 2 weeks, etc. At the end of each questionnaire, reminders about the materials use will be presented.

PA + SB + Sleep Group (Integrated Approach)

The intervention strategies for the integrated approach group will be the same as for the dyadic approach group except that the intervention content will target sleep hygiene in addition to PA and SB (**Table 1**). For example, the sleep recommendations for young children and strategies to change parents' practices related to their children's sleep hygiene will be provided.

Wait-List Control Group

Parents in the wait-list control group will not receive the intervention. They will be given access to the educational materials after the intervention and follow-up.

Outcomes

Primary Outcomes

Activity Sleep Index

Similar to the activity-sleep index created for adults (27), a composite movement behavior score will be created to summarize the multiple dimensions of PA, SB, and sleep among preschoolers. The composite movement behavior score will comprise scores for the following six dimensions representing broad variables that have been examined in relation to the 24-h movement guidelines (28, 29) and in previous studies on sleep among young children (30):

1. PA: total time on PA of all intensities.
2. PA: total time on MVPA.
3. Screen time.
4. Sleep: bedtime duration (time in bed).
5. Sleep: sleep onset variability (variability in sleep onset times).
6. Sleep: morning wake-time variability (variability in wake times).

Each item will be rescaled from 0 to 10, with a higher score indicating healthier movement behaviors. The formula for rescaling is as follows (27):

$$Rescaled\ score\ = \left(\frac{(X - X_{\min})}{X_{Range}}\right) \times 10$$

where X is the observed value, $X_{\min}$ is the minimum value observed, and X_{range} is the difference between the maximum and minimum values observed (27). A total score ranging from 0 to 60 will be obtained by summing the scores for all items, with higher scores indicating healthier movement behaviors.

Compositional Data

Compositional data analysis has been suggested to examine movement behaviors occurring within a finite period, specifically when they are continuously measured using accelerometers (31). The time spent on one movement behavior relative to all other behaviors will be presented as isometric log-ratio coordinates (*ilr*), which will be the outcome variable in the regression models. For example, a 24-h period can be divided into time spent in PA, SB, and sleep. Taking PA as an example, the equation is as follows:

$$ilr_1 = \sqrt{\frac{2}{3}} \ln\left(\frac{PA}{\sqrt[2]{SB^{*}Sleep}}\right)$$

where ilr_1 represents sleep relative to all other movement behaviors.

The time allocated to SB relative to other movement behaviors can be assessed using the ilr_2, which can be expressed as follows:

$$ilr_2 = \sqrt{\frac{2}{3}} \ln\left(\frac{SB}{\sqrt[2]{PA^{*}Sleep}}\right)$$

Similarly, the time allocated to sleep relative to other movement behaviors can be assessed using ilr_3, which can be expressed as follows:

$$ilr_3 = \sqrt{\frac{2}{3}} \ln\left(\frac{Sleep}{\sqrt[2]{PA^{*}SB}}\right)$$

Children's Physical Activity and Sedentary Behavior

ActiGraph accelerometers (ActiGraph, Pensacola, Florida, USA) will be used to assess children's PA and sedentary time. During a school visit, trained researchers will help children attach the ActiGraph to their non-dominant wrist using a wrist band (32). Children will be asked to wear the device for seven consecutive days during 24-h period. The ActiGraph should be removed when children undertake any water-based activities (e.g., bathing and swimming), and parents will be asked to complete a log sheet to record the time and reasons for removing the device. The ActiGraph data will be collected at a sampling rate of 30 Hz (32). Data will be downloaded using ActiLife software v6.13.4. and analyzed in 5-s epochs. A time period of more than 60 min of zero counts continuously will be regarded as non-wear time. Days with at least 16 hours recorded as wearing time will be regarded as valid (33). To reflect children's habitual behavior patterns, only children who provide data for at least 3 days including at least 1 weekend day will be included in the final analysis (34). Cut-off points that have been validated in preschool-aged children will be used. Specifically, sedentary time, LPA, and MVPA will be defined as $\leq$328 counts, 329–1392 counts, and $\geq$1393 counts per 5 seconds for vector magnitude, respectively (32). Total PA (TPA) will be calculated by summing LPA and MVPA.

Children's Screen Time

Screen time will be reported by parents using a question modified from the Children's Leisure Activities Study Survey questionnaire–Chinese version (CLASS-C) (35): How much time does your child spend on sedentary screen time (e.g., watching TV/DVDs, playing video games, using computers, using tablets and mobile phones)?

Children's Sleep Duration

Sleep duration will be assessed using ActiGraph data matched with a parent-reported diary and nap schedule provided by kindergartens. The duration of nighttime sleep will be estimated using ActiLife software v6.13.4 in 60-s epochs. The automated Sadeh et al. algorithm (36) will be applied to identify bedtime and wakeup time, and the Tudor-Locke algorithm (37) will be used to detect periods of sleep. For the duration of daytime naps, bedtime and wakeup time will be identified using ActiLife software and matched with the nap schedule provided by kindergartens and

TABLE 1 | Strategies and behavior change techniques involved in the PA + SB + sleep group.

Approach	Time	Strategies	Behavior change technique (code) (53)	Contents
Education materials	Week 1 & 2	Attitude toward the behavior, subjective norm, monitoring, goal setting	Information about health consequences (5.1) Information of others' approval (6.3) Feedback on behavior (2.2) Discrepancy between current behavior and goal (1.6) Goal-setting (behavior) (1.1)	1. WHO 24-h movement guidelines for preschoolers 2. Benefits of having a healthy lifestyle (i.e., high physical activity, low sedentary behavior, low screen time, sufficient sleep) for preschoolers 3. What important others think about the behavior 4. Individual report on children's current level of movement behaviors and the gap with the guidelines 5. Steps and strategies of goal-setting (e.g., SMART goals)
	Week 3 & 4	Planning, intention	Action planning (1.4) Non-specific incentive (10.6)	1. Examples of improving physical activity, reduce sedentary behavior, and improve sleep 2. Examples of giving incentives for child when he/she make effort/progress in performing the behavior
	Week 5 & 6	Perceived behavioral control, planning, intention	Problem-solving (1.2) Action planning (1.4) Non-specific incentive (10.6)	1. Strategies to overcome barriers 2. Examples of improving physical activity, reduce sedentary behavior, and improve sleep 3. Examples of giving incentives for child when he/she make effort/progress in performing the behavior
	Week 7 & 8	Monitoring, perceived behavioral control, planning, habit development	Feedback on behavior (2.2) Problem-solving (1.2) Action planning (1.4) Habit formation (8.3)	1. Individual report on children's current level of movement behaviors and the gap with the guidelines 2. Strategies to overcome barriers 3. Examples of improving physical activity, reduce sedentary behavior, and improve sleep 4. Examples of habits
	Week 9 & 10	Planning, habit development	Action planning (1.4) Behavioral substitution (8.2) Habit formation (8.3)	1. Examples of improving physical activity, reduce sedentary behavior, and improve sleep 2. Strategies for developing habits (substitution, repetition)
	Week 11 & 12	Monitoring, habit development	Feedback on behavior (2.2) Behavioral substitution (8.2) Habit formation (8.3)	1. Individual report on the change of children's movement behaviors during the past 10 weeks (based on parent-reported interactive questionnaires) 2. Strategies for developing habits (substitution, repetition)
Workshops	Week 1	Subjective norm, attitude toward the behavior, goal setting	Information of others' approval (6.3) Information about health consequences (5.1) Goal-setting (behavior) (1.1)	1. Introduction of the program 2. WHO 24-h movement guidelines for preschoolers 3. Benefits of having a healthy lifestyle (i.e., high PA, low SB, low screen time, sufficient sleep) for preschoolers 4. Steps and strategies of goal setting
	Week 3	Perceived behavioral control, intention	Problem-solving (1.2) Verbal persuasion about capability (15.1)	1. Solve problems that families have faced using materials 2. Provide strategies to parental perceived barriers 3. Sharing experiences 4. Encouraging families to comply with the intervention
	Week 6	Perceived behavioral control, intention, habit development	Problem-solving (1.2) Verbal persuasion about capability (15.1) Habit formation (8.3)	1. Provide strategies to parental perceived barriers 2. Sharing experiences 3. Encouraging families to comply with the intervention 4. Example of habits 5. Strategies for developing habits
Interactive questionnaires	Week 2, 4, 6, 8, & 10	Goal setting, monitoring	Review behavior goals (1.5) Self-monitoring of behavior (2.3)	1. Movement behaviors over the past two weeks (duration, whether achieve the goal or not) 2. Bi-weekly goals for each movement behavior 3. Reminders of materials use

log sheets completed by parents. The total sleep duration in a day will be defined as the sum of nighttime sleep and daytime naps.

Secondary Outcomes

Children's Sleep Quality

Children's sleep quality will be measured using the Chinese version of the Children's Sleep Habits Questionnaire (CSHQ) (38), which has been used to measure Chinese preschoolers' sleep patterns and problems based on parental reports. The CSHQ consists of 33 items in eight dimensions: bedtime resistance, sleep onset delay, sleep duration, sleep anxiety, night waking, parasomnias, sleep-disordered breathing, and daytime sleepiness. Three options are provided for each item: 5 to 7 times a week (scored 3), 2 to 4 times a week (scored 2), and 0 to 1 time a week (scored 1). Higher scores indicate greater sleep problems. The Chinese version of the CSHQ has shown good reliability (Cronbach's $\alpha = 0.73$) and validity (38).

Children's Body Mass Index

Preschoolers' heights and weights will be measured by trained researchers during school visits. Children's body mass index (BMI) will be calculated as weight (kg)/height (m^2).

Parents' Physical Activity and Sedentary Behavior

The Chinese version of the International Physical Activity Questionnaire–Short Form (IPAQ-SF) (39) will be used to estimate parents' PA (walking, moderate-intensity PA [MPA], vigorous-intensity PA [VPA], total energy expenditure) and SB over the previous seven days. Energy expenditure corresponding to walking, MPA, and VPA are 3.3 metabolic equivalents (METs), 4.0 METs, and 8.0 METs, respectively. The sum of energy expenditure on walking, MPA, and VPA will be considered total energy expenditure (MET-minutes/week).

Parents' Screen Time

Parents will respond to two questions: (1) on average, in a 24-h day, how much time do you usually spend on sedentary screen time (e.g., using computers, tablets, and mobile phones) for work, and (2) how much time do you usually spend on sedentary screen time (e.g., watching TV/DVDs, playing video games, using computers, using tablets, and mobile phones) for leisure and entertainment?

Parents' Sleep Duration and Quality

Parents' sleep duration and quality over the previous month will be measured using the Chinese version of the Pittsburgh Sleep Quality Index (PSQI) (40). The PSQI consists of 18 self-reported items in seven dimensions: sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbance, sleep medication used, and daytime dysfunction. Four options scored from 0 to 4 are provided for each item and a higher PSQI score indicates worse sleep quality. The PSQI has shown good reliability (Cronbach's $\alpha = 0.84$) and validity among Chinese adults (40).

Cognitive Function

The Childhood Executive Functioning Inventory (CHEXI) (41) will be used to evaluate the executive function of the preschoolers. The CHEXI consists of 24 items in two domains: working memory (13 items) and inhibition (11 items). For each item, five options ranging from "1 = definitely not true" to "5 = definitely true" are provided, where a higher score indicates worse executive function. The CHEXI has demonstrated high reliability and has been translated into traditional Chinese (42). It can be downloaded freely online (https://chexi.se/onewebmedia/CHEXI-TraditionalChinese2016.pdf).

Covariates

Preschoolers' characteristics (age, sex, number of siblings), parents' characteristics (age, sex, height, weight, education level), family income, family size, family structure, and type of residence will be reported by parents. Children's eating habits will be measured using questions based on a previous study conducted among preschoolers in Hong Kong (43). Five domains (fruit, vegetables, dairy products, breakfast, high-energy-density foods) will be covered using five items. Responses to all items will be made on a 5-point Likert scale. For example, breakfast intake will be assessed using one question: How often does your child eat breakfast? Possible answers will be as follows: <1 day/week, 1–2 days/week, 3–4 days/week, 5–6 days/week, and every day. Possible answers for the other questions will be <1 serving/day, 1–2 servings/day, 3–4 servings/day, 5–6 servings/day, and >6 servings/day.

Feasibility and Acceptability

Feasibility. Retention rates for each group and reasons given by participants who remove, withdraw, or are lost to follow-up will be recorded. Adverse effects, if any, will be documented.

Fidelity and Adherence. Intervention fidelity will be monitored, including the delivery of three workshops, six educational materials, two brief reports of measurements, and five questionnaires and reminders (one brief questionnaire every 2 weeks) for each person (24).

Acceptability. Based on a previous study (17), five items will be used to separately measure the PA and SB components for the two intervention groups. For the integrated approach, an additional five items will be used to evaluate the sleep component. Among the five items for each component, one item will be used to evaluate the overall intervention (poor, average, or good). The other four items will be used to evaluate each strategy separately (i.e., educational material, workshop, report of measurements, interactive questionnaire and reminder about material use). Parents will be asked to rate the usefulness using 5-point Likert scales (from "1 = not useful" to "5 = very useful").

Randomization and Blinding

Randomization and group assignment will be conducted using computer-generated random numbers by a third person who is blinded to the purpose of the study. After baseline data collection, the participants will be randomly allocated to one of three arms. The trained staff who will be responsible for data collection will also be blinded to group assignment. Although blinding participants to the intervention is not feasible for this study, families in the two intervention groups will not be disclosed of the differences in the intervention contents.

Statistical Methods

Analyses will be performed using SPSS 27.0. The significance level will be set at 0.05. Descriptive statistics will be presented for the children's baseline movement behaviors. Feasibility and acceptability will be presented using percentages. Differences in movement behaviors across three groups at baseline will be assessed using analysis of covariance. The intention-to-treat principle (all participants) and sensitivity analysis (participants with complete data) will be used to compare primary outcomes between groups. Generalized estimating equations will be applied to examine the effects of the intervention (PA + SB group vs. control group, PA + SB + sleep group vs. control group) on primary outcomes (children's overall movement behaviors, total PA, MVPA, sedentary time, screen time, sleep duration) and secondary outcomes, adjusting for covariates. Also, the difference of the effect between two intervention groups (PA + SB group vs. PA + SB + sleep) will be examined using generalized estimating equations.

DISCUSSION

The aim of the proposed study will be to explore the impact of an integrated movement behaviors (PA + SB + sleep) intervention on promoting overall 24-h movement behaviors (based on activity sleep index and compositional data) and to evaluate how changes in overall 24-h movement behaviors mediate the effect of interventions on health outcomes among preschoolers. At the time this study was initiated, to the best of our knowledge, no studies have examined the effect of an intervention targeting change in all 24-h movement behaviors among preschoolers.

Engaging in a healthy combination of movement behaviors has been related to health among young children (1). In Hong Kong, low compliance with the WHO 24-h movement guidelines among preschoolers has been reported, suggesting the need for interventions aimed at improving all three behaviors (7). Although previous interventions have been demonstrated to be effective in improving individual behaviors among preschoolers (11–13), no study has simultaneously targeted all three 24-h movement behaviors using integrated strategies for the early years. To fill this gap, the proposed intervention will target all three behaviors, and we will examine how these behaviors change as a whole. Two indicators—an activity sleep index and compositional behavior data—will be used to examine preschoolers' overall behaviors. The activity sleep index provides a total score for different dimensions of movement behaviors, with a higher score indicating better overall movement behaviors (27). This indicator may therefore better reflect the overall pattern of 24-h movement behaviors (total PA, MVPA, screen time, and duration and timing of sleep) and can provide insight into how different behaviors change simultaneously. The other primary outcome will be compositional data that reveal the time spent on one behavior relative to other behaviors, which has been increasingly used (31). Previous studies have used compositional data analysis when examining 24-h movement behaviors and health outcomes among preschool-aged children, but most of them applied cross-sectional designs and measured sleep duration subjectively (44–47). Therefore, an intervention study adopting device-based measurement is needed to objectively explore the effect on compositional behavior data in this age group.

In addition to improving children's movement behaviors, our secondary outcomes will be the changes of children's health-related outcomes after the intervention. We will focus on two health indicators: body weight status and cognitive function. Obesity has become a global health issue, and 39 million 0-to-5-year-olds were categorized as overweight or obese in 2020 (48). Therefore, not surprisingly, body weight status has been the most commonly examined indicator in previous studies examining the associations between meeting the 24-h movement guidelines and health outcomes in the early years (6). Cognitive function, which is supported by brain development and linked to future academic performance, develops rapidly during the preschool period (49). Systematic reviews have reported that PA interventions benefit children's cognitive functions consistently (2, 50), but studies of SB and sleep interventions that examine cognitive function in children are limited (3, 4). Despite the importance of healthy body weight and cognitive function for preschoolers, there has been no convincing evidence of the relationship between adherence to movement guidelines and these two indicators because of the limited number of studies and the cross-sectional designs used in most of them (6). In addition, a recent systematic review called for experimental studies to explore the effects on health of meeting the guidelines (6). The proposed study will respond to this demand. It is expected that children in both intervention groups will show better health and children in the integrated intervention group will have superior improvement.

Through this intervention, we will also aim to help parents develop a healthier lifestyle. Evidence from a systematic review suggests that there are small but positive associations between parents' and children's movement behaviors, based on a majority of cross-sectional studies (51). A consensus statement on the importance of the family to the movement behaviors of children and youth noted that parents can support their children by improving their lifestyles in various ways, including modeling and co-participation (16). An ongoing 6-month-intervention that aims to increase children's PA will evaluate parents' PA, but no results are available yet (52). Thus, there is a need to explore the changes in parents' movement behaviors after our proposed interventions. We hypothesize that parents in the intervention groups will improve their movement behaviors.

The proposed study has numerous strengths, including targeting all three 24-h movement behaviors, the application of a theoretical framework, objective measurement of children's movement behaviors, and an RCT design. The proposed intervention is parent-focused and will explore an integrated approach targeting all three movement behaviors for preschool-aged children. The findings will help to determine best practices for behavior change. The beneficiaries will include

families with young children and other stakeholders in early education.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Research Ethics Committee, Hong Kong Baptist University.

AUTHOR CONTRIBUTIONS

WH and JF conceptualized and designed the study. CS contributed to concept and design refinement. JF prepared the first draft under the supervision of WH. All authors contributed to revising the manuscript and approving the final manuscript.

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Cardiometabolic Effects of a 12-Month, COVID-19 Lockdown-Interrupted Lifestyle Education Program for Arab Adolescents

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Background: Childhood obesity and pediatric metabolic syndrome (MetS) have steadily increased during the last decade in Saudi Arabia. Intervention programs to prevent cardiometabolic disorders in Arab youth are needed.

Objective: In this multi-school intervention study which was disrupted by COVID-19-imposed lockdowns (September 2019–April 2021), a 12-month lifestyle education program focused on improving the cardiometabolic status of Arab adolescents was investigated.

Methods: A total of 2,677 Saudi students aged 12–18 years were recruited from 60 different secondary and preparatory year schools in Riyadh city, Saudi Arabia. The intervention was initially in-person counseling sessions and the subsequent sessions conducted virtually post-pandemic. Baseline anthropometrics and fasting blood samples for glucose, HbA1c, and lipid assessments were collected at baseline and after 12 months (704 participants).

Results: Only 704 out of 2,677 (73.7% dropout) completed the intervention. At baseline, 19.6% of the participants were overweight and 18.1% were obese. A modest but significant decrease in the prevalence of central obesity [11.2 vs. 6.7% (−4.5% change, $p = 0.002$)], hypertension [22.3 vs. 11.4% (−10.9% change, $p < 0.001$)], and low-HDL cholesterol [61.6 vs. 23.3% (−38.3% change, $p < 0.001$)] was noted. Consequently, the prevalence of hypertriglyceridemia increased from 22.7 to 56.3% (+ 33.6%, $p < 0.001$) overtime. Also, the proportion of subjects who were able to change their status from MetS to non-MetS was significantly more in overweight/obese at baseline than normal weight (16.9 vs. 3.6%, adjusted OR = 3.42, $p < 0.001$).

Conclusion: Interrupted lifestyle education programs secondary to COVID-19-imposed lockdowns still provided modest effects in improving cardiometabolic indices of Arab adolescents. Given the high digital literacy of Arab youth, improving the delivery of virtual lifestyle education programs may prove beneficial.

Keywords: COVID-19 lockdown, metabolic syndrome, adolescents, lifestyle education, school

INTRODUCTION

Overweight and obesity in children and adolescents have consistently increased in the last three decades and have emerged as a modern-day public health challenge (1). In the United States, data from the National Health and Nutrition Examination Survey indicated that obesity in youth aged 2–19 years increased from 13.9% in 1999–2000 to 18.5% in 2015–2016 (2). Unhealthy eating patterns and sedentary behavior have been mostly blamed for this increasing trend in childhood overweight and obesity (3, 4). The widespread pediatric obesity is also prevalent in Saudi Arabia and has been increasing to around 6.4% in 2002 and 9.3% in 2010, reaching 15.9% in 2015 (5). Following the discovery of oil in the 1960s, the Arabian Gulf States saw tremendous economic expansion, linked to a rise in the incidence of overweight and obesity (6). Obesity in adolescence and childhood is a risk factor for adult obesity, which is associated with chronic health complications such as type 2 diabetes, cardiovascular diseases, and metabolic syndrome (MetS) (7, 8).

MetS, a clinical low-grade inflammation state consisting of several cardiometabolic risk factors such as obesity, hypertension, dyslipidemia, and hyperglycemia, is common in obese adults but on a rising trend in adolescents in developing countries including Saudi Arabia (9, 10). Although cardiovascular events show up mostly in adults, the risk factors start developing earlier. Furthermore, the recent literature suggests that these risk factors, especially MetS, may be present silently in children and adolescents (11, 12). Therefore, effective intervention programs to reduce metabolic stress and life-threatening diseases should not be limited to high-risk groups such as obese adults. Still, they may be implemented as a prevention strategy in children and adolescents in a school setting. This is especially important in Saudi Arabia, where economic boom in the recent past has not only seen a parallel increase in the prevalence of obesity and metabolic syndrome but also because of the fact that the population of children and adolescents in Saudi Arabia is high with 31.3% of the total population under the age of 20 years, according to the semi-annual report of 2021 by the General Authority of Statistics, Kingdom of Saudi Arabia (13).

Earlier reviews of school-based lifestyle change interventions targeted at reducing the rising prevalence of obesity in adolescents yielded mixed results in terms of effectiveness (14, 15), and there have been very few studies on the effectiveness of lifestyle change programs in reducing different components of MetS in this age group, particularly in this part of the world with a surge in pediatric obesity in the past few decades. At the domestic level, education programs aimed at increasing awareness about vitamin D deficiency have been introduced, and while these programs modestly improve cardiometabolic profiles of adolescents, the primary outcome was the correction of micronutrient deficiency and not harder outcomes such as MetS and obesity (16, 17). This rising prevalence of obesity and associated metabolic disorders in adolescents are concerning. Hence, preventive measures based on the lifestyle education may prove beneficial in this population. In this context, the researchers at the Chair for Biomarkers in Chronic Diseases (CBCD), King Saud University (KSU), together with the Saudi Charitable Association of Diabetes (SCAD), initially designed an in-person, school-based 12-month intervention program where counseling about the benefits of good dietary habits and improved physical activity behavior was implemented. Unfortunately, this intervention program was interrupted following the nationwide COVID-19 lockdown in March 2020 but was eventually resumed, albeit virtually. In this study, thus, the efficacy of a 12-month lifestyle education program disrupted by the COVID-19 lockdown was investigated.

MATERIALS AND METHODS

Study Participants and Baseline Assessment

A cluster-randomized school-based convenience sample educational interventional program was conducted in 60 high schools and preparatory year schools in Riyadh, Saudi Arabia. This was a 12-month lifestyle change educational program conducted by the Chair for Biomarkers of Chronic diseases (CBCD), King Saud University (KSU), in collaboration with the Saudi Charitable Association of Diabetes (SCAD) the program started in September 2019 and it lasted till March 2021. This program was designed to educate about the rising prevalence of obesity and MetS in children and adolescents in Saudi (10, 18). The study was approved by the institutional review board (IRB) of the College of Medicine, KSU, Saudi Arabia (no. E-19-4239, 29 October 2019), and the participants were recruited after obtaining parental informed consent. During the program, 2,677 school-attending children and adolescents from the age of 12–18 years initially agreed to participate. At recruitment, the participants were invited for a baseline assessment, which included an 8-h fasting blood sample withdrawal and anthropometrics to assess the status of BMI and different components of MetS before the inclusion of the study. This phase lasted for 5 months from the start of the program, and the entire baseline data were obtained before COVID-19-imposed lockdown in march 2020.

Intervention

This 12-month counseling and educational health promotion initiative was centered on the importance of a balanced diet

and physical exercise in a cohort of school-aged children and adolescents. The baseline assessment included orientation sessions where standardized health education into topics like healthy dietary habits such as reducing junk food and sugar-sweetened beverages and juices, and so on, encouraging reduction in portion sizes and discouraging sedentary behaviors. Besides, the participants were educated on the current rising prevalence of obesity and metabolic disorders and their adverse health effects in children. Also, the participants were educated about diabetes and its health effects, its prevention by reducing body weight by at least 5%, by learning about different constituents of daily caloric requirement and reducing fat intake and increasing the dietary fiber intake to at least 15 g/1,000 kcal. Emphasis was also laid on increasing physical activity, and participants were encouraged to at least devote 20 min/day of exercises of moderate intensity or activities such as swimming, cycling, walking, running, and so on. In addition, the program included the distributing educational materials (**Supplementary Material 1**) in pamphlets, booklets, infographics, videos, gamification, etc.

The intervention program was designed to be imparted by health professionals in the form of a 20-min group educational session where lectures on eating healthy and being more physically active were delivered. Each participant was planned to be given five such educational sessions, one at baseline followed by 3 months of the intervening period. All the educational sessions were intended to be delivered in the respective schools; the baseline orientation was completed as planned; however, due to the emergence of COVID-19 and the resulting lockdown, most of the follow-up sessions were conducted through virtual meeting platforms such as Zoom, and social communications apps such as WhatsApp, Telegram, Facebook, Twitter, and so on. Therefore, the anthropometric data and the fasting blood samples of the study participants were collected at baseline and after 12 months post-intervention; baseline visit being completed in the respective schools whereas the 12-month data and samples were collected in selected health centers organized by the SCAD due to the emergence of COVID-19 infection and the closure of schools during the study period. The participants recruited during the study period are depicted in the form of a time series graph in **Figure 1**. Out of 2,677 participants recruited initially, only 704 agreed to visit for the delivery of fasting blood samples and post-intervention data at 12 months.

Anthropometric Assessment, Sample Collection, and Biochemical Analysis

The anthropometric assessment and fasting blood sample collection were performed at baseline and 12 month post-intervention by trained research coordinators. The participants were informed before coming for delivering an 8-h fasting blood sample. The visit included an anthropometric assessment of weight (kg), height (cm), waist and hip circumferences (cm), and blood pressure (mm Hg) using standard methodology. Body mass index (BMI) was calculated as weight (kg) divided by height in meters. It was used to categorize the participants into normal, overweight, and obese using age and sex -specific cutoffs given by Cole et al. (19), which are equivalent to adult cutoffs of 25 and 30 kg/m2 for overweight and obesity, respectively.

The fasting blood samples collected at baseline and post-intervention were immediately transported to the CBCD laboratory, where they were aliquoted and stored at appropriate storing conditions for biochemical analysis. The biochemical analysis included assessing lipid profile and circulating glucose levels by standard routine kits by an automated biochemical analyzer, Konelab 20XT (Thermo Scientific, Vantaa, Finland). HbA1c was analyzed by the D-10 Hemoglobin Testing System (Bio-Rad Laboratories, California, United States). LIAISON XL, an automated quantitative analyzer, quantified serum 25 (OH) vitamin D levels (DiaSorin, Saluggia, Italy). It employs a sophisticated chemiluminescence approach with magnetic microparticle separation to achieve the highest sensitivity and accuracy of the test.

Data Analysis

Anthropometric and biochemical data for baseline and post-intervention visits were used to check the status of full MetS and its risk components. The pediatric cutoff points for individual MetS components are different from adult cutoff points; however, the National Cholesterol Education Program's (NCEP) MetS defining criteria of $\geq$3 MetS components (20) were used. The sex-specific pediatric cutoff points for individual MetS components were taken from the criteria given by Cook et al. (21), and these, as used in our data, are presented in **Table 1**.

Statistical Package for Social Sciences (SPSS) was used to examine the anthropometric and biochemical data and the status of MetS components in the participants at baseline and post-intervention (version 21, Armonk, NY, IBM). Frequencies (%) were used to represent the categorical variables. Continuous data were reported as mean and standard deviation (SD) for Gaussian variables and median (1st and 3rd quartiles) for non-Gaussian variables. Chi-square tests were used to compare the categorical variables. The independent Student's *t*-test was used to compare groups at baseline, and the paired *t*-test was performed to compare mean differences between baseline and post-intervention visits. For non-Gaussian variables, the Mann–Whitney U test and the Wilcoxon test were utilized. The statistical significance was tested for two-tailed distributions at $p < 0.05$.

RESULTS

Baseline Characteristics of Participants

At baseline, 2,677 Saudi adolescents were recruited for the study from 60 randomly chosen schools in Riyadh, Saudi Arabia (**Table 2**). These included 1,059 boys (39.6%) and 1,618 girls (60.4%). A large proportion (37.7%) of the total participants (44.2% boys and 33.5% girls) was overweight or obese. The adolescents recruited from primary and secondary schools were 61.6 (57.9% for boys and 64.1% for girls) and 38.4% (42.1% for boys and 35.9% for girls), respectively. The adolescents with MetS risk components were identified using the anthropometric and biochemical measurements according to the specialized criteria

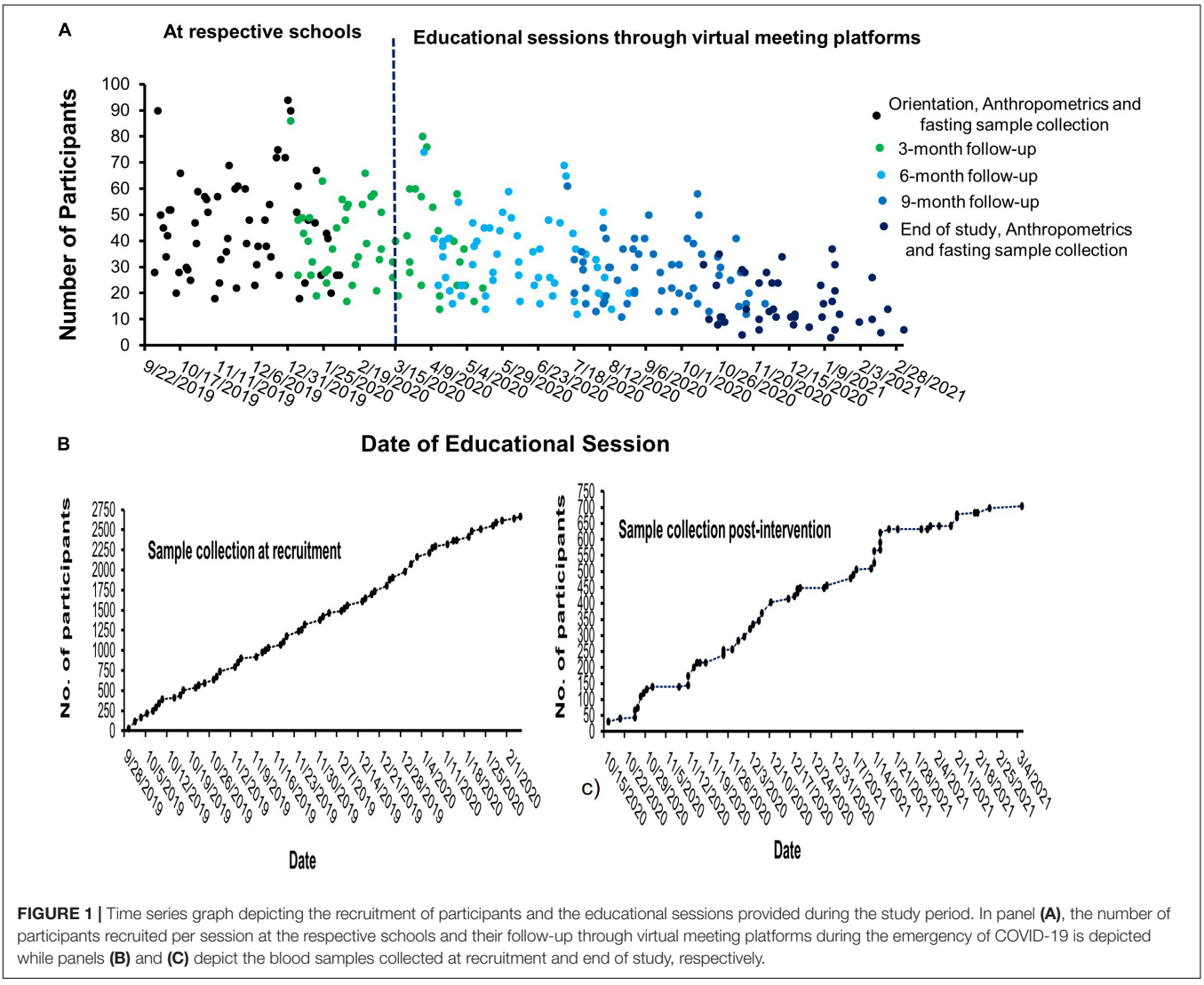

FIGURE 1 | Time series graph depicting the recruitment of participants and the educational sessions provided during the study period. In panel **(A)**, the number of participants recruited per session at the respective schools and their follow-up through virtual meeting platforms during the emergency of COVID-19 is depicted while panels **(B)** and **(C)** depict the blood samples collected at recruitment and end of study, respectively.

TABLE 1 | Pediatric definition of MetS.

MetS components	Cutoff	Boys						Girls					
		12	13	14	15	16	> 16	12	13	14	15	16	> 16
Central Obesity	WC (cm) ≥ 90th percentile	90	95.5	97	101.6	101.6	101.6	82	86	88	88.9	88.9	88.9
Hypertension	SBP (mmHg) ≥ 90th Percentile	126	130	130	130	130	130	130	130	130	130	130	130
	DBP (mmHg) ≥ 90th Percentile	85	85	85	85	85	85	85	85	85	85	85	85
Hypertriglyceridemia	TG ≥ 110 mg/dl or 1.24 mmol/L for 15 years below; TG ≥ 150 mg/dl or 1.7 mmol/L for 16 and above												
Low HDL-Cholesterol	HDL ≤ 40 mg/dl or 1.03 mmol/L												
Hyperglycemia	FBG ≥ 110 mg/dl or 6.1 mmol/L												
Full MetS	≥ 3 MetS components												

The data at baseline were used to define the 90th percentile of waist circumference and blood pressure. Definition of Pediatric MetS based on Cook et al. (18). "WC" is waist circumference, "SBP" and "DBP" are systolic and diastolic blood pressure, respectively, "TG" is triglyceride, "HDL" is high-density lipoprotein, "FBG" is fasting blood sugar, and "MetS" is metabolic syndrome.

set by NCEP ATP III for them, and 256 (9.6% of total) met the criteria for full MetS. The prevalence of full MetS in boys and girls was 11.0 and 8.6%, respectively. Overall, among the individual components of MetS, low HDL-cholesterol was the most predominant (61.7%), and hyperglycemia (6.4%) was the least predominant. A similar trend in the predominance of the individual risk components of MetS was seen in both boys and girls as far as the baseline data were concerned.

TABLE 2 | Characteristics of study participants at the time of recruitment.

	All (2,677)	Boys (1,059)	Girls (1,618)
Educational status			
Primary	1,650 (61.6)	613 (57.9)	1,037 (64.1)
Secondary	1,027 (38.4)	446 (42.1)	581 (35.9)
BMI Status*			
Normal	1,667 (62.3)	591 (55.8)	1,076 (66.5)
Overweight	526 (19.6)	204 (19.3)	322 (19.9)
Obese	484 (18.1)	264 (24.9)	220 (13.6)
Anthropometrics			
Age (years)	14.76 ± 1.7	14.89 ± 1.6	14.68 ± 1.7
Weight (Kg)	57.25 ± 18.6	61.89 ± 21.9	54.22 ± 15.4
Height (cm)	156.38 ± 10.7	159.45 ± 11.3	154.37 ± 9.8
BMI (Kgm^{-2})	23.34 ± 7.2	24.1 ± 7.6	22.85 ± 6.9
Waist (cm)	73.59 ± 17	74.62 ± 23	72.92 ± 11.6
Hips (cm)	89.00 ± 18.9	84.38 ± 25	92.01 ± 12.5
Systolic BP (mm HG)	118.6 ± 16.9	119.45 ± 14.8	118.04 ± 18.1
Diastolic BP (mm HG)	72.35 ± 12.5	67.8 ± 10.2	75.33 ± 13
Biochemical characteristics			
Cholesterol (mmol/l)	4.4 ± 0.8	4.33 ± 0.8	4.45 ± 0.8
HDL-Chol (mmol/l)	0.99 ± 0.2	1.00 ± 0.2	0.98 ± 0.2
Triglycerides (mmol/l)	0.96 (0.8,1.3)	1.03 (0.8,1.4)	0.93 (0.8,1.2)
FBG (mmol/l)	5.23 ± 1.2	5.31 ± 1.1	5.17 ± 1.2
HbA1c	5.10 ± 0.7	5.25 ± 0.7	5.00 ± 0.7
25 (OH) D (nmol/l)	29.8 (22.2,39.4)	36.1 (29,45.8)	25.6 (20,34)
MetS components			
Central Obesity	286 (10.7)	111 (10.5)	175 (10.8)
Hypertension	602 (22.5)	213 (20.1)	389 (24.0)
Hypertriglyceridemia	625 (23.3)	298 (28.1)	327 (20.2)
Low HDL_Cholesterol	1,652 (61.7)	598 (56.5)	1,054 (65.1)
Hyperglycemia	170 (6.4)	81 (7.6)	89 (5.5)
Full MetS	256 (9.6)	117 (11.0)	139 (8.6)
MetS Components (N)	1.25 ± 0.9	1.23 ± 1.1	1.26 ± 0.9

*Data for categorical variables are presented as frequency (%) while for continuous variables are presented either as mean ± standard deviation or as median (quartile 1, quartile 3); *Based on the definition of Cole et al. (17), "BMI" is body mass index and "FBG" is fasting blood sugar.*

Changes in Clinical Characteristics Post-intervention

From the total of 2,677 adolescents who provided questionnaire data and blood samples at the beginning of the study, 1,973 (73.7%) of the subjects either lost to follow-up, discontinued, or did not consent for a follow-up fasting blood sample appointment at various stages due to COVID-19 situation prevalent during the study program. The final analysis was done for the remaining 704 adolescents (47.0% boys and 55.8% girls) for whom all of the data necessary to evaluate MetS pre- and post-intervention were collected (**Table 3**). Overall, there was an insignificant decrease of 3.3% in overweight or obesity percentage from baseline to end of the study. A modest but statistically significant improvement in BMI ($p = 0.017$) was seen post-intervention in all subjects; however, the significance disappeared when data were seen individually for either sex. Statistically significant increase in lipids ($p < 0.001$ for total cholesterol, HDL-cholesterol, and triglycerides) was accompanied by an increase in fasting glucose levels ($p < 0.001$) post-intervention when all subjects. A similar trend could be seen in either sex. Circulating vitamin D levels also increased post-intervention when data from all subjects were analyzed; however, when data were looked at individually for sexes, this significant increase in vitamin D levels was seen only in females ($p < 0.001$).

Change in MetS and Its Individual Components Post-intervention

There was an insignificant decrease of 1.7% from 9.5% at baseline to 7.8% intervention for the prevalence of full MetS when data were analyzed for all subjects, and it did not change significantly for either sex (**Table 4**). However, after an investigation into individual components that sum up to full MetS, a modest but statistically significant decrease in the prevalence was noted in central obesity (4.5%, $p = 0.002$) and hypertension (10.9%, $p < 0.001$) and a significant parallel increase in hyperglycemia (12.2%, $p < 0.001$). The components that showed maximum changes in the prevalence post-intervention were low-HDL cholesterol which decreased from 61.6 to 23.3% (a decrease of 38.3%, $p < 0.001$) and hypertriglyceridemia, which increased from 22.7 to 56.3% post-intervention (an increase of 33.6%, $p < 0.001$). Similar trends were seen when data were analyzed for different sexes.

Prevalence of Positive Change in the Status of MetS and Its Components Post-intervention

The prevalence of subjects in which the status of MetS and its components changed from "yes" at baseline to "no" post-intervention was tabulated as **Table 5**. The percentages of positive change (from "yes" at baseline to "no" post-intervention) and negative change (from "no" at baseline to "yes" post-intervention) were plotted as bar graphs for all subjects and both sexes in **Figure 2**.

Bivariate regression analysis in this status between the baseline status of overweight/obese and normal weight revealed a statistically significant improvement in those who were overweight/obese at baseline compared to those who had normal weight (16.9 vs. 3.6%, adjusted OR of full MetS = 3.42, 95% CI 1.8–6.5, $p < 0.01$). Additionally, the positive change in status of MetS components hypertension (26.1 vs. 13.5%, adjusted OR = 2.28 and $p < 0.01$) and low HDL-cholesterol (50.2 vs. 42.0%, adjusted OR = 1.36 and $p = 0.04$) was significantly higher in participants who were overweight/obese at baseline compared to normal weight. Furthermore, when the proportion of subjects was compared between these groups where the status of at least one MetS component changed from "yes" to "no" post-intervention, a statistically significant improvement was seen in those who were overweight/obese at baseline compared to normal weight (71.6 vs. 53.9%, adjusted O.R. = 2.14, $p < 0.01$).

TABLE 3 | Change in anthropometry and biochemical characteristics for those who completed the lifestyle change educational program.

	All (704)			Boys (331)			Girls (373)		
				Baseline	Follow-up		Baseline	Follow-up	
BMI status									
Overweight or Obese	261 (37.1)	238 (33.8)	0.07	151 (45.6)	141 (42.6)	0.453	110 (29.5)	97 (26.0)	0.287
Anthropometrics									
Age (years)		14.91 ± 1.7			14.81 ± 1.6			14.99 ± 1.8	
Weight (kg)	57.97 ± 20.1	59.85 ± 17.9	< 0.001	62.87 ± 23.8	64.86 ± 21.2	< 0.001	53.62 ± 14.8	55.4 ± 12.8	< 0.001
Height (cm)	156.62 ± 1.3	160.52 ± 11.3	< 0.001	159.45 ± 11.3	162.56 ± 11.9	< 0.001	154.71 ± 10.2	158.72 ± 10.9	< 0.001
BMI (kg/m^2)	23.54 ± 7.8	23.25 ± 6.7	0.017	24.61 ± 8.2	24.38 ± 7.1	0.131	22.59 ± 7.3	22.25 ± 6.3	0.066
Waist (cm)	75.54 ± 16.2	77 ± 14.9	0.006	79.82 ± 19.7	86.2 ± 13.3	< 0.001	71.75 ± 11	68.83 ± 11.1	< 0.001
Hips (cm)	90.14 ± 17.4	85.25 ± 15.7	< 0.001	89.14 ± 21.5	91.47 ± 14.4	0.009	91.03 ± 12.8	79.74 ± 14.8	< 0.001
Systolic BP (mm HG)	119.78 ± 16.3	111.18 ± 13.6	< 0.001	119.47 ± 14.8	117.63 ± 9	0.034	120.06 ± 17.5	105.45 ± 14.3	< 0.001
Diastolic BP (mm HG)	71.98 ± 11.9	72.71 ± 8.4	0.161	67.76 ± 9.5	73.17 ± 9.7	< 0.001	75.72 ± 12.5	72.3 ± 7	< 0.001
Biochemical characteristics									
Cholesterol (mmol/l)	4.44 ± 0.8	6.23 ± 1.6	< 0.001	4.4 ± 0.8	6.01 ± 1.4	< 0.001	4.48 ± 0.8	6.42 ± 1.7	< 0.001
HDL-Chol (mmol/l)	0.99 ± 0.2	1.57 ± 0.6	< 0.001	1.01 ± 0.2	1.35 ± 0.5	< 0.001	0.97 ± 0.2	1.76 ± 0.7	< 0.001
Triglycerides (mmol/l)	0.95 (0.8,1.3)	1.53 (1.1,2.1)	< 0.001	1.03 (0.8,1.3)	1.63 (1.1,2.2)	< 0.001	0.91 (0.7,1.1)	1.46 (1,1.9)	< 0.001
FBG (mmol/l)	5.24 ± 0.9	5.66 ± 2.8	< 0.001	5.33 ± 1.2	5.79 ± 2.6	0.005	5.16 ± 0.7	5.54 ± 2.9	0.01
HbA1c	5.11 ± 0.6	5.32 ± 1.3	< 0.001	5.23 ± 0.6	5.24 ± 1.2	0.679	5.00 ± 0.6	5.38 ± 1.3	< 0.001
25 (OH) D (nmol/l)	30.7 (22.9,39.5)	38.7 (25.1,58.5)	< 0.001	35.6 (28.8,46.2)	34.6 (24.4,49.5)	0.253	25.7 (19.8,34)	41.55 (25.6,63.1)	< 0.001

Data for categorical variables are presented as frequency (%) while for continuous scalar variables are presented either as mean ± standard deviation or as median (quartile 1, quartile 3). Relevant statistical tests were employed to check the differences pre- and post-intervention. $p < 0.05$ was considered statistically significant. "BMI" is body mass index and "FBG" is fasting blood sugar.

TABLE 4 | Prevalence of MetS and its individual components in Saudi adolescent's pre- and post-intervention.

	Overweight or Obese	Central Obesity	Hypertension	Hyper triglyceridemia	Low HDL-Cholesterol	Hyperglycemia	Full MetS	MetS Components (*N*)
All subjects (704)								
Baseline	261 (37.1)	79 (11.2)	157 (22.3)	167 (22.7)	434 (61.6)	53 (7.5)	67 (9.5)	1.26 ± 0.9
Follow-up	238 (33.8)	47 (6.7)	80 (11.4)	396 (56.3)	164 (23.3)	139 (19.7)	55 (7.8)	1.12 ± 0.9
Change	3.3●	4.5●	10.9●	33.6●	38.3●	12.2●	1.7●	0.14●
p	0.07	0.002	< 0.001	<0.001	< 0.001	<0.001	0.238	0.002
Boys (331)								
Baseline	151 (45.6)	48 (14.5)	64 (19.3)	95 (28.7)	179 (54.1)	28 (8.5)	39 (11.8)	1.25 ± 1.1
Follow-up	141 (42.6)	28 (8.5)	61 (18.4)	199 (60.1)	106 (32)	69 (20.8)	45 (13.6)	1.32 ± 0.9
Change	3.0●	6.0●	0.9●	31.4●	22.1●	12.3●	1.8●	0.07●
p	0.453	0.015	0.769	< 0.001	<0.001	< 0.001	0.487	0.337
Girls (373)								
Baseline	110 (29.5)	31 (8.3)	93 (24.9)	72 (19.3)	255 (68.4)	25 (6.7)	28 (7.5)	1.28 ± 0.9
Follow-up	97 (26.0)	19 (5.1)	19 (5.1)	197 (52.8)	58 (15.5)	70 (18.8)	21 (5.6)	0.93 ± 0.8
Change	3.5●	3.2●	19.8●	33.5●	52.9●	12.1●	1.9●	0.35●
p	0.287	0.08	< 0.001	<0.001	< 0.001	<0.001	0.301	< 0.001

Data are presented as frequency (%). Relevant statistical tests were employed to check the differences in the prevalence pre- and post-intervention. ● Depicts an increase while and ● depicts a decrease in prevalence post-intervention. $p < 0.05$ was considered statistically significant.

DISCUSSION

This school-based lifestyle intervention and counseling program, aimed at mitigating the growing prevalence of metabolic disorders in children and adolescents in Saudi Arabia, suggested its effectiveness in improving the cardiometabolic indices, particularly the components of MetS such as low-HDL cholesterol, hypertension, and central obesity. The status of full MetS showed an insignificant overall decrease of 1.7% from baseline; however, 60 (8.5%) of the total 704 participants who completed the program were able to change the status of MetS at baseline to non-MetS post-intervention. This is taking into full consideration that the COVID-19 lockdown disrupted the intervention program. The effectiveness of the

TABLE 5 | Age-adjusted odds of the positive change in status of MetS and its components post intervention in participants with "overweight/obese" compared to the normal.

MetS_components	Baseline	Follow-up	All (704)	Overweight/obese (B) (261)	Normal weight (B) (443)	Normal weight (B)	Overweight/obese (B)			
							O.R. (95% C.I.)	*p*	O.R. (95% C.I.)[a]	*p*[a]
Central Obesity	Yes	No	43 (6.1)	43 (16.5)	0 (0.0)	Ref.	-	-	-	-
Hypertension	Yes	No	128 (18.2)	68 (26.1)	60 (13.5)	Ref.	2.25 (1.5–3.3)	< 0.01	2.28 (1.5–3.4)	< 0.01
Hypertriglyceridemia	Yes	No	58 (8.2)	28 (10.7)	30 (6.8)	Ref.	1.65 (1.0–2.8)	0.07	1.70 (1.0–2.9)	0.06
Low HDL-Cholesterol	Yes	No	317 (45)	131 (50.2)	186 (42.0)	Ref.	1.39 (1.0–1.9)	0.035	1.36 (1.0–1.9)	0.04
Hyperglycemia	Yes	No	41 (5.8)	19 (7.3)	22 (5.0)	Ref.	1.50 (0.8–2.8)	0.21	1.48 (0.8–2.8)	0.23
Subjects where status of at least one MetS components improved			426 (60.5)	187 (71.6)	239 (53.9)	Ref.	2.16 (1.6–3.0)	< 0.01	2.14 (1.5–3.0)	< 0.01
Full MetS	Yes	No	60 (8.5)	44 (16.9)	16 (3.6)	Ref.	5.41 (2.9–9.8)	< 0.01	3.42 (1.8–6.5)[b]	< 0.01[b]

Data presented as frequency (%) represents the proportions of individuals where status changed from "yes" to "no" post intervention. Bivariate regression analysis was carried out to check the odds of these proportions in "overweight/obese at baseline" compared to "normal weight at baseline." Superscripts "a" and "b" represents, respectively, "adjusted with age" and "adjusted with age and central obesity component." $p < 0.05$ was considered statistically significant.

intervention may also be determined by the fact that in 426/704 (60.5%) of the individuals, at least one of the five MetS risk components changed from being present at baseline to being absent post-intervention. This is heartening because this sort of multi-platform counseling intervention is feasible to be delivered in school settings and may be productive, especially in a population such as Saudi Arabia where economic upsurge from last five decades has had a parallel surge in cardiometabolic risk factors such as obesity and MetS in children and adolescents.

The prevalence of 37.7% overweight/obesity in Saudi adolescents from total of 2,677 participants at baseline in our study which correlates with a similarly reported prevalence of 40.5% is almost the same age group in a recently published study by Hazzaa et al. (22). There has been an increasing trend of adolescent obesity over the past three decades, which has been linked to a parallel increase in chronic health issues such as type 2 diabetes, cardiovascular disease, and MetS in Saudi adolescents (23, 24). Physical inactivity, sedentary behaviors, and unhealthy dietary habits, particularly the popularization and overtake of westernized foods, have been associated with the rising prevalence of obesity and its health effects in adolescents in this part of the world (25, 26). This is alarming and preventive steps through interventions based on lifestyle change counseling in adolescents, particularly in Saudi Arabia, have been limited in the past and need to be scaled up (27, 28). One way of mitigating the problem is to focus on delivering intensive lifestyle change programs in adolescents at high risk of MetS; however, the better way, especially when unhealthy lifestyle behavior is so prevalent and health awareness is low in this age group, is to deliver general health awareness and lifestyle change programs. Lifestyle change programs in high-risk adults have been implemented earlier by our group (29–33). In adolescents, school settings for these lifestyle interventions may prove to be the best setting. In collaboration with SCAD, our group completed this 12-month lifestyle change awareness program based on the educational counseling sessions delivered in the school setting, and the results indicated that it was effective in reducing cardiovascular risk factors in adolescents despite interruptions caused by the COVID-19 pandemic during the program.

School-based settings like one used in the present program are important for behavioral interventions aimed at mitigating the risks of obesity and overweight, as well as increasing nutrition and physical activity levels in children and adolescents because they give an accessible way to reach this age group (34). In some countries such as the United Kingdom, health education delivered during school or after school hours has been part of the government's strategy to address the rising prevalence of obesity and its health effects in children and adolescents (35). Initiatives like these should be adopted by policymakers and other involved entities, and the health education counseling practices may be included in the normal educational curriculum. Some earlier reviews of lifestyle change interventions based on the school setting showed mixed results of its effectiveness (36, 37); however, recent bigger systematic review and meta-analysis by Liu et al. comprising 50 interventions (38) and by Jacob et al. (39) comprising 33 school-based health education interventions in children and adolescents suggested its effectiveness to lower BMI toward a healthier range. The results of the 12-month counseling-based education program that we did in 60 schools in Riyadh city are consistent with the findings of this meta-analysis since there was a modest but significant overall drop (−4.5%) in the prevalence of central obesity post-intervention.

MetS, a group of cardiometabolic risk factors, is on the rise among adolescents, particularly in developing countries such as Saudi Arabia, and has long-term health effects, including the development of more serious health risks such as type 2 diabetes, endocrine disorders, and cardiovascular disease (10, 40, 41). It is not recommended to apply the adult definition of MetS in children and adolescents in whom the development of the definition has faced the challenges (42); however, researchers

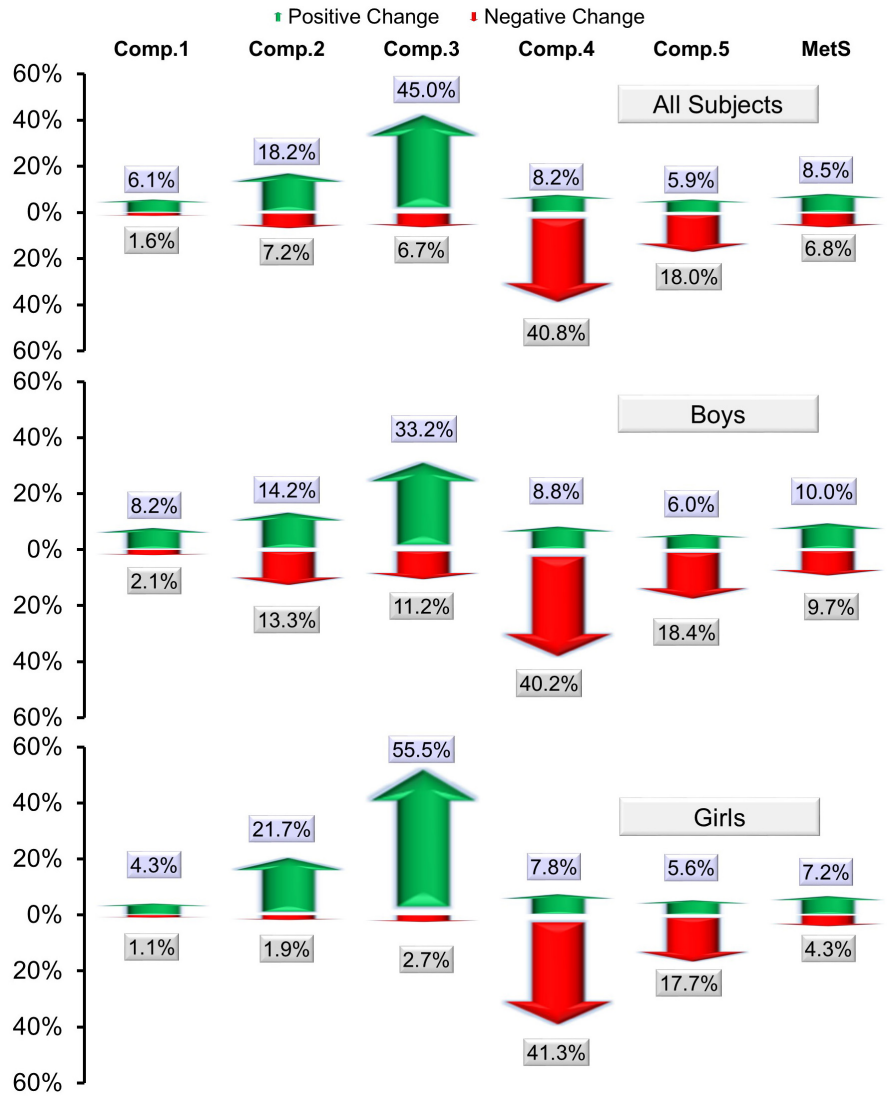

FIGURE 2 | A bar graph showing the percentages of positive change (from "yes" at baseline to "no" post-intervention) and negative change (from "no" at baseline to "yes" post-intervention) in MetS and its components. Here, comp. 1, 2, 3, 4, and 5 represent "central obesity," "hypertension," "low-HDL cholesterol," "hypertriglyceridemia," and "hyperglycemia," respectively.

agree that more focus should be on recognizing the clustering of cardiometabolic risk factors in children and adolescents rather than on defining whether they have reached the critical cutoff of the diagnosis of MetS (43). Therefore, screening each cardiometabolic risk factor and seeking an improvement in all of them should be the main goal of lifestyle intervention programs for MetS, especially in children and adolescents. Though there are a lot of observational and interventional studies targeted at lowering the risk of obesity in children and adolescents, studies on the lifestyle change program's effectiveness in reducing metabolic diseases in this age range are limited. However, the few performed before suggest long-lasting benefits of such programs in reducing MetS in children and adolescents (44, 45). Furthermore, because sedentary lifestyles and the risk of cardiometabolic diseases go hand in hand, school-based counseling and physical activity promotion offer an effective intervention in mitigating the risks of MetS in children and adolescents regardless of BMI status, as seen in previous interventions (46, 47). At the same time, we need to look at differences in sociodemographic conditions of the communities to devise such intervention programs targeted at changing the dietary patterns and physical activity levels of the adolescents at risk (48). The results of this counseling-based intervention program in Saudi schools are in line with the results of these interventions and suggest its effectiveness in individual components of MetS, particularly low HDL-cholesterol.

This study found a moderate but insignificant drop in the prevalence of the full MetS phenotype post-intervention, despite certain components decreasing, but a corresponding increase

in the prevalence of hypertriglyceridemia in the participants post-intervention. One of the reasons might be the interruption of the planned face-to-face educational counseling delivered at schools post the emergence of COVID-19 restrictions and the closure of schools in March 2020. All the counseling sessions (five per participant) were initially planned to be delivered face-to-face in schools, and the orientation sessions were done as planned; however, most of the follow-up sessions were conducted through virtual meeting platforms, which might have impacted the results. While less is known of the impact of interruptions caused by COVID-19 pandemic on school-based lifestyle interventions, some reports suggest an overall negative impact on such interventions (49, 50). Furthermore, the constraints imposed by COVID-19 on such school-based initiatives may lead to an increase in risk factors such as obesity in children and adolescents owing to an increase in sedentary behaviors and screen time (51, 52). Considering the overall impact of these restrictions, as well as the fact that school closures have increased the tendency of children and adolescents toward an obesogenic environment, an initiative like the current study, which has at least helped in mitigating the rising prevalence of MetS in the study participants over 12 months, may still be considered effective and may be adopted as a model to curb this menace by the relevant authorities.

This study should be interpreted taking into consideration the following limitations. First, the lack of control group limits the findings to at best, suggestive, since the changes observed overtime cannot be directly attributed to the intervention given. Second, we provided education to the study participants in the form of general health awareness counseling in place of intensive monitoring to specific risk groups such as for overweight and obese adolescents. Third, we did not actively monitor dietary and physical activity changes since the intervention was more of guidance rather than intensive approach. The high attrition rate may have limited some aspects of the results, but was justified due to the restrictions imposed during the study program. In future interventions, behavioral counseling such as self-efficacy, goal setting, and feedback should be applied more aggressively.

CONCLUSION

Despite COVID-19-related interruption and the overall increase in the prevalence of hypertriglyceridemia and hyperglycemia, the multi-platform, counseling-based health awareness education campaign modestly improved the cardiometabolic status of Arab adolescents, with at least one of the MetS risk components showing a favorable change post-intervention in 2 out of every 3 Arab adolescents. Given the quasi-experimental design, the results should be replicated with the inclusion of a control group. Regardless, interventions like these may have clinical implications in policymaking toward an academic curriculum equipped with awareness in healthy eating and physical education.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the corresponding author as per the guidelines of the institution.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Board (IRB) of the College of Medicine, KSU, Saudi Arabia (No. E-19-4239, 29 October 2019). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

NA-D, KW, and SS designed the study. AA and OA worked in the methodology. KW and MK did the statistical analysis. NA, HA, MA, and AH helped in the data curation. KW wrote the manuscript. SS revised the manuscript. NA-D did the study supervision. All authors contributed and approved the final version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fped.2022.887138/full#supplementary-material

Supplementary Material 1 | Example of the study materials distributed to the study participants.

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