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Physical activity, health equity and health-related outcomes,
volume II

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Physical activity, health equity and health-related outcomes, volume II

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Editorial: Physical activity, health equity and health-related outcomes, volume II

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Editorial on the Research Topic
Physical activity, health equity and health-related outcomes, volume II

Despite the established benefits of physical activity (PA) in the prevention and treatment of disease, most population groups continue to suffer from the burden of non-communicable diseases (NCDs) including diabetes, cancer, and cardiovascular disease (1). Therefore, research into reducing health inequality and improving quality of life through promoting PA and associated healthy lifestyle behavior, is essential to impact public health policies and practice.

This Research Topic, "*Physical activity, health equity and health-related outcomes, Volume II*" (https://www.frontiersin.org/research-topics/28849/physical-activity-health-equity-and-health-related-outcomes-volume-ii/magazine), extends the findings of Volume-I (2). This Research Topic investigates emerging research on PA and disease epidemiology in special populations, which includes novel determinants of PA in a health equity and outcomes context, as well as effective PA-related intervention approaches amongst under-represented groups, including women, certain racial and ethnic groups, older adults, and children with poor PA and healthcare access. Publications in this Research Topic made an immediate impact, with 25,000 article views and 17,000 full-text views, and over 6,000 downloads. Out of the 41 submissions, we publish 13 high-quality manuscripts following rigorous editing and peer-reviewing. Research types varied from countrywide epidemiological surveys in Asia, Europe and the USA, to cross-sectional data analysis of longitudinal population surveys, PA and lifestyle determinants in children and adolescents, predictive tools, clinical and randomized controlled trials involving patients and high-risk populations.

Children and adolescents are considered as high-risk groups due to growing concern about childhood obesity and associated comorbidities, with over 2.1 billion worldwide (3). Alarmingly, there is an increased disparity in such prevalence between Low and Middle Income Countries (LMICs) and High Income Countries (HICs). Our team published a systematic review (Obita and Alkhatib) which involved 651,659 children, and showed a significantly higher prevalence of childhood obesity comorbidities in LMICs than in HICs (hypertension 36 vs. 13%, metabolic syndrome 27 vs. 6%, non-alcoholic fatty liver disease 48 vs. 23% in LMICs than HICs, respectively). Further disparity was found between global regions, where Asia had the highest prevalence of childhood obesity-related hypertension (38.6%) followed by South America (25.3%) and Europe (20.1%). Within HICs disparity was also found, where minority ethnic communities had higher childhood obesity and comorbidities than their white counterparts, especially in the prevalence of cardiometabolic risks of insulin resistance, dyslipidaemia and acanthosis. Global and local public health policies are needed to reduce disparity in childhood obesity and associated comorbidities through effective targeted interventions.

Explaining childhood obesity and comorbidity disparity requires deciphering various underlying lifestyle health behaviors by socioeconomic status (SES). A systematic review by Gautam et al. showed that children and adolescents with lower SES face an elevated risk of unhealthy behaviors such as initiation of smoking, energy-dense foods, lower PA, and drug abuse compared with their counterparts. Conversely, those from higher SES showed a higher prevalence of health-promoting behaviors including increased consumption of fruit and vegetables, dairy products, regular breakfast, and engagement in PA. These findings emphasize the need for interventions aimed at supporting families from disadvantaged SES to mitigate lifestyle disparities in health behavior among children and adolescents. For example, Shi et al. showed that promoting PA and sports participation, and muscle strengthening in schools is more effective than active commuting to schools. Their cross-sectional study involved 3,807 children and adolescents from 12 schools in South-eastern China. This finding is in line with recent preventative lifestyle models for children and adolescents, encouraging direct and intense forms of sport participation alongside wider PA promotion (4). For those in the earlier childhood preschool years, direct parental caregiving has been shown to be essential for developing children's fundamental movement skills (FMS), enhancing their PA participation, and developing physical and cognitive fitness (Hu et al.). The latter cross-sectional study involved 698 boys and 628 girls, aged 4–6 years, and showed that direct parenting, especially for girls is superior to grandparenting in developing children's FMS and learning more complex physical and sporting activities.

Nonetheless, reducing disparity should be addressed across all age groups. A longitudinal analysis (2010–2018) from the Chinese General Social Survey reported SES disparities and inequality of mass sports participation among 4,940 residents in China (Dong et al.). A higher frequency of PA participation was found in urban residents and higher social classes than in rural residents and lower social classes. Public-sector jobs, high income and higher education levels were associated with higher PA participation, and older adults reported more motivation to exercise than the young. Ethnic minority status, alone or in conjunction with SES were also a determinant of mass sports participation. Population sports participation often serves government health preventative policy. Whether it is mass sports, PA or regular exercise, sport and health policies should reduce disparity and inequality in both access and participation in PA.

Access to PA was particularly important throughout the COVID-19 pandemic, and thus PA interventions using remote across different populations need to be explored further. Two interesting studies focused on this Research Topic in China and India. Zhang et al. published an analysis of the China Family Panel Survey of 24,000 adults in the period preceding COVID-19 to understand the functional mechanisms determining PA and internet use. They showed a positive correlation between internet use duration and PA and fitness. The researchers suggested that the mediating effect of psychological health risk perceptions was more important than that of social capital determining PA behaviors. In India, a clinical trial involving tele-yoga as an adjunct PA along with standard treatment was an effective method in reducing COVID-19 symptoms in hospitalized patients with mild and moderate COVID-19 (Majumdar et al.). Perhaps remote PA environments are effective for a controlled community (e.g., quarantine) or hospital environments, but psychological health mechanisms should be considered alongside other lifestyle behaviors and environments. One study reviewed the impact of the environment on PA engagement and consequent health benefits (Hernández et al.). The study concluded that environmental social programs (e.g., school building design, parks, bicycle paths, or community or workspaces) generate positive changes in increasing PA levels and associated healthy lifestyle behavior among children and adults.

Epidemiological analysis of country-wide data sets is also essential in understanding the underlying mechanisms of disease in high-risk groups, and to mitigate such risks through targeted interventions. In Lithuanian populations, two biomarkers of cardiovascular disease (visceral adiposity index, and atherogenic index of plasma), were associated with all-cause mortality risk in groups of middle-aged men and women (Tamosiunas et al.). The Afghanistan WHO-STEPS survey 2018, analyzed sedentariness among 3,956 adults using the Global Physical Activity Questionnaire (Pengpid et al.). They reported that almost 50% of Afghani populations as sedentary while one in four had both high sedentary behavior and low PA. Another study in Greece (Knappe et al.) reported on the physical fitness (based on maximal oxygen uptake) and mental wellbeing of 150 men (50% women) living in refugee camps and suffering from post-traumatic stress disorder (PSTD). One in four participants met the criteria of metabolic syndrome, and a third met the criteria of anxiety, insomnia and PSTD, which highlights the intervention needs in this vulnerable population group.

Finally, reducing disparities and improving health equity requires the design of culturally and environmentally appropriate lifestyle interventions to ensure effective implementation in communities (5). The study protocol (Greeven et al.) designed multilevel PA-based interventions in rural communities based on concepts of (1) Basic Psychological Needs mini-theory within Self-Determination Theory; (2) Biopsychosocial Model (3) Multilevel Research Framework from the National Institute on Minority Health and Health Disparities. Another study focussed on validating the PA tool as an effective method to engage young students in PA (Liu et al.). The authors validated a device combining heart rate variability and accelerometry (Firstbeat Bodyguard 2) to measure time spent at different intensity zones in free-living environments.

This Research Topic highlights diverse PA preventative roles across different age groups, ethnicities, genders and different environments and elucidates on important physiological, psychological and socioeconomic factors that determine the effectiveness of PA participation and applications. Such research efforts alongside public health policies will improve health and quality of life for all populations.

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References

1. Roth GA, Mensah GA, Johnson CO, Addolorato G, Fuster V, GBD-NHLBI-JACC Global Burden of Cardiovascular Diseases Writing Group. Global burden of cardiovascular diseases and risk factors, 1990-2019: update from the GBD 2019 Study. *J Am Coll Cardiol.* (2020) 76:2982–3021. doi: 10.1016/j.jacc.2020.11.010

2. Barengo NC, Alkhatib A. Editorial: physical activity, health equity and health related outcomes. *Front Public Health.* (2022) 10:828108. doi: 10.3389/fpubh.2022.828108

3. World Health Organisation (WHO) (2018). Available online at: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight (accessed January 27, 2024).

4. Alkhatib, A. Optimizing lifestyle behaviors in preventing multiple long-term conditions. *Encyclopedia.* (2023) 3:468–77. doi: 10.3390/encyclopedia3020032

5. Obita G, Alkhatib A. Effectiveness of lifestyle nutrition and physical activity interventions for childhood obesity and associated comorbidities among children from minority ethnic groups: a systematic review and meta-analysis. *Nutrients.* (2023) 15:2524. doi: 10.3390/nu15112524

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SYSTEMATIC REVIEW
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Disparities in the Prevalence of Childhood Obesity-Related Comorbidities: A Systematic Review

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Background: Non-communicable diseases among children are serious consequences of childhood obesity. However, less is known about the disparities in childhood obesity comorbidities burden. This review describes the salient pattern of disparities in the prevalence of childhood obesity-related non-communicable diseases and relevant inequalities in both high- and low/medium-income countries.

Method: A systematic literature search was performed in MEDLINE, Embase, CINAHL, PsycInfo, Scopus, and Web of Science databases by two independent reviewers. Inclusion criteria were as follows: age 2–18 years; the prevalence or incidence of childhood obesity comorbidities reported; and studies published in English from January 2010 to date. No restrictions on the setting. The prevalence data were analyzed using range and median for subgroups based on the country's development status, gender, and geographical region.

Results: Our search identified 6,837 articles, out of which we examined 145 full-text articles and included 54 articles in the analysis. The median prevalence of childhood obesity-related hypertension was 35.6 vs. 12.7% among middle- and low-income countries compared with high-income countries; 37.7 vs. 32.9% among boys compared with girls; and 38.6, 25.3, and 20.1% in Asia, South America, and Europe, respectively. For metabolic syndrome, the median prevalence was 26.9 vs. 5.5% among middle- and low-income countries compared with high-income countries; 55.2 vs. 12.0% among boys compared with girls; and 40.3, 25.8, and 7.7% in South America, Asia, and Europe, respectively. The prevalence of childhood obesity-related non-alcoholic fatty liver disease was 47.5 vs. 23% among middle- and low-income countries compared with high-income countries; and 52.1, 39.7, and 23.0% in Asia, South America, and Europe, respectively. The median prevalence of dyslipidemia was 43.5 vs. 63% among middle- and low-income countries compared with high-income countries; 55.2 vs. 12.0% among boys compared to girls; and 73.7 and 49.2% in Australia and Europe, respectively.

Conclusion: There are disparities in the prevalence of childhood obesity-related hypertension, metabolic syndrome, and non-alcoholic fatty liver disease, with middle- and low-income countries, boys, and Asian region having higher prevalence. Implementing targeted interventions for childhood obesity comorbidities should consider socioeconomic disparities and strengthening of research surveillance methods for a better understanding of non-communicable disease burden in the pediatric population.

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INTRODUCTION

There is a growing burden of non-communicable diseases (NCD) among children and adolescents worldwide (1). Over 2.1 billion children and adolescents under the age of 20 years were estimated to be affected by NCD globally. These include cardiovascular diseases (CVD) (13.9 million), cancers (5.9 million), chronic respiratory disorders (108.9 million), type 2 diabetes mellitus (T2DM) (8.8 million), mental health disorders (231.3 million), and injuries and violence (170.4 million). Children with NCD face lifelong burden of illness and contribute to over one-thirds of adulthood NCD incidence (2). The rise in the risk of NCD in children has been associated with the increase in childhood obesity prevalence (3, 4). Childhood obesity rate increased over 3-fold worldwide over the past three decades (5), indicating a growing global epidemic of childhood obesity. It is estimated that about 10% of school-aged children worldwide contribute to childhood obesity with an increased risk of developing chronic NCD (2). Besides the increased risk of NCD, childhood obesity causes wider societal impact such as stigma and discrimination, increased care-related cost to the affected families, cost to the community through the diversion of resources for the treatment of obesity and related conditions, and the direct healthcare cost for treating obesity and related conditions. It is estimated that obesity constitutes l−5% of total healthcare costs in various countries (6).

The American Medical Association (AMA) and World Health Organization (WHO) recognized obesity as a distinct disease (7, 8). Moreover, the World Obesity Federation identifies it as a "chronic, relapsing, progressive, disease process" (9). Obesity as a disease entity may coexist with other conditions as part of multimorbidity (MM) or as an index condition in comorbidity (10–14). MM and comorbidity increase the complexities of long-term care of affected individuals (15). In this regard, the most commonly reported obesity comorbidities include hypertension, T2DM, non-alcoholic fatty liver disease (NAFLD), CVD, and a cluster of NCD such as metabolic syndrome.

The mechanism through which obesity leads to the development of NCD is complex, but it involves its inflammatory, oxidative stress, and insulin resistance effects (16). Insulin resistance leads to compensatory hyperinsulinemia, which in turn is responsible for most of the metabolic and cardiovascular comorbidities associated with obesity (17, 18). Insulin resistance is the first step in T2DM pathogenesis followed by impaired insulin secretion, which ultimately manifests as clinical T2DM (17–19). Insulin resistance is also part of the metabolic syndrome, characterized by hyperinsulinemia, insulin resistance, dyslipidemia, hypertension, and central obesity (20), and is implicated in gastrointestinal comorbidities such as NAFLD (21).

The association between obesity and NCD has been demonstrated in several observational studies (22–27). For example, Pantalone et al. (24) found that there was a higher prevalence of T2DM, pre-diabetes, hypertension, and CVD in higher body mass index (BMI) categories compared with lower BMI, $p < 0.0001$. A recent systematic review and meta-analysis of 52 studies demonstrated the association between childhood obesity and NCD, with prevalence ratios of 1.4 for hyperlipidemia, 21.2 for CVD, 26.1 for NAFLD, 1.7 for pulmonary disorders, and 4.0 for hypertension (23). The Bogalusa Heart Study, a long-term epidemiological study in Louisiana, USA, also showed that hypertension increased 8.5-fold and dyslipidemia increased from 3.1- to 8.3-fold in overweight adolescents as compared with healthy weight adolescents (28, 29). Therefore, obesity in childhood that persists in adolescence has a causal link with multiple NCD.

Disparities in childhood obesity prevalence are well documented, especially those related to ethnicity and socioeconomic status. For example, in a study of ethnic and race disparity in early childhood obesity, Zilanawala et al. (30) reported that, compared with white children, the odd of obesity was higher among black Caribbean children, odds ratio (OR) = 1.7 (95% CI: 1.1–2.6), whereas Pakistani children had a lower OR = 0.60 (95%CI: 0.37–0.96). On the contrary, black African children were more likely to be overweight, OR = 1.40 (95% CI: 1.04–1.88) (30). Falconer et al. (31) found that among school-aged children in England, a higher percentage of Asian and black children than white children were overweight or obese (21–27 vs. 16%), lived in the most deprived areas (24–47 vs. 14%), and reported lifestyle that leads to obesity (38 vs. 16%). With regard to socioeconomic factors, studies show that socioeconomic disadvantage is associated with childhood obesity that is sustained in subsequent generations (32). In a cohort of 22,810 participants, BMI was found to be higher in those in the lowest socioeconomic class than those in the highest socioeconomic class by 2.0 kg/m^2 ($p < 0.001$) (33). Analysis of a nationally representative data in the United States (USA) showed that children from middle- and high-income households were 0.78 (95% CI: 0.72–0.83) and 0.68 (95% CI: 0.59–0.77) times more likely to be overweight or obese compared with those from low-income households (34). The United Kingdom's (UK) Millennium Cohort Study shows that at the age of 17 years, 27.6% of those from the lowest income quintile classify as obese compared with 13.7% ($p = 0.001$) of those from the richest households (35). These studies provide evidence of disparities in childhood obesity by ethnicity and socioeconomic status.

Despite ample evidence of disparities in childhood obesity, there is a lack of literature on disparities in the prevalence of childhood obesity-related comorbidities. Often, literature on childhood obesity-related comorbidities describes the association between overweight/obesity and comorbidities (23). In a few instances, gender disparity in prevalence is reported (36–38). Nevertheless, there are some indications of ethnic disparity in the prevalence of NCD among children with obesity. For example, Cheung et al. (39) showed that the prevalence of hypertension among obese adolescents differed by ethnicity, with a significant difference among Hispanic (3.1%), African Americans (2.7%), and white (2.6%) adolescents ($p = 0.02$). Although it is not clear whether and how disparities in childhood obesity-related comorbidities prevalence are based on socioeconomic status, recent systematic reviews have shown disparities in MM burden between low- and middle-income countries (LMICs) and high-income countries (HICs) (14, 40–42). Such analyses are essential for devising effective preventative approaches in community and primary care settings (41).

Because many kinds of NCD are associated with obesity, prevention and management of obesity and its related NCD have become the focus of attention worldwide (43). A good understanding of disparities in childhood obesity-related NCD prevalence among different population groups provides insight into potential reasons for the differences and helps to address the common risk factors. This supports the WHO global strategy of reducing NCD burden through an integrated prevention approach of risk factors at individual, family, community, and population level (44). However, currently, there is no systematic review that has analyzed disparities in childhood obesity-related comorbidities prevalence. While there is evidence of disparity in childhood obesity burden, such evidence cannot be extrapolated to explain the disparity in childhood obesity-related NCD prevalence. Therefore, this review aims to describe the salient pattern of disparities in the prevalence of childhood obesity-related NCD comorbidities between HICs and LMICs, by gender and geographical region, with a view to potentially inform the development of interventions that address the most at-risk groups worldwide.

METHOD

Search Strategy

The protocol for this review was registered with the International Prospective Register of Systematic Reviews (PROSPERO: CRD42021288607), and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement was followed (45). We conducted a systematic search in MEDLINE, Embase, CINAHL, PsycInfo, Scopus, and Web of Science using a combination of free text and medical subheadings (MeSH) terms. We also searched the general Internet using the Discovery portal and a list of reference of relevant articles. Initially, a specific search strategy for MEDLINE was developed (Search strategies are available *via* the PROSPERO registry). This was then adapted to other databases. The search terms used were as follows: (children or adolescents or pediatric or students or school pupils or youth or boys or girls or school age or juvenile or preteens or teens) AND (obesity or body weight or adiposity or body mass index or waist circumference or neck circumference) AND (comorbidity or Type 2 Diabetes Mellitus or hypertension or high blood pressure or cardiovascular disease or CVD or metabolic syndrome or non-alcoholic fatty liver disease or NAFLD or depression or psychological problem or anxiety or self-esteem or sleep apnea or asthma or respiratory problem or dyslipidemia or musculoskeletal problems) AND (prevalence or incidence or odds ratio or risk ratio or occurrence or epidemiology).

Inclusion and Exclusion Criteria

The inclusion criteria for selecting studies were as follows: (1) Participants were children or adolescents aged 2–18 years, based on the WHO definition of childhood obesity (3); however, some countries used above 18 years as childhood cutoff point (46). (2) Data that were reported on the prevalence or incidence of comorbidities or relevant information could be used to generate reliable prevalence estimates of childhood obesity-related NCD comorbidities. (3) The studies used a cross-sectional or case–control or prospective cohort design or randomized control trial where prevalence or incidence data were reported. (4) Only studies published in English or translated into English from January 2010 were included to reflect more current information. (5) There were no restrictions on the setting. Studies reporting prevalence/incidence of childhood obesity comorbidity at national or specific setting such as the community, school setting, or primary care worldwide were included.

Studies were excluded if they (1) were conducted in selected population groups, such as those identified through special clinics and children with obesity as a symptom of an underlying condition, for example, Prader-Willi syndrome, Cushing syndrome, hypothyroidism, and Hashimoto disease, or a side effect from medication such as antipsychotics; (2) were case series, opinion papers, and all types of qualitative studies. Whenever a particular dataset was published more than once, the most recent publication was used.

Study Selection, Quality Assessment, and Data Extraction

Two reviewers screened the title and abstract of retrieved articles to exclude studies that were not eligible. The two reviewers independently appraised the full text of studies that met the inclusion criteria. Any discrepancies were resolved through consensus. Search results are reported according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flow diagram (47), including reasons for excluding a full-text study. The reviewers were not blind to the journal titles.

The two reviewers assessed the quality of selected studies independently using the Joanna Briggs Institute's (JBI) Critical Appraisal Checklist for Studies Reporting Prevalence Data (48, 49), adopting a scoring system of 0–5 for poor quality and 6–10 for high quality. The checklist assesses sample representativeness, reliability of measurement, and whether sufficient details of weight classification and comorbidity definition were reported. Each of the two reviewers independently assessed the quality of each selected article. Discrepancies were resolved through consensus. Poor-quality studies were excluded from the analysis.

A single reviewer extracted data regarding the first author, year of publication, study design, country, sample size, participants' age group, type of comorbidity, diagnosis criteria, and the reported prevalence or incidence into a spread sheet. The second reviewer examined the extracted data and any discrepancies were resolved through discussions.

Data Synthesis and Analysis

The extracted data were first grouped by the countries' developmental/income status (HICs vs. LMICs, according to the United Nations development status, 1999 and World Bank classification of countries by income) (50, 51); geographical region (North America, South America, Europe, Asia, Africa, and Australasia); and gender (male vs. female). Comorbidities were grouped into the following categories: (1) Metabolic syndrome, (2) dyslipidemia, (3) hypertension, (4) NAFLD, (5) pulmonary disorder, (6) psychological comorbidities, and (7) other comorbidities. To compare the prevalence of a specific comorbidity between subgroups, descriptive statistics of range and median were used to summarize the prevalence estimate of the subgroups within development/income status, geographical region, and gender (52). SPSS version 26 was used to calculate the median based on the formula: $[(n + 1) \div 2]$th, where "n" is the number of items in the set and "th" just means the (n)th number (52). Meta-analysis was not possible because the studies were not sufficiently homogeneous in terms of methodology, participants' age groups, and measurement.

RESULTS

Search Results

The search identified a total of 6,868 articles, 301 of which were duplicates. Titles and abstracts of 6,837 articles were screened, resulting in 145 full texts being examined for eligibility. Totally, 54 of the examined full texts met our inclusion criteria (**Figure 1**).

Characteristics of Selected Studies

The 54 selected studies that described the prevalence of childhood obesity comorbidities in the obese weight categories included a total of 651,659 participants. The 54 studies were conducted in 27 countries across five continents, with 27 articles from Asia, 17 from Europe, six from South America, two from North America, one from Africa, and one from Australasia (**Table 1**). The most commonly reported comorbidity was hypertension, followed by metabolic syndrome (NB includes hypertension) and dyslipidemia. The least reported comorbidities were asthma and emotional disorders (**Table 1**).

While a few studies provided separate estimates for children (≤10 years) and adolescents (≥10 years) (53, 54), the majority reported combined prevalence, with ages ranging from 2 to 18 years. This means that the prevalence of different age subgroups could not be compared. Eleven papers reported assessing prevalence by gender, but only two provided breakdowns by gender and age group. All the studies were observational in design with the majority being cross-sectional surveys. **Table 2** summarizes the characteristics of included studies.

Disparity in Childhood Obesity Comorbidity Based on Geographical Ethnicity and Country

There was evidence of disparities in childhood obesity-related comorbidity prevalence between HICs and LMICs as shown in **Table 3**. The prevalence of hypertension in LMICs ranged from 13.8 to 60.7%, with a median of 35.6%, whereas in the HICs it ranged from 3 to 26% with a median of 12.7%. The highest hypertension prevalence, 60.7%, was reported among Chinese males (109), followed by Indian girls at 50% (86), then Thai children at 49.5 % (80), and Turkish males at 43.5% (110).

Similarly, the prevalence of metabolic syndrome among children with obesity was shown to be higher among the LMICs, with a range of 12 to 72.8% and a median of 26.9%, compared with a range of 3 to 8% and a median of 5.5% in HICs. Colombian children had the highest prevalence of metabolic syndrome at 72.8% (108), followed by Chinese children with a prevalence of 41% and Mexican children at 40% (59, 85). Among HICs, Italian children had the highest prevalence of metabolic syndrome at 8.2% and Danish children had the lowest prevalence at 3.1% (96, 102).

The prevalence of childhood obesity-related NAFLD was higher among children from LMICs with a prevalence range of 31.6 to 56.4% and a median of 47.5%, compared with a range of 9.5–35.4% and a median of 23% in HICs. Up to 56.4% of Turkish children were reported to have NAFLD (82). The highest prevalence among HICs, 35.4%, was reported among Italian children (97).

The prevalence pattern of dyslipidemia, however, differed from the other comorbidities. Higher prevalence of dyslipidemia was reported among the HICs with a range of 52 to 74% and a median of 63% compared with a range of 43 to 52% and a median of 43.5% in LMICs. Canadian and Australian children had a prevalence of 52 and 74%, respectively (101, 103), while Turkish and Chilean children had a prevalence of 43 and 54%, respectively (82, 108).

A limited number of studies reported respiratory problems (asthma and wheezes) among children with obesity (95, 100), as well as the prevalence of psychological problems of anxiety and depression (90). However, disparity was difficult to discern for these comorbidities due to the small number of studies that met the inclusion criteria.

Disparity of Childhood Obesity Comorbidities by Gender

In total, eleven of the included studies disaggregated data by gender for the comorbidities of hypertension and metabolic syndrome. Nine reported on hypertension disaggregated by gender (53, 56, 62, 73, 79, 86, 87, 99, 111). Hypertension prevalence among girls ranged from 11.0 to 58.2% with a median of 32.9%. Among boys, the range was 21.0 to 60.7% with a median of 37.6% (**Table 4**). Only two studies reported metabolic syndrome by gender (87, 88). One of the studies showed a marked difference in the prevalence of metabolic syndrome between boys and girls (55.2 vs. 12.0%) (88).

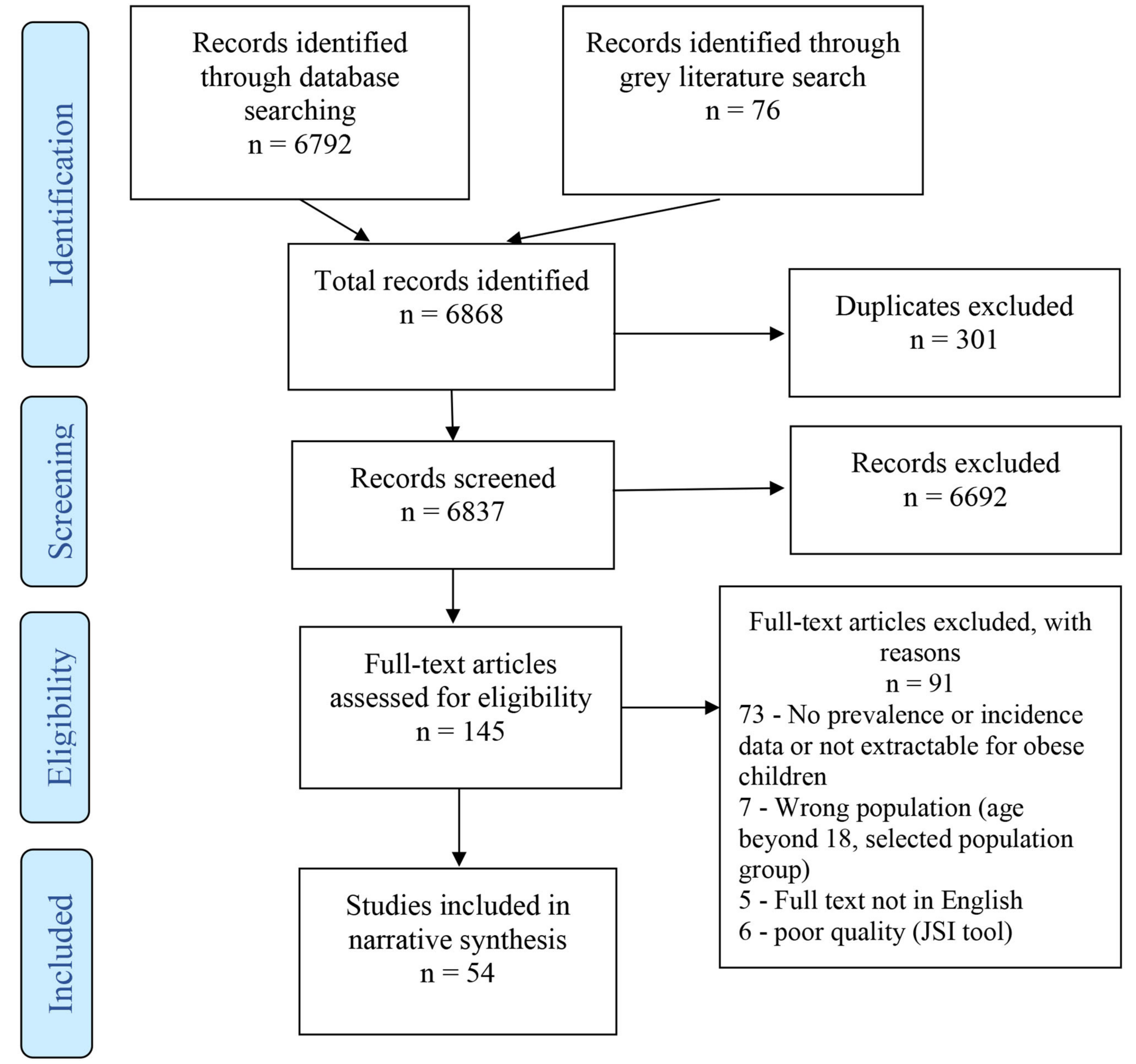

FIGURE 1 | Flowchart of study selection based on Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.

Disparity of Childhood Obesity Comorbidities by Global Regions

The range of the prevalence of hypertension among obese children in Asia was 11.0 to 60.7%, median 38.6%, compared with 18.8 to 30.9%, median 25.3% in South America, and 8.6 to 55.0%, median of 20.1% in Europe. North America had only one study that report on hypertension, whereas Africa, Australia, and Antarctica had none.

The prevalence range of metabolic syndrome was 26.3 to 72.8%, median 40.3% in South America; 6.6 to 52.1%, median 25.8% in Asia; and 7.7 to 33.0%, median 7.7% in Europe. One study reported on metabolic syndrome from North Africa with a prevalence of 14.3% (63), while none was reported from the remaining global regions (Australasia and North America).

With regard to NAFLD, the prevalence ranged from 45.0 to 52.1%, median 52.1% in Asia; 26.0 to 50.0%, median 39.7% in South America; and 9.5 to 36.4%, median 23% in Europe. The other regions had no studies reporting on NAFLD. For anxiety/depression, only one study was reported from Asia, with a prevalence of 30.9%, and one from Europe, with a prevalence of 16.8%. Similarly, two studies reported dyslipidemia from Europe, prevalence 43.5 to 54%, median 48.8%, and two from South

TABLE 1 | Childhood obesity comorbidities prevalence by geographical region.

Childhood obesity comorbidity	Continental region	Prevalence range	Prevalence median
Hypertension	Asia	12.0–61.7%	38.6%
	South America	18.8–30.9%	25.3%
	Europe	8.6–48.8%	20.1%
	North America	8.2–8.2%	8.2%
	Africa	No studies	No studies
	Australasia	No studies	No studies
Metabolic syndrome	South America	26.3–72.8%	40.3%
	Asia	6.6–52.1%	25.8%
	Europe	7.7–33.0%	20.4%
	Africa	14.3–14.3% (single study)	14.3%
	Australasia	No studies	No studies
	North America	No studies	No studies
NAFLD	Asia	45.0–52.1%	48.6%
	Europe	9.5–36.4%	23.0%
	South America	26.0–50.0%	39.7%
	Africa	No studies	No studies
	Australasia	No studies	No studies
	North America	No studies	No studies
Dyslipidemia	Europe	43.5–54.0%	48.8%
	South America	52.0–74.0%	63.0%
	North America	No studies	No studies
	Africa	No studies	No studies
	Australasia	No studies	No studies
	Asia	No studies	No studies
Asthma	North America	11.6–11.6% (single study)	11.6%
	Europe	No studies	No studies
	South America	No studies	No studies
	Africa	No studies	No studies
	Australasia	No studies	No studies
	Asia	No studies	No studies
Anxiety-depression	Asia	30.9–30.9% (single study)	30.9%
	Europe	16.8–16.8% (single study)	16.8%
	North America	No studies	No studies
	South America	No studies	No studies
	Africa	No studies	No studies
	Australasia	No studies	No studies
	Antarctica	No studies	No studies

NAFLD, Non-alcoholic fatty liver disease.

America, prevalence 52.0 to 74%, median 63%. One study in North America reported on Asthma, prevalence 11.6% (95).

DISCUSSION

The main findings of this review were that the prevalence of childhood obesity-related hypertension, metabolic syndrome, and NAFLD were higher among populations in LMICs than those in HICs. Gender disparity was also apparent among children with obesity-related hypertension and dyslipidemia, where the prevalence was higher among boys than girls. Globally, the Asian region had the highest prevalence of childhood obesity-related hypertension followed by South America and then Europe. The prevalence of childhood obesity-related metabolic syndrome was highest in South America, followed by Asia and then Europe.

Explaining the observed disparities in childhood obesity-related comorbidities is expected to be as complex as defining populations' obesity disparity because of the intricate interplay between adiposity and known NCD risk factors, such as biological, environmental, lifestyle, genetic, socioeconomic, racial, and cultural factors. Nevertheless, understanding the prevalence of obesity-related NCD across pediatric populations, through the review of studies that described childhood obesity comorbidities (**Table 2**), is likely to provide evidence that could help develop strategies

TABLE 2 | Characteristics of studies that described childhood obesity comorbidities.

Reference	Study design	Sample size (number)	Country	Age group (years)	Comorbidity type	Diagnosis criteria	Prevalence in children with obesity	Quality score
China Medical Association (55)	Cluster sample survey	22,071	China	7–16	Metabolic syndrome	International Diabetes Federation (IDF) Criteria	16.8%	6
Badeli et al. (56)	Cross-sectional survey	2,072	Iran	7–17	Hypertension	SBP and/or DBP 95th percentile for age, sex, and height	51.5% (M) 12.5% (F)	8
Basiratnia. et al. (57)	Cross-sectional survey	2,000	Iran	11–17	Hypertension	SBP and/or DBPs > 95th percentile for age, sex, and height	30.7%	7
Cheng. et al. (58)	Prospective cohort	2,189	China	6–16	Hypertension	SBP and/or DBP > 95th percentile for age-sex-height	32.4%	6
Cheng et al. (59)	Multi-stage Cluster-sample survey	1,309	China	10–17	Metabolic syndrome	According to Metabolic syndrome and prophylaxis and treatment proposal in Chinese children and adolescents	41.2%	6
Dong et al. (60)	Cross-sectional survey	4,898	China	6–17	Hypertension	The age- and gender-specific BP cutoff points in Chinese children and adolescents	38.7%	9
Esposito et al. (61)	Case-control study	148	Italy	79	Anxiety-depression	CDI	16.8%	6
Genovesi et al. (62)	Cross-section survey	5,131	Italy	5–11	Hypertension	When SBP and/or DBP at first screening were > or = 90th percentile and the mean of three subsequent measures was > or =95th percentile.	21.5% (M) 20.1% (F)	6
Jmal et al. (63)	Cross-sectional survey	306	Tunisia	10–12	Metabolic syndrome	IDF criteria.	14.3%	7
Koebnick et al. (64)	Cross-sectional survey	237,238	USA	6–17	Hypertension	Two BP ≥ 95th percentile (or ≥140/90 mm Hg even if lower than the 95th percentile	8.2%	8
Luo et al. (65)	Cross-sectional survey.	7,893	China	6–18	Hypertension	SBP and/or DBP > 95^{th} Percentile	19.2%	8
Manios et al. (66)	Cross-sectional survey	2,263	Greece	13–18	Hypertension	SBP and/or DBP > 95^{th} Percentile	48.3%	8
Nkeh-Chungag et al. (67)	Cross-sectional survey	388	Czech Republic	13–17	Hypertension	SBP and DBP ≥ 95th percentile for height, age and sex	17.7%	7
Ogunleye et al., [2013]	Cross-sectional survey	5,983	England	10–16	Mean arterial pressure (MAP)	MAP = 2/3 DBP + 1/3 SBP	29.7%	6
Pećin et al. (68)	Cross-sectional survey	750	Croatia	15.9	Hypertension	According to the current ESH/ESC guidelines	20.0%	9
Pontiles de Sánchez. et al. (69)	Cross-sectional survey	85	Venezuela	3–6	NAFLD	Fatty liver pancreas-US	50.0%	8
				7–11	NAFLD	Fatty liver pancreas-US	39.7%	
				12–17	NAFLD	Fatty liver pancreas-US	31.6%	
Rakočević et al. (70)	Cross-sectional	173	Croatia	7–16	Hypertension	BP => 130/85 mm Hg	25%	6
Sangun et al. (71)	Records review	614	Turkey	7-18	Metabolic syndrome	IDF criteria	33.0%	7
Saury-Paredes et al. (72)	Cross-sectional.	259	Mexico	5–11	Hypertension	SBP and/or DBP ≥ 95^{th} percentile for gender, age	18.8%	8
Shirasawa et al. (73)	Cross-sectional survey	1,297	Japan	9–10	Hypertension	an SBP ≥ 135 mm Hg or DBP ≥ 80 mm Hg	39.4% (M) 58.1% (F)	9
		1,088		12–13	Hypertension	an SBP ≥140 mm Hg or DBP ≥ 85 mm Hg was defined as HT in boys, while an SBP ≥ 135 mm Hg or DBP ≥ 80 mm Hg was defined as HT in girls.	35.7% (M) 38.5% (F)	
Steinthorsdottir et al. (74)	Cross-sectional survey	1,071	Iceland	9–10	Hypertension	BP ≥ 95th percentile at all three visits	8.6%	8

(Continued)

TABLE 2 | Continued

Reference	Study design	Sample size (number)	Country	Age group (years)	Comorbidity type	Diagnosis criteria	Prevalence in children with obesity	Quality score
Suarez-Ortegón et al. (75)	Cross-sectional	1,461	Colombia	10–16	Metabolic syndrome	IDF criteria	72.8%	7
Suazo et al. (76)	Cross-sectional survey	259	Chile	6–12	Metabolic syndrome	the definitions by Cook et al.	26.3%	7
Xu et al. (54)	Cross-sectional survey	8,764	China	7–11	Metabolic syndrome	IDF criteria	33.7% (>10 yrs) 21.8% (<10 yrs)	6
Zhang et al. (77)	Cross-sectional survey	38,702	China	7–17	Hypertension	SBP and/or DBP ≥ 95th percentile for age and gender	60.7 (M) 58.2% (F)	8
Zhang et al. (78)	Cross-sectional survey.	8,568	China	7–18	Hypertension	The 95th percentile of BP cutoff	57.8%	7
Zhang et al. (79)	Cross-sectional survey.	38,822	China	7–17	Hypertension	SBP and/or DBP C 95th percentile for age and gender	48.6% (M) 38.8% (F)	6
Zhou et al. (37)	Cross-sectional survey	387	China	12–17	NAFLD	Diagnostic criteria recommended by the Fatty liver and Alcoholic Liver Disease Study Group of Liver Disease Association in China	45.0%	8
Rerksuppaphol et al. (80)	Cross-sectional survey.	3,991	Thailand	4–17	Hypertension	SBP and/or DBP ≥95th percentile for age and gender	49.5	6
Önsüz et al. (53)	Cross-sectional survey	2,166	Turkey	6–15	Hypertension	Having the average SBP) or DBP between the 95th percentile and the 99th percentile for sex, age, and height	27.7% (All) 23.4% (M<10) 43.5% (M>10) 21.9% (F<10) 36.0% (F>10)	9
Minghelli et al. (81)	Cross-sectional survey	966	Portugal	10–16	Hypertension	SBP or DBP > 95th percentile	12.7%	9
					Lower back pain		6.1%	
Elmaogullari et al. (82)	Cross-sectional (Retrospective record review)	823	Turkey	2–18	Dyslipidemia	Dyslipidemia criteria	42.9%	9
					NAFLD	USS	56.4%	
Sukhonthachit et al. (83)	Cross-sectional survey		Thailand	8–12	hypertension	SBP and/or DBP ≥ 95th percentile for hypertension	13.8%	9
Lim et al. (84)	Cross-sectional survey	1,526	Korea	10–19	Hypertension	SBP and/or DBP ≥ 95th percentile for hypertension	28.4%	9
					Metabolic syndrome	2007 IDF criteria	24.7%	
					Dyslipidemia		55.4%	
					High glucose		9.2%	
Elizondo-Montemayor et al. (85)	Cross-sectional survey	236	Mexico	6–12	Metabolic syndrome	Cook's criteria	40.3%	6
Dyson et al. (86)	Cross-sectional survey.	12,730	China	12–18	Hypertension	Mean SBP or DBP reading (or both) 95th per centile for the predicted value based on gender, age and height	21.0% (M) 29.7% (F)	9
			India	12–18	Hypertension		44.4% (M) 50.0% (F)	
			Mexico	12–18	Hypertension		30.9% (M) 25.3% (F)	
Wang et al. (87)	Cross-sectional survey	3,373	China	16–18	Hypertension		25.5% (M) 11.0% (F)	6
					Metabolic syndrome	IDF definition >=10yrs	14.7% (M) 13.7% (F)	

(Continued)

TABLE 2 | Continued

Reference	Study design	Sample size (number)	Country	Age group (years)	Comorbidity type	Diagnosis criteria	Prevalence in children with obesity	Quality score
						Cook's <10yrs	18.8% (M) 26.9% (F)	
						Cook's >=10yrs	33.7% (M) 30.5% (F)	
Mehairi et al. (88)	Cross-sectional survey	1,018	UAE	12–18	Metabolic syndrome	IDF criteria	55.2% (M) 12.0% (F)	6
Gong et al. (89)	Cross-sectional survey.	538	China	9–15	NAFLD	USS	52.1%	8
Zakeri et al. (90)	Cross-sectional survey	9,172	Iran	10–18	Emotional problems	Global School-based Health Survey (GSHS)	24.0%	6
					Depressive problems	Global School-based Health Survey (GSHS)	30.9%	
					Anxiety problems	Global School-based Health Survey (GSHS)	9.7%	
Papoutsakis et al. (91)	Prospective study	1,138	Greece	10–14	Metabolic Syndrome	IDF	7.7%	6
					Elevated BP		55.0%	
Chen et al. (92)	Cross-sectional survey	3,814	China	6–18	Metabolic syndrome	IDF criteria	27.6%	6
Wiegand et al. (93)	Cross-sectional survey	16,390	The Netherland	1–20	NAFLD	elevated AST and/or ALT	9.5%	5
					Hypertension	95th percentile of European reference data	16.7%	
					Hyperlipidemia	according to the American Heart Association	36.8%	
Rafraf et al. (94)	Cross-sectional survey	985	Iran	14–17	Hypertension	SBP and/or DBP $\geq$ 95th percentile	46.4%	6
Noonan et al. (95)	Cross-sectional survey	1,852	USA	9–18 (4^{th}-12^{th} graders)	Asthma	Questionnaire: (physician or other health professional had told them they had asthma)	11.6%	6
Kloppenborg et al. (96)	Cross-section survey	3,978	Denmark	9–15	IFG	WHO definition	3.4 (F) 4.1 (M)	6
Di Bonito et al. (97)	Multi-center cross-section records review	1,769	Italy	5–18	NAFLD	USS	36.4%	6
Sadeghi-Demneh et al. (98)	Multi-level cluster survey	667	Iran	7–14	Flexible foot	Clinical assessment	52.8%	9
	Multi-level cluster survey				Rigid foot	Clinical assessment	25.0%	6
	Multi-level cluster survey				Activity pain	Clinical assessment	3.2%	6
Schwandt et al. (99)	Analysis of secondary data	22,051	Germany	3–18	Hypertension		18.6 (F) 24.0% (M)	6
Rerksuppaphol et al. (80)	Cross-sectional survey	3,991	Thailand	4–17	Hypertension		49.5	6
Kajbaf et al. (100)	Cross-sectional survey	903	Iran	7–11	Wheeze in the past		68.7%	9
Kajbaf et al. (100)	Cross-sectional survey				Exercise induced wheeze		23.4%	6
Bell et al. (101)	Case control-incidence study	283	Australia	6–13	IGT		5.3%	6
					Hyperinsulism		38.9%	
					Hypertension		19.0%	
					Dyslipidemia		73.7%	

ALT, Alanine transferase; AST, aspartate transferase; BP, blood pressure; CDI, The Children Depression Inventory (CDI); DBP, diastolic blood pressure; F, female; GSHS, Global School-based Health Survey; IDF, International Diabetes Federation; IGT, impaired glucose test; M, male; MAP, mean arterial pressure; NAFLD, non-alcoholic fatty liver disease; SBP, systolic blood pressure; USS, ultra sound scan; WHO, World Health Organization.

TABLE 3 | Childhood obesity comorbidity prevalence range in children aged 2–18 years by development status.

Childhood obesity comorbidity	Range of prevalence of obesity comorbidity in HICs (2 to 18 years).	Range of prevalence range of obesity comorbidity in LMICs (2 to 18 years).	Median of prevalence of obesity comorbidity in HICs (2 to 18 years). (95% CI)	Median of prevalence of obesity comorbidity in LMICs (2 to 18 years) (95% CI)	Comments
Hypertension (SBP and/or DBP > 95th percentile)	3–26% (62, 64, 74, 81, 84, 93, 99, 102–104)	14–61% (36, 53, 56–58, 60, 65–68, 70, 72, 77, 78, 80, 83, 86, 87, 105–107)	13%	36%*	Higher prevalence of hypertension among children in Thailand, Turkey, China and Mexico than in any of the Western developed countries
MetS (IDF criteria)	3–8% (96, 102)	12–73% (55, 59, 63, 71, 75, 76, 84, 87, 88, 92)	6%	27%**	Children from Colombia aged 10–16 had highest prevalence (~73%) compared to highest the developed countries, Greece at 8%
NAFLD (steatosis echogenicity)	10–36% (93, 97)	32–56% (37, 69, 82, 89)	23%	48%**	Higher prevalence of NAFLD in developing countries
Dyslipidemia (fasting lipids > 95th percentile)	52–74% (84, 101)	43–54% (82, 108)	63%	44%**	Highest prevalence of dyslipidemia was in Australian children
Anxiety–Depression (CDI/ GSHS)	10–17% (61, 103)	10% (90)	13%	10%	No discernable trends

*BP, Blood pressure; CDI, The Children Depression Inventory; CI, confidence interval; DBP, diastolic blood pressure; GSHS, Global School-based Health Survey; IDF, International Diabetes Federation; NAFLD, non-alcoholic fatty liver disease; SBP, systolic blood pressure. *$p < 0.05$; **$p > 0.05$.*

TABLE 4 | Childhood obesity comorbidity by gender.

Obesity comorbidity	Prevalence range boys	Prevalence range girls	Prevalence median boys	Prevalence median girls
Hypertension	21.0–60.7%	11.0–58.2%	37.6%	32.9%
Metabolic syndrome	14.7–55.2%	12.0–13.7%	35.0%	12.9%

to ameliorate obesity and associated health risks in the pediatric population.

The review showed that LMICs and global regions with lower income status had higher prevalence of the common childhood obesity-related NCD than HICs (**Tables 1**, **3**). This is consistent with reports that populations living in LMICs or having low socioeconomic status in HICs are at increased risk of developing NCD such as CVD, NAFLD, and T2DM (112–114). For example, the adjusted incidence of stroke was reported to have doubled from 52 to 117 per 100,000 person-years in LMICs, but decreased in HICs by about 42% over a 4-year period (113). Furthermore, Sposato et al. (114) also found that lower per capita gross domestic product adjusted for purchasing power parity correlated with a higher incident risk of stroke ($p = 0.027$, $R^2 = 0.32$) (114). While it is estimated that the global NCD burden will increase by 17% in the next 10 years, in the African region it is projected to increase by up to 27% (5). Similarly, almost half of all deaths of all ages in Asia are now attributable to NCD, accounting for 47% of the global burden of disease (5). At present, India is projected to have the highest global number of patients with diabetes, at 79.4 million in 2030 (115). Therefore, understanding NCD burdens specific to LMICs in the pediatric populations could help in devising effective prevention strategies for childhood obesity and its consequences based on the understanding of challenges found in LMICs. Such prevention challenges that may be shared with high-risk adult population include poverty, increased urbanization, lifestyle factors, and poor air quality, which are common in LMICs (14).

Although evidence suggests that living in LMICs is associated with an increased risk of developing NCD, the causal pathway between socioeconomic status and NCD is complex and not well understood (116). Some studies suggest that earlier adoption of healthy behaviors by advantaged socioeconomic groups is followed by an increased prevalence of risky behaviors among the disadvantaged socioeconomic groups (117, 118). For example, Marins et al. (119) reported a strong association between a low level of schooling and cardiovascular risk factors in an urban center in Brazil (OR1·77, 95% CI 1·39–2·26). While there is no conclusive explanation of the causal pathway between socioeconomic status and NCD, our analysis shows that children from LMICs are at more risk of NCD (**Table 4**). The reasons for this observed pattern may include material deprivation, exposure to unhealthy living conditions and unsafe environment, and limited access to high-quality health services and prevention interventions (120, 121). Adopting NCD prevention through awareness and behavioral interventions in LMICs should therefore adopt an economic-based model, in which community disparities are addressed. Such an approach was recently suggested for preventing MM in LMICs through targeting a cluster of NCD with a multipronged intervention approach (14). This may be adopted for specific age groups, including children with obesity, especially personalized interventions that prevent several metabolic risk factors (122, 123).

Several studies have reported that rapid urbanization and air pollution are linked to NCD in LMICs for all adults (124–130), and hence, children might be particularly disadvantaged in this regard and likely to benefit from early interventions that are appropriate for LMICs. In addition, relative poverty and its associated adverse effects on intrauterine environment affect the functional development of a fetus and lead to an increased risk of development of NCD in adolescence and later life (131). Epidemiological studies have linked small size births with increased risk of CVD and other NCD (132). Insufficient nutrition in the intrauterine life may result in increased susceptibility to lifestyle-related NCD risk factors (133). This is an important factor in childhood NCD burden in many LMICs, where the realities are increased urbanization associated with high levels of urban poverty and marginalization of the rural poor (134, 135). These might, in part, explain the observed differences in childhood obesity-related hypertension, metabolic syndrome, and NAFLD prevalence between LMICs and HICs reported in this review (**Table 3**).

In terms of ethnic and cultural disparity, ethnic minority groups within HICs are known to have a higher risk of obesity and associated NCD such as insulin resistance and metabolic disease (118). Several studies have reported the interplay among lifestyle, environmental, and genetic factors to explain a higher degree of hyperinsulinemia and correlation with adiposity, among South Asian compared with white children of similar age (131, 136–138). However, explaining disparities due to geographical ethnicity or country found in this review (**Table 2**) is complex. Biologically mediated racial or ethnic differences in NCD risks are reported but the actual genetic differences remain unclear as putative genes or gene variants have not yet been identified (139). However, exposure to NCD during fetal life and infancy is reported to increase the risk of developing childhood NCD (140). The Bogalusa Heart Study, for example, shows that the offspring of diabetic parents displays quicker progression to insulin resistance characteristics in the early years to adolescence (25), providing plausible evidence of biological factors at play. High prevalence of adult NCD among some population groups, therefore, increases the risk of childhood NCD in their offspring.

Interestingly, the trend in the prevalence of dyslipidemia departed from other childhood obesity-related NCD between HICs and LMICs in this review (**Table 3**). Although some previous studies in adults have shown lower levels of lipids in ethnic minority groups than in white counterparts, for instance, the mean plasma triglyceride concentration was estimated to be 20 mg/dl lower in African-Americans compared with their white counterparts (141), several studies have also shown that dyslipidemia and excessive body fat occur at lower levels of BMI in South Asians than in white ethnic group (131, 142–144). Given that there were only four studies that reported on dyslipidemia in this review, the differences may not reflect the true picture of disparity.

Our results on gender disparity in childhood comorbidity (hypertension and metabolic syndrome) in boys than girls are irrespective of whether they occurred within LMICs or HICs. This is consistent with previous reports on gender disparity in obesity among children. World Obesity Federation Atlas of Childhood Obesity (2019) showed that about 65% of countries reported a higher prevalence of obesity among boys than girls aged 5–19 years, most of which were in high- and middle-income countries (3). Furthermore, the national Canadian data 2004–2013 showed a 2-fold higher prevalence of obesity among boys than girls (145). Similarly, in China, among children aged 7–18 years, boys had a higher prevalence of obesity than girls (146). In the UK, the National Child Measurement Program (NCMP) shows that boys, children from most deprived areas, and ethnic minorities have a disproportionately higher prevalence of obesity (147). These differences are attributed to risk factors shared with other NCD such as biological differences in body composition and sociocultural differences between sexes. For example, girls in the HICs are reported to prefer food lower in energy, while boys consume more meat and energy-dense food (148). The findings of the review are therefore consistent with the expected gender disparities in obesity-related NCD.

BOX 1 | Implications for practice and research.

- The need for interventions that target at-risk population groups to be culturally and contextually sound through the involvement of specific population group. This should take into consideration the socioeconomic realities of the specific population, informed by local evidence and cultural appropriateness.
- The need to design and conduct research studies on how best to reach the at-risk population with an individualized approach in countries with resource constraints and weak health systems.
- The need to strengthen methods for surveillance of childhood obesity-related NCD to guide local policies and interventions. The WHO STEP-wise survey approach has a limitation when it comes to children as it targets adults aged 25–64 years (149). Development of tailored methodological approaches that take into consideration childhood obesity-related NCD is therefore required.

Implications for Practice and Research

Given the disparity in burden and underlying risks factors of childhood obesity comorbidities, the key implications for practice and research are summarized in **Box 1**.

Limitations

First of all, we included children aged 2 and 18 years based on the WHO definition of childhood obesity (3). However, some countries adopt a higher cutoff age for the definition of childhood obesity (46). As a result, we had to exclude some articles because they did not meet our inclusion criteria for the cutoff age. Second, each of the 54 selected studies used different methodological approaches in selecting study population, study setting, and survey methods (national survey, local community schools). Thus, it was not possible to perform a meta-analysis; instead, we provided median prevalence for predefined subgroups. Nevertheless, it was possible to draw several useful trends from the complex datasets of heterogeneous studies. Third, the majority of studies on LMICs seemed to have assessed hypertension more frequently than other NCDs, perhaps due to resource limitations. Consequently, this may have biased the true picture of the distribution of childhood obesity-related NCD in LMICs. Research using advanced screening in LMICs is therefore needed to provide a comprehensive picture of childhood obesity comorbidities burden.

CONCLUSION

Childhood obesity, with its associated NCD comorbidities, is a major global public health problem. Globally, there is a disparity in the prevalence of childhood obesity-related hypertension, metabolic syndrome, dyslipidemia, and NAFLD comorbidities, between HICs and LMICs, different global regions, and genders. Socioeconomic factors seem to be the main determinant for disparity between LMICs and HICs, besides biological, environmental, cultural, and modifiable lifestyle differences. Implementing targeted lifestyle interventions that are context specific to the socioeconomic realities of the population and informed by local evidence is required. Furthermore, strengthening research and surveillance methods for childhood obesity-related NCD to improve local policies and appropriate interventions is needed.

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

GO and AA contributed to conception, design of the study, performed article screening, and quality assessment. GO organized literature search and wrote the first draft of the manuscript. AA critically revised and edited the manuscript. Both authors reviewed and approved the finally submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.923744/full#supplementary-material

REFERENCES

1. Proimos J, Klein JD. Noncommunicable diseases in children and adolescents. *Pediatrics.* (2012) 130:379–81. doi: 10.1542/peds.2012-1475
2. Guariguata L, Jeyaseelan S. *Children and Non-Communicable Diseases: Global Burden Report*. NCD Child (2019). Available online at: http://www.ncdchild.org/media/1603/ncdchild_global_burden-report-2019.pdf (accessed December 15, 2021).
3. WHO. *Obesity and Overweight.* World Health Organization (2018). Available online at: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight (accessed December 20, 2021).
4. Swinburn BA, Caterson I, Seidell JC, James WP. Diet, nutrition and the prevention of excess weight gain and obesity. *Public Health Nutr.* (2004) 7:123–46. doi: 10.1079/PHN2003585
5. WHO. *World Health Organization New Air Pollution Data*. World Health Organization (2018). Available online at: http://www.ccacoalition.org/en/news/world-health-organization-releases-new-global-air-pollution-data (accessed December 28, 2021).
6. Seidell JC. Societal and personal costs of obesity. *Exp Clin Endocrinol Diabetes*. (1998) 106:7–10. doi: 10.1055/s-0029-1212029
7. Galuska DA, *Dietz WH. Obesity and Overweight (ICD-10 E66). Chronic Disease Epidemiology and Control* 3rd Ed. (2010). p. 269–90.
8. Pollack A. *AMA Recognizes Obesity as a Disease*. The New York Times (2013). p. 18.
9. Bray G, Kim K, Wilding J, Federation WO. Obesity: a chronic relapsing progressive disease process. a position statement of the world obesity federation. *Obes Rev.* (2017) 18:715–23. doi: 10.1111/obr.12551
10. Yancik R, Ershler W, Satariano W, Hazzard W, Cohen HJ, Ferrucci L. Report of the national institute on aging task force on comorbidity. *J Gerontol A Biol Sci Med Sci.* (2007) 62:275–80. doi: 10.1093/gerona/62.3.275
11. Mercer SW, Smith SM, Wyke S, O'Dowd T, Watt GC. Multimorbidity in primary care: developing the research agenda. *Fam Pract.* (2009) 26:79–80. doi: 10.1093/fampra/cmp020
12. Uijen AA, van de Lisdonk EH. Multimorbidity in primary care: prevalence and trend over the last 20 years. *Eur J Gen Pract.* (2008) 14:28–32. doi: 10.1080/13814780802436093
13. Fortin M, Hudon C, Haggerty J, Akker M, Almirall J. Prevalence estimates of multimorbidity: a comparative study of two sources. *BMC Health Serv Res.* (2010) 10:111. doi: 10.1186/1472-6963-10-111
14. Alkhatib A, Nnyanzi LA, Mujuni B, Amanya G, Ibingira C. Preventing Multimorbidity with Lifestyle Interventions in Sub-Saharan Africa: a new challenge for public health in low and middle-income countries. *Int J Environ Res Public Health*. (2021) 18:12449. doi: 10.3390/ijerph182312449
15. Fried LP, Ferrucci L, Darer J, Williamson JD, Anderson G. Untangling the concepts of disability, frailty, and comorbidity: implications for improved targeting and care. *J Gerontol A Biol Sci Med Sci.* (2004) 59:255–63. doi: 10.1093/gerona/59.3.M255
16. Güngör NK. Overweight and obesity in children and adolescents. *J Clin Res Pediatr Endocrinol.* (2014) 6:129–43. doi: 10.4274/jcrpe.1471
17. Gungor N, Bacha F, Saad R, Janosky J, Arslanian S. Youth type 2 diabetes: insulin resistance, beta-cell failure, or both? *Diabetes Care.* (2005) 28:638–44. doi: 10.2337/diacare.28.3.638
18. Kahn SE. Clinical review 135: the importance of beta-cell failure in the development and progression of type 2 diabetes. *J Clin Endocrinol Metab.* (2001) 86:4047–58. doi: 10.1210/jc.86.9.4047
19. Gungor N, Libman I, Arslanian S. Type 2 diabetes mellitus in children and adolescents. In: Pescovitz and Eugster, editors. *Pediatric Endocrinology: Mechanisms, Manifestations and Management.* Lippincott, Williams and Wilkins (2004).
20. Lee L, Sanders RA. Metabolic syndrome. *Pediatr Review.* (2012) 33:459. doi: 10.1542/pir.33.10.459
21. Schwimmer JB, Deutsch R, Rauch JB, Behling C, Newbury R, Lavine JE. Obesity, insulin resistance, and other clinicopathological correlates of pediatric nonalcoholic fatty liver disease. *J Pediatr.* (2003) 143:500–5. doi: 10.1067/S0022-3476(03)00325-1

22. Khaodhiar L, McCowen KC, Blackburn GL. Obesity and its comorbid conditions. *Clin Cornerstone.* (1999) 2:17–31. doi: 10.1016/S1098-3597(99)90002-9
23. Sharma V, Coleman S, Nixon J, Sharples L, Hamilton-Shield J, Rutter H, et al. A systematic review and meta-analysis estimating the population prevalence of comorbidities in children and adolescents aged 5 to 18 years. *Obes Rev.* (2019) 20:1341–9. doi: 10.1111/obr.12904
24. Pantalone KM, Hobbs TM, Chagin KM, Kong SX, Wells BJ, Kattan MW, et al. Prevalence and recognition of obesity and its associated comorbidities: cross-sectional analysis of electronic health record data from a large US integrated health system. *BMJ Open.* (2017) 7:e017583. doi: 10.1136/bmjopen-2017-017583
25. Srinivasan SR, Myers L, Berenson GS. Predictability of childhood adiposity and insulin for developing insulin resistance syndrome (syndrome X) in young adulthood: the Bogalusa heart study. *Diabetes.* (2002) 51:204–9. doi: 10.2337/diabetes.51.1.204
26. Field AE, Byers T, Hunter DJ, Laird NM, Manson JE, Williamson DF, et al. Weight cycling, weight gain, and risk of hypertension in women. *Am J Epidemiol.* (1999) 150:573–9. doi: 10.1093/oxfordjournals.aje.a010055
27. Dyer AR, Elliott P. The INTERSALT study: relations of body mass index to blood pressure. INTERSALT Co-operative research group. *J Hum Hypertens.* (1989) 3:299–308.
28. Li S, Chen W, Srinivasan SR, Xu J, Berenson GS. Relation of childhood obesity/cardiometabolic phenotypes to adult cardiometabolic profile: the Bogalusa heart study. *Am J Epidemiol.* (2012) 176:S142–9. doi: 10.1093/aje/kws236
29. Srinivasan SR, Bao W, Wattigney WA, Berenson GS. Adolescent overweight is associated with adult overweight and related multiple cardiovascular risk factors: the Bogalusa heart study. *Metabolism.* (1996) 45:235–40. doi: 10.1016/S0026-0495(96)90060-8
30. Zilanawala A, Davis-Kean P, Nazroo J, Sacker A, Simonton S, Kelly Y. Race/ethnic disparities in early childhood BMI, obesity and overweight in the United Kingdom and United States. *Int J Obes.* (2015) 39:520–9. doi: 10.1038/ijo.2014.171
31. Falconer CL, Park MH, Croker H, Kessel AS, Saxena S, Viner RM, et al. Can the relationship between ethnicity and obesity-related behaviours among school-aged children be explained by deprivation? a cross-sectional study. *BMJ Open.* (2014) 4:e003949. doi: 10.1136/bmjopen-2013-003949
32. Mayor S. Socioeconomic disadvantage is linked to obesity across generations, UK study finds. *BMJ.* (2017) 356:j163. doi: 10.1136/bmj.j163
33. Bann D, Johnson W, Li L, Kuh D, Hardy R. Socioeconomic inequalities in body mass index across adulthood: coordinated analyses of individual participant data from three British birth cohort studies initiated in 1946, 1958 and 1970. *PLoS Med.* (2017) 14:e1002214. doi: 10.1371/journal.pmed.1002214
34. Weaver RG, Brazendale K, Hunt E, Sarzynski MA, Beets MW, White K. Disparities in childhood overweight and obesity by income in the United States: an epidemiological examination using three nationally representative datasets. *Int J Obes (Lond).* (2019) 43:1210–22. doi: 10.1038/s41366-019-0331-2
35. Chandalia M, Lin P, Seenivasan T, Livingston EH, Snell PG, Grundy SM, et al. Insulin resistance and body fat distribution in South Asian men compared to Caucasian men. *PLoS ONE.* (2007) 2:e812-e. doi: 10.1371/journal.pone.0000812
36. Zhang Y-x, Wang S-r. Blood pressure level profiles among children and adolescents with various types of obesity: study in a large population in Shandong, China. *Clin Res Cardiol.* (2014) 103:553–9. doi: 10.1007/s00392-014-0683-5
37. Zhou X, Hou D-q, Duan J-l, Sun Y, Cheng H, Zhao X-y, et al. [Prevalence of nonalcoholic fatty liver disease and metabolic abnormalities in 387 obese children and adolescents in Beijing, China]. *Zhonghua liu xing bing xue za zhi.* (2013) 34:446–50.
38. Andes LJ, Cheng YJ, Rolka DB, Gregg EW, Imperatore G. Prevalence of prediabetes among adolescents and young adults in the united States, 2005-2016. *JAMA Pediatr.* (2020) 174:e194498. doi: 10.1001/jamapediatrics.2019.4498
39. Cheung EL, Bell CS, Samuel JP, Poffenbarger T, Redwine KM, Samuels JA. Race and obesity in adolescent hypertension. *Pediatrics.* (2017) 139:e20161433. doi: 10.1542/peds.2016-1433
40. Ioakeim-Skoufa I, Poblador-Plou B, Carmona-Pírez J, Díez-Manglano J, Navickas R, Gimeno-Feliu LA, et al. Multimorbidity patterns in the general population: results from the epichron cohort study. *Int J Environ Res Public Health.* (2020) 17:4242. doi: 10.3390/ijerph17124242
41. Smith SM, Wallace E, Clyne B, Boland F, Fortin M. Interventions for improving outcomes in patients with multimorbidity in primary care and community setting: a systematic review. *Syst Rev.* (2021) 10:1–23. doi: 10.1186/s13643-021-01817-z
42. Garin N, Koyanagi A, Chatterji S, Tyrovolas S, Olaya B, Leonardi M, et al. Global multimorbidity patterns: a cross-sectional, population-based, multi-country study. *J Gerontol A Biomed Sci Med Sci.* (2016) 71:205–14. doi: 10.1093/gerona/glv128
43. WHO. *Childhood Overweight and Obesity.* World Health Organization (2018). Available from: https://www.who.int/dietphysicalactivity/childhood/en/ (accessed January 15, 2022).
44. Bauman A, Craig CL. The place of physical activity in the WHO global strategy on diet and physical activity. *Int J Behav Nutr Phys Act.* (2005) 2:1–6. doi: 10.1186/1479-5868-2-10
45. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JPA, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *Ital J Public Health.* (2009) 6:354–91. doi: 10.1371/journal.pmed.1000100
46. Rolland-Cachera MF, Group FTECO. Childhood obesity: current definitions and recommendations for their use. *Int J Pediatr Obes.* (2011) 6:325–31. doi: 10.3109/17477166.2011.607458
47. Moher D, Liberati A, Tetzlaff J, Altman DG, The PG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* (2009) 6:e1000097. doi: 10.1371/journal.pmed.1000097
48. Lizarondo L, Stern C, Carrier J, Godfrey C, Rieger K, Salmond S, et al. *Chapter 8: Mixed Methods Systematic Reviews.* The Joanna Briggs Institute (2017). Available online at: https://reviewersmanual.joannabriggs.org/ (accessed January 20, 2022).
49. Munn Z, Moola S, Riitano D, Lisy K. The development of a critical appraisal tool for use in systematic reviews addressing questions of prevalence. *Int J Health Policy Manag.* (2014) 3:123–8. doi: 10.15171/ijhpm.2014.71
50. UN. *Standard Country or Area Codes for Statistical Use.* United Nations, Statistics Division (1999). Available online at: https://unstats.un.org/unsd/methodology/m49/ (accessed January 20, 2022).
51. Fantom NJ, Serajuddin U. *The World Bank's Classification of Countries by Income. World Bank Policy Research Working Paper.* (2016). doi: 10.1596/1813-9450-7528
52. Manikandan S. Measures of central tendency: Median and mode. *J Pharmacol Pharmacother.* (2011) 2:214–5. doi: 10.4103/0976-500X.83300
53. Önsüz FM, Demir F. Prevalence of hypertension and its association with obesity among school children aged 6-15 living in Sakarya Province in Turkey. *Turk J Med Sci.* (2015) 45:907–12. doi: 10.3906/sag-1407-120
54. Xu H, Li Y, Liu A, Zhang Q, Hu X, Fang H, et al. Prevalence of the metabolic syndrome among children from six cities of China. *BMC Public Health.* (2012) 12:13. doi: 10.1186/1471-2458-12-13
55. CMA. [Prevalence of metabolic syndrome of children and adolescent students in Chinese six cities]. *Zhonghua er ke za zhi.* (2013) 51:409–13.
56. Badeli H, Hassankhani A, Naeemi Z, Hosseinzadeh S, Mehrabi S, Pourkarimi M, et al. Prevalence of hypertension and obesity-related hypertension in urban school-aged children in Rasht. *Iran J Kidney Dis.* (2016) 10:364–8.
57. Basiratnia M, Derakhshan D, Ajdari S, Saki F. Prevalence of childhood obesity and hypertension in south of Iran. *Iran J Kidney Dis.* (2013) 7:282–9.
58. Cheng H, Yan Y-k, Duan J-l, Er Y-l, Mi J. [Association between obesity in childhood and hypertension incidence: a prospective cohort study] *Zhonghua yu fang yi xue za zhi.* (2011) 45:696–701.
59. Cheng X, Wang H, Yuan B, Guan P, Wang L. [Prevalence of metabolic syndrome and its family factors for children and adolescents in Chongqing City in 2014]. *Wei Sheng Yan Jiu.* (2017) 46:557–62.
60. Dong J, Guo X-L, Lu Z-L, Cai X-N, Wang H-C, Zhang J-Y, et al. Prevalence of overweight and obesity and their associations with blood pressure among

children and adolescents in Shandong, China. *BMC Public Health.* (2014) 14:1080. doi: 10.1186/1471-2458-14-1080
61. Esposito M, Gallai B, Roccella M, Marotta R, Lavano F, Lavano SM, et al. Anxiety and depression levels in prepubertal obese children: a case-control study. *Neuropsychiatr Dis Treat.* (2014) 10:1897–902. doi: 10.2147/NDT.S69795
62. Genovesi S, Antolini L, Giussani M, Brambilla P, Barbieri V, Galbiati S, et al. Hypertension, prehypertension, and transient elevated blood pressure in children: association with weight excess and waist circumference. *Am J Hypertens.* (2010) 23:756–61. doi: 10.1038/ajh.2010.50
63. Jmal L, Jmal A, Abdennebi M, Feki M, Boukthir S. Prevalence of metabolic syndrome in Tunisian overweight and obese children. *Tunis Med.* (2019) 97:133–9.
64. Koebnick C, Black MH, Wu J, Martinez MP, Smith N, Kuizon B, et al. High blood pressure in overweight and obese youth: implications for screening. *J Clin Hypertens.* (2013) 15:793–805. doi: 10.1111/jch.12199
65. Luo J-S, Chen S-K, Fan X, Tang Q, Feng Y. [Prevalence of hypertension and relationship between hypertension and obesity in children and adolescents in Nanning of Guangxi Province]. *Zhongguo Dang Dai Er Ke Za Zhi.* (2014) 16:1040–4.
66. Manios Y, Androutsos O, Lambrinou C-P, Cardon G, Lindstrom J, Annemans L, et al. A school- and community-based intervention to promote healthy lifestyle and prevent type 2 diabetes in vulnerable families across Europe: design and implementation of the Feel4Diabetes-study. *Public Health Nutr.* (2018) 21:3281–90. doi: 10.1017/S1368980018002136
67. Nkeh-Chungag BN, Sekokotla AM, Sewani-Rusike C, Namugowa A, Iputo JE. Prevalence of hypertension and pre-hypertension in 13-17 year old adolescents living in Mthatha - South Africa: a cross-sectional study. *Cent Eur J Public Health.* (2015) 23:59–64. doi: 10.21101/cejph.a3922
68. Pećin I, Samovojska R, Heinrich B, Zeljković-Vrkić T, Laganović M, Jelaković B. Hypertension, overweight and obesity in adolescents: the CRO-KOP study. *Coll Antropol.* (2013) 37:761–4.
69. Pontiles de Sánchez M, Morón de Salim A, Rodríguez de Perdomo H, Perdomo Oramas G. [Prevalence of no alcohol fatty liver disease (NAFLD) in a population of obese children in Valencia, Venezuela]. *Arch Latinoam Nutr.* (2014) 64:73–82.
70. Rakočević L, Rakočević V. Incidence of cardiovascular risk factors in obese children. *Acta Clin Croat.* (2016) 55:407–13. doi: 10.20471/acc.2016.55.03.09
71. Sangun Ö, Dündar B, Köşker M, Pirgon Ö, Dündar N. Prevalence of metabolic syndrome in obese children and adolescents using three different criteria and evaluation of risk factors. *J Clin Res Pediatr Endocrinol.* (2011) 3:70–6. doi: 10.4274/jcrpe.v3i2.15
72. Saury-Paredes LA. [Prevalence of high blood pressure and their association with body mass index in children between 5 and 11 years of Nahbalam, Yucatan]. *Gac Med Mex.* (2016) 152:640–4.
73. *!!! INVALID CITATION !!! {Badeli, 2016 #6206; Genovesi, 2010 #1720; Shirasawa, 2010 #9819; Zhang, 2014 #7876}.*
74. Steinthorsdottir SD, Eliasdottir SB, Indridason OS, Agustsdottir IM, Palsson R, Edvardsson VO. Prevalence of hypertension in 9- to 10-year-old Icelandic school children. *J Clin Hypertens.* (2011) 13:774–9. doi: 10.1111/j.1751-7176.2011.00496.x
75. Suarez-Ortegón MF, Aguilar-de Plata C. Prevalence of metabolic syndrome in children aged 5-9 years from southwest colombia: a cross-sectional study. *World J Pediatr.* (2016) 12:477–83. doi: 10.1007/s12519-016-0008-z
76. Suazo J, Hodgson MI, Obregón AM, Valladares M, Weisstaub G, Amador P, et al. Prevalence of metabolic syndrome in obese Chilean children and association with gene variants of the leptin-melanocortin system. *J Pediatr Endocrinol Metab.* (2013) 26:1131–9. doi: 10.1515/jpem-2013-0084
77. Zhang Y-x, Zhao J-s, Chu Z-h, Zhou J-y. Prevalence of elevated blood pressure is associated with the increasing prevalence of obesity among children and adolescents in Shandong, China. *Int J Cardiol.* (2015) 201:150–1. doi: 10.1016/j.ijcard.2015.07.105
78. Zhang Y-X, Wang S-R. Monitoring of blood pressure in overweight and obese children in Shandong, China. *Ann Hum Biol.* (2011) 38:603–7. doi: 10.3109/03014460.2011.582884
79. Zhang Y-X, Wang S-R. Comparison of blood pressure levels among children and adolescents with different body mass index and waist circumference: study in a large sample in Shandong, China. *Eur J Nutr.* (2014) 53:627–34. doi: 10.1007/s00394-013-0571-1
80. Rerksuppaphol S, Rerksuppaphol L. Association of obesity with the prevalence of hypertension in school children from central Thailand. *J Res Health Sci.* (2015) 15:17–21.
81. Minghelli B, Oliveira R, Nunes C. Association of obesity with chronic disease and musculoskeletal factors. *Rev Assoc Med Bras (1992).* (2015) 61:347–54. doi: 10.1590/1806-9282.61.04.347
82. Elmaogullari S, Tepe D, Uçaktürk SA, Karaca Kara F, Demirel F. Prevalence of dyslipidemia and associated factors in obese children and adolescents. *J Clin Res Pediatr Endocrinol.* (2015) 7:228–34. doi: 10.4274/jcrpe.1867
83. Sukhonthachit P, Aekplakorn W, Hudthagosol C, Sirikulchayanonta C. The association between obesity and blood pressure in Thai public school children. *BMC Public Health.* (2014) 14:729. doi: 10.1186/1471-2458-14-729
84. Lim H, Xue H, Wang Y. Association between obesity and metabolic co-morbidities among children and adolescents in South Korea based on national data. *BMC Public Health.* (2014) 14:279. doi: 10.1186/1471-2458-14-279
85. Elizondo-Montemayor L, Ugalde-Casas PA, Lam-Franco L, Bustamante-Careaga H, Serrano-González M, Gutiérrez NG, et al. Association of ALT and the metabolic syndrome among Mexican children. *Obes Res Clin Pract.* (2014) 8:e79–87. doi: 10.1016/j.orcp.2012.08.191
86. Dyson PA, Anthony D, Fenton B, Matthews DR, Stevens DE. High rates of child hypertension associated with obesity: a community survey in China, India and Mexico. *Paediatr Int Child Health.* (2014) 34:43–9. doi: 10.1179/2046905513Y.0000000079
87. Wang Q, Yin J, Xu L, Cheng H, Zhao X, Xiang H, et al. Prevalence of metabolic syndrome in a cohort of Chinese schoolchildren: comparison of two definitions and assessment of adipokines as components by factor analysis. *BMC Public Health.* (2013) 13:249. doi: 10.1186/1471-2458-13-249
88. Mehairi AE, Khouri AA, Naqbi MM, Muhairi SJ, Maskari FA, Nagelkerke N, et al. Metabolic syndrome among Emirati adolescents: a school-based study. *PLoS ONE.* (2013) 8:e56159. doi: 10.1371/journal.pone.0056159
89. Gong CD, Wu QL, Chen Z, Zhang D, Zhao ZY, Peng YM. Glycolipid metabolic status of overweight/obese adolescents aged 9- to 15-year-old and the BMI-SDS/BMI cut-off value of predicting dyslipidemiain boys, Shanghai, China: a cross-sectional study. *Lipids Health Dis.* (2013) 12:129. doi: 10.1186/1476-511X-12-129
90. Zakeri M, Sedaghat M, Motlagh ME, Tayari Ashtiani R, Ardalan G. BMI correlation with psychiatric problems among 10-18 years Iranian students. *Acta Med Iran.* (2012) 50:177–84.
91. Papoutsakis C, Yannakoulia M, Ntalla I, Dedoussis GV. Metabolic syndrome in a Mediterranean pediatric cohort: prevalence using International Diabetes Federation-derived criteria and associations with adiponectin and leptin. *Metabolism.* (2012) 61:140–5. doi: 10.1016/j.metabol.2011.06.006
92. Chen F, Wang Y, Shan X, Cheng H, Hou D, Zhao X, et al. Association between childhood obesity and metabolic syndrome: evidence from a large sample of Chinese children and adolescents. *PLoS ONE.* (2012) 7:e47380. doi: 10.1371/journal.pone.0047380
93. Wiegand S, Keller KM, Röbl M, L'Allemand D, Reinehr T, Widhalm K, et al. Obese boys at increased risk for nonalcoholic liver disease: evaluation of 16,390 overweight or obese children and adolescents. *Int J Obes.* (2010) 34:1468–74. doi: 10.1038/ijo.2010.106
94. Rafraf M, Gargari BP, Safaiyan A. Prevalence of prehypertension and hypertension among adolescent high school girls in Tabriz, Iran. *Food Nutr Bull.* (2010) 31:461–5. doi: 10.1177/156482651003100308
95. Noonan CW, Brown BD, Bentley B, Conway K, Corcoran M, FourStar K, et al. Variability in childhood asthma and body mass index across Northern Plains American Indian communities. *J Asthma.* (2010) 47:496–500. doi: 10.3109/02770901003759436
96. Kloppenborg JT, Fonvig CE, Nielsen TRH, Mollerup PM, Bøjsøe C, Pedersen O, et al. Impaired fasting glucose and the metabolic profile in Danish children and adolescents with normal weight, overweight, or obesity. *Pediatr Diabetes.* (2018) 19:356–65. doi: 10.1111/pedi.12604
97. Di Bonito P, Miraglia Del Giudice E, Chiesa C, Licenziati MR, Manco M, Franco F, et al. Preclinical signs of liver and cardiac damage in youth with metabolically healthy obese phenotype. *Nutr Metab Cardiovasc Dis.* (2018) 28:1230–6. doi: 10.1016/j.numecd.2018.08.007

98. Sadeghi-Demneh E, Azadinia F, Jafarian F, Shamsi F, Melvin JM, Jafarpishe M, et al. Flatfoot and obesity in school-age children: a cross-sectional study. *Clin Obes*. (2016) 6:42–50. doi: 10.1111/cob.12125
99. Schwandt P, Scholze JE, Bertsch T, Liepold E, Haas GM. Blood pressure percentiles in 22,051 German children and adolescents: the PEP family heart study. *Am J Hypertens*. (2015) 28:672–9. doi: 10.1093/ajh/hpu208
100. Kajbaf TZ, Asar S, Alipoor MR. Relationship between obesity and asthma symptoms among children in Ahvaz, Iran: a cross sectional study. *Ital J Pediatr*. (2011) 37:1. doi: 10.1186/1824-7288-37-1
101. Bell LM, Curran JA, Byrne S, Roby H, Suriano K, Jones TW, et al. High incidence of obesity co-morbidities in young children: a cross-sectional study. *J Paediatr Child Health*. (2011) 47:911–7. doi: 10.1111/j.1440-1754.2011.02102.x
102. Mameli C, Krakauer NY, Krakauer JC, Bosetti A, Ferrari CM, Moiana N, et al. The association between a body shape index and cardiovascular risk in overweight and obese children and adolescents. *PLoS ONE*. (2018) 13:e0190426. doi: 10.1371/journal.pone.0190426
103. Leon G, de Klerk E, Ho J, Jackman M, Reimer RA, Connors KE, et al. Prevalence of comorbid conditions pre-existing and diagnosed at a tertiary care pediatric weight management clinic. *J Pediatr Endocrinol Metab*. (2018) 31:385–90. doi: 10.1515/jpem-2016-0245
104. Guijarro de, Armas MAG, Monereo Megías S, Merino Viveros M, Iglesias Bolaños P, Vega Piñero B. [Prevalence of metabolic syndrome in a population of obese children and adolescents] *Endocrinol Nutr*. (2012) 59:155–9. doi: 10.1016/j.endonu.2012.01.003
105. Çam HH, Ustuner Top F. Prevalence of hypertension and its association with body mass index and waist circumference among adolescents in Turkey: a cross-sectional study. *J Pediatr Nurs*. (2021) 57:e29–33. doi: 10.1016/j.pedn.2020.09.017
106. Lu X, Shi P, Luo C-Y, Zhou Y-F, Yu H-T, Guo C-Y, et al. Prevalence of hypertension in overweight and obese children from a large school-based population in Shanghai, China. *BMC Public Health*. (2013) 13:24. doi: 10.1186/1471-2458-13-24
107. Duzova A, Yalçinkaya F, Baskin E, Bakkaloglu A, Soylemezoglu O. Prevalence of hypertension and decreased glomerular filtration rate in obese children: results of a population-based field study. *Nephrol Dial Transplant*. (2013) 28:iv166–71. doi: 10.1093/ndt/gft317
108. Sapunar J, Aguilar-Farías N, Navarro J, Araneda G, Chandía-Poblete D, Manríquez V, et al. [High prevalence of dyslipidemia and high atherogenic index of plasma in children and adolescents]. *Rev Med Chil*. (2018) 146:1112–22. doi: 10.4067/S0034-98872018001001112
109. Zhang Y-x, Wang S-r, Zhao J-s, Chu Z-h. Blood pressure level profiles among obese children and adolescents with different stature. *Int J Cardiol*. (2015) 182:6–7. doi: 10.1016/j.ijcard.2014.12.107
110. Erdal I, Yalçin SS, Aksan A, Gençal D, Kanbur N. How useful are anthropometric measurements as predictive markers for elevated blood pressure in adolescents in different gender? *J Pediatric Endocrinol Metab*. (2020) 33:1203–11. doi: 10.1515/jpem-2020-0175
111. Shirasawa T, Ochiai H, Ohtsu T, Nishimura R, Morimoto A, Hoshino H, et al. LDL-cholesterol and body mass index among Japanese schoolchildren: a population-based cross-sectional study. *Lipids Health Dis*. (2013) 12:77. doi: 10.1186/1476-511X-12-77
112. Hosseinpoor AR, Bergen N, Kunst A, Harper S, Guthold R, Rekve D, et al. Socioeconomic inequalities in risk factors for non communicable diseases in low-income and middle-income countries: results from the world health survey. *BMC Public Health*. (2012) 12:912. doi: 10.1186/1471-2458-12-912
113. Sommer I, Griebler U, Mahlknecht P, Thaler K, Bouskill K, Gartlehner G, et al. Socioeconomic inequalities in non-communicable diseases and their risk factors: an overview of systematic reviews. *BMC Public Health*. (2015) 15:914. doi: 10.1186/s12889-015-2227-y
114. Sposato LA, Saposnik G. Gross domestic product and health expenditure associated with incidence, 30-day fatality, and age at stroke onset. *Stroke*. (2012) 43:170–7. doi: 10.1161/STROKEAHA.111.632158
115. Ramachandran A, Snehalatha C, Kapur A, Vijay V, Mohan V, Das AK, et al. High prevalence of diabetes and impaired glucose tolerance in India: national urban diabetes survey. *Diabetologia*. (2001) 44:1094–101. doi: 10.1007/s001250100627
116. Curtis LJ. An economic perspective on the causal explanations for the socioeconomic inequalities in health. *Rev Panam Salud Publica*. (2018) 42:e53-e. doi: 10.26633/RPSP.2018.53
117. Hidayat K, Du X, Shi B-M, Qin L-Q. Foetal and childhood exposure to famine and the risks of cardiometabolic conditions in adulthood: a systematic review and meta-analysis of observational studies. *Obes Rev*. (2020) 21:e12981. doi: 10.1111/obr.12981
118. Blakely T, Hales S, Kieft C, Wilso.n N, Woodward A. *Distribution of risk factors by poverty. Comparative quantification of health risks: Global and regional burden of disease attributable to selected major risk factors*. Geneva: World Health Organization (2004). p. 1941–2127.
119. Marins VM, Almeida RM, Pereira RA, Sichieri R. The association between socioeconomic indicators and cardiovascular disease risk factors in Rio de Janeiro, Brazil. *J Biosoc Sci*. (2007) 39:221–9. doi: 10.1017/S0021932006001246
120. Tunstall-Pedoe H. *Preventing Chronic Diseases. A Vital Investment: WHO Global Report*. Geneva: World Health Organization, Oxford University Press 2006. (2005). p. 200. CHF 30.00. ISBN 92 4 1563001. Available online at: http://www.who.int/chp/chronic_disease_report/en
121. Seabrook JA, Avison WR. Socioeconomic status and cumulative disadvantage processes across the life course: implications for health outcomes. *Can Rev Sociol*. (2012) 49:50–68. doi: 10.1111/j.1755-618X.2011.01280.x
122. Alkhatib A. Personalising exercise and nutrition behaviours in diabetes lifestyle prevention. *Eur Med J*. (2020) 5:67–77. doi: 10.33590/emj/19-00139
123. Alkhatib A, Tsang C, Tiss A, Bahorun T, Arefanian H, Barake R, et al. Functional foods and lifestyle approaches for diabetes prevention and management. *Nutrients*. (2017) 9:1310. doi: 10.3390/nu9121310
124. Islam SMS, Purnat TD, Phuong NTA, Mwingira U, Schacht K, Fröschl G. Non-communicable diseases (NCDs) in developing countries: a symposium report. *Global Health*. (2014) 10:81. doi: 10.1186/s12992-014-0081-9
125. Goryakin Y, Rocco L, Suhrcke M. The contribution of urbanization to non-communicable diseases: Evidence from 173 countries from 1980 to 2008. *Econ Hum Biol*. (2017) 26:151–63. doi: 10.1016/j.ehb.2017.03.004
126. Allender S, Wickramasinghe K, Goldacre M, Matthews D, Katulanda P. Quantifying urbanization as a risk factor for noncommunicable disease. *J Urban Health*. (2011) 88:906. doi: 10.1007/s11524-011-9586-1
127. Yarahmadi S, Etemad K, Hazaveh AM, Azhang N. Urbanization and non-communicable risk factors in the capital city of 6 big provinces of Iran. *Iran J Public Health*. (2013) 42:113.
128. Juma K, Juma PA, Mohamed SF, Owuor J, Wanyoike A, Mulabi D, et al. First Africa non-communicable disease research conference 2017: sharing evidence and identifying research priorities. *J Glob Health*. (2019) 8:020301. doi: 10.7189/jogh.09.010201
129. Khorrami Z, Etemad K, Yarahmadi S, Khodakarim S, Kameli M, Hezaveh AM, et al. Urbanization and noncommunicable disease (NCD) risk factors: WHO STEPwise Iranian NCD risk factors surveillance in 2011. *East Mediterr Health J*. (2017) 23:469. doi: 10.26719/2017.23.7.469
130. Bickler SW, Wang A, Amin S, Halbach J, Lizardo R, Cauvi DM, et al. Urbanization in sub-Saharan Africa: declining rates of chronic and recurrent infection and their possible role in the origins of non-communicable diseases. *World J Surg*. (2018) 42:1617–28. doi: 10.1007/s00268-017-4389-5
131. Misra A, Khurana L, Isharwal S, Bhardwaj S. South Asian diets and insulin resistance. *Br J Nutr*. (2009) 101:465–73. doi: 10.1017/S0007114508073649
132. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990-2017: a systematic analysis for the global burden of disease study 2017. *Lancet*. (2018) 392:1923–94. doi: 10.1016/S0140-6736(18)32225-6
133. Pullar J, Wickramasinghe K, Demaio AR, Roberts N, Perez-Blanco K-M, Noonan K, et al. The impact of maternal nutrition on offspring's risk of non-communicable diseases in adulthood: a systematic review. *J Global Health*. (2019) 9:020405. doi: 10.7189/jogh.09.020405
134. Fay M. *The Urban Poor in Latin America*. World Bank Publications (2005). doi: 10.1596/0-8213-6069-8
135. Mercado S, Havemann K, Sami M, Ueda H. Urban poverty: an urgent public health issue. *J Urban Health*. (2007) 84:7–15. doi: 10.1007/s11524-007-9191-5

136. Dhawan J, Bray CL, Warburton R, Ghambhir DS, Morris J. Insulin resistance, high prevalence of diabetes, and cardiovascular risk in immigrant Asians. genetic or environmental effect? *Heart.* (1994) 72:413–21. doi: 10.1136/hrt.72.5.413
137. Kain K, Catto A, Grant P. Associations between insulin resistance and thrombotic risk factors in high-risk South Asian subjects. *Diabet Med.* (2003) 20:651–5. doi: 10.1046/j.1464-5491.2003.00958.x
138. Misra A, Khurana L. Obesity-related non-communicable diseases: South Asians vs White Caucasians. *Int J Obes.* (2011) 35:167–87. doi: 10.1038/ijo.2010.135
139. Caprio S, Daniels SR, Drewnowski A, Kaufman FR, Palinkas LA, Rosenbloom AL, et al. Influence of race, ethnicity, and culture on childhood obesity: implications for prevention and treatment: a consensus statement of Shaping America's health and the obesity society. *Diabetes Care.* (2008) 31:2211–21. doi: 10.2337/dc08-9024
140. Fall CHD. Fetal programming and the risk of noncommunicable disease. *Indian J Pediatr.* (2013) 80:S13–20. doi: 10.1007/s12098-012-0834-5
141. Hutchinson RG, Watson RL, Davis CE, Barnes R, Brown S, Romm F, et al. Racial differences in risk factors for atherosclerosis: the ARIC study. *Angiology.* (1997) 48:279–90. doi: 10.1177/000331979704800401
142. Zhao D, Li Y, Zheng L, Yu K. Brief communication: body mass index, body adiposity index, and percent body fat in Asians. *Am J Phys Anthropol.* (2013) 152:294–9. doi: 10.1002/ajpa.22341
143. Wang J, Thornton JC, Russell M, Burastero S, Heymsfield S, Pierson Jr RN. Asians have lower body mass index (BMI) but higher percent body fat than do whites: comparisons of anthropometric measurements. *Am J Clin Nutr.* (1994) 60:23–8. doi: 10.1093/ajcn/60.1.23
144. Misra A. Revisions of cutoffs of body mass index to define overweight and obesity are needed for the Asian-ethnic groups. *Int J Obes.* (2003) 27:1294–6. doi: 10.1038/sj.ijo.0802412
145. Janssen I, Katzmarzyk P, Boyce W, King M, Pickett W. Overweight and obesity in Canadian adolescents and their association with dietary habits and physical activity pattern. *J Adolesc Health.* (2004) 35:360–7. doi: 10.1016/S1054-139X(04)00058-8
146. Zhang J, Zhai Y, Feng XQ, Li WR, Lyu YB, Astell-Burt T, et al. Gender differences in the prevalence of overweight and obesity, associated behaviors, and weight-related perceptions in a national survey of primary school children in China. *Biomed Environ Sci.* (2018) 31:1–11. doi: 10.3967/bes2018.001
147. Baker C. *Briefing Paper: Obesity Staistics*. UK parliament (2019). Available online at: https://commonslibrary.parliament.uk/topic/social-policy/health/ (accessed February 20, 2022).
148. Shah B, Tombeau Cost K, Fuller A, Birken CS, Anderson LN. Sex and gender differences in childhood obesity: contributing to the research agenda. *BMJ Nutr Prev Health.* (2020) 3:387–90. doi: 10.1136/bmjnph-2020-000074
149. WHO. *The WHO STEPwise Approach to Surveillance*. World Health Organization. Regional Office for Europe (2021).

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Associations of sport participation, muscle-strengthening exercise and active commuting with self-reported physical fitness in school-aged children

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Background: Numerous studies suggest a positive association between physical activity and physical fitness in schoolchildren. However, little is known about some neglected forms of physical activity and their associations with physical fitness. This study was conducted *via* a self-reported questionnaire, owing to the COVID-19 pandemic in many regions in China.

Purpose: This study explores the associations between participating in sports, muscle-strengthening exercises, and active commuting with self-reported physical fitness assessed by the International Fitness Scale (IFIS).

Methods: A total of 3,807 study participants (ages 11–17) from 12 public schools in South-eastern China were recruited, with 2,407 providing valid data on variables for analysis. Study participants were asked to self-report their sociodemographic factors (i.e., sex, grade, age), participation in sports (never, 1–3 times per month, 1–2 times per week, and 3 or more times per week), muscle-strengthening exercise (0–7 days) and active commuting (0–5 days). Generalized linear models were used to explore the associations between sports participation, muscle-strengthening exercise, and active commuting with self-reported physical fitness (comprising general physical fitness, cardiorespiratory fitness, muscular strength, speed and agility, and flexibility). A total of 2,407 children and adolescents with a mean age of 13.82 (±2.1) years were included in the study's final analysis.

Results: The study found no significant association between active commuting and physical fitness. Regarding participating in sports and muscle-strengthening exercises, positive, significant associations were found, which showed that a higher frequency of participating in sports and more participation in muscle-strengthening exercises are associated with improved physical fitness.

Conclusion: This study offered evidence on the roles of some aspects of physical activity in physical fitness. To promote health in children and adolescents, they should be encouraged to participate in more sports and engage in muscle-strengthening exercises.

KEYWORDS

sports participation, muscle strengthening exercise, active school travel, self-reported physical fitness, China

Highlights

- Physical fitness levels should be improved considerably in Chinese children and adolescents.
- Sports participation and muscle-strengthening exercise (MSE) were associated with higher levels of self-reported physical fitness.
- Active commuting might not be a contributor to self-reported physical fitness in Chinese children and adolescents.

Introduction

Physical fitness is defined as a set of attributes that people have or achieve while maintaining physical activity (1, 2). It is a well-recognised marker of an individual's health status (3–5). Physical fitness is classified as health-related and skill-related fitness (6). Five components compromise health-related physical fitness (HRPF): cardiorespiratory fitness, body composition, muscular strength, muscular endurance, and flexibility (6). Much evidence has demonstrated the importance and health benefits of higher levels of HRPF in children and adolescents (7, 8). For example, adolescents with higher levels of HRPF have a reduced risk of cardiovascular disease in later life (9). Cardiorespiratory fitness in adolescents is also directly associated with mental wellbeing and quality of life (10, 11). Also, higher cardiorespiratory fitness is positively associated with academic performance among adolescents (12). Muscular fitness (e.g., strength and endurance) is associated with lower risks of adiposity and cardiometabolic parameters and greater bone health in later life (13, 14). Because of the significance of HRPF, it is important to identify more effective ways to encourage it in children and adolescents. Nevertheless, synthesized data shows that lower levels of HRPF have been observed over the past two decades in children and adolescents (15).

Participating in regular and sufficient physical activity is associated with greater levels of HRPF in children and adolescents (7, 8). However, these studies focused on the overall levels of physical activity instead of different types of physical activity. According to earlier studies, adolescents can participate in many types of physical activity, including some that have been shown to be significantly associated with health outcomes and fitness components (8, 16, 17). For example, among the different types of physical activity, sports participation, muscle-strengthening exercise (MSE), and active commuting (AC) can all be organised frequently in school settings, while AC can happen daily. These two types are essential components of global surveillance of active lifestyles (18, 19). In terms of MSE, the World Health Organization recommends that young people (aged 11–17) should engage in it at least three times a week (20). Moreover, a large body of evidence indicates that participating in sports, MSE, and AC are associated with HRPF in adolescents (21–23).

Participating in sports is considered crucial to promoting positive health outcomes in children and adolescents (24, 25). Evidence has demonstrated higher levels of HRPF can be gained from participating in sports (26). A systematic review indicated that participating in organized sports was positively associated with muscular fitness among adolescents. AC plays a prominent role in preventing the risk of mental disorders (27, 28) and may reduce risks associated with poorer HRPF levels (21, 23). MSE is negatively associated with mental health disorders in adolescents and it can also promote muscular fitness (29). This evidence illustrates the importance of participating in sports, MSE, and AC for young people and promoting their health.

Studying the association between different types of physical activity and fitness helps design efficient and contextual fitness or health promotion plans. However, these associations remain rare in literature, limiting researchers' understanding of fitness promotion. It is, therefore, valuable to explore the associations of participating in sports, MSE, and AC with HRPF.

With the COVID-19 pandemic still active in many Chinese regions, assessing HRPF in adolescents using field-based assessment (such as a shuttle run for cardiorespiratory fitness) is unrealistic. Therefore, it is necessary to find an alternative to assess HRPF in adolescents. The International Fitness Scale (IFIS) is an option that can assess adolescents' HRPF simply and conveniently (30). The IFIS was developed in 2011 and much evidence has indicated that it is a reliable and valid instrument to assess HRPF in adolescents (30), with many studies confirming the psychometric properties of the IFIS in adolescents from various countries (31, 32). Unfortunately, evidence linking the benefits of participating in sports, MSE, and AC with self-reported HRPF is very rare, but this makes it worth studying.

To fill the research gap, this study, therefore, aims to explore the links between participating in sports, MSE, and AC (three different types of physical activity) with self-reported HRPF using a sample of Chinese adolescents.

Methods

Study design and participants

This study was a cross-sectional survey conducted between March and October in south-eastern China. 12 public schools in four cities in the South-eastern region were contacted, comprising 5 elementary schools, 5 middle schools and 2 high schools. In each school, 1–3 classes of each grade were randomly selected by a contact assigned to each school. This procedure recruited the initial sample comprising 3,807 children and adolescents (ages 11–17). Study participants providing information on variables of interest were included in this study, while those who did not report data on any variables (e.g., independents, outcomes and covariates) of interest that this study needed were excluded from the initial sample. For this study and further analysis, only 2,407 study participants were included as they provided valid data on variables this study needed. All the children and adolescents involved in the study, as well as their parents or guardians, were specifically advised that participation was completely voluntary. The study protocol and procedure were approved by the Institutional Review Board (IRB) of the Shanghai University of Sport with a Grant Number of 102772021RT071.

Measures

Independent variables (sports participation, MSE, AC)

Sports participation was measured by one question about the participation in organized sports and/or programs over the past 12 months. Participants were required to answer the frequency of sports participation in one week, with answer options of *(1) Never, (2) 1–3 times per month, (3) 1–2 times per week, and (4) 3 or more times per week*. This item has demonstrated good reliability and validity in assessing sports participation of children and adolescents (33).

MSE was assessed by the following question: "*In the past week, how many days did you engage in exercise to strengthen or tone the muscle, such as push-ups, sit-ups, or lifting weights?*" The possible responses were: *0 = none, 1 = 1 day, 2 = 2 days, 3 = 3 days, 4 = 4 days, 5 = 5 days, 6 = 6 days, and 7 = 7 days*. This measure has been confirmed as reliable and valid in assessing MSE among Chinese children and adolescents (34). Based on the recommendation of the World Health Organization, participants who responded for 3 days or more were considered to meet the MSE guideline, otherwise, they were classified as not meeting the guideline (20).

AC was assessed by two independent questions: (1) *On the weekdays, how many days did you go to school by walking, riding cycles, or other active ways*? and (2) *On the weekdays, how many days did go home after school by walking, riding cycles or other active ways?*. The answer options for both the questions were 0–5 days.

Outcome variable (physical fitness)

The International Fitness Scale (IFIS) was used to evaluate the self-reported levels of HRPF, using a five-point Likert scale (very poor, poor, average, good, and very good). The IFIS contains five components, including general physical fitness, cardiorespiratory fitness, muscular strength, speed and agility, and flexibility. The scale has demonstrated acceptable reliability and validity in adolescents (32). In addition to the study sample for further analysis, 544 Chinese children and adolescents were also recruited, who took part in a reliability study. The unpublished results indicated that the IFIS had acceptable reliability (weighted kappa: 0.42–0.52; coefficient of internal consistency of 0.72) in Chinese children and adolescents (35). There has been convincing evidence to demonstrate the validity of the IFIS in children and adolescents (30). Hence, it was deemed that the IFIS can be used as a workable and valid instrument to assess HRPF in study participants of this study.

Controlling variables

Information on study participants' age, sex, siblings, living with parents or not, grade, residence, father and mother education level, and perceived family affluence (0–10 scale) were measured by a self-reported questionnaire. These sociodemographic factors were treated as covariates in further statistical analysis. Besides, study participants' moderate to vigorous physical activity and recreational screen time was assessed by the measures derived from the Health Behaviour in School-aged Children survey, with acceptable reliability and validity in Chinese children and adolescents (36). Sleep duration was measured by the Pittsburgh Sleep Scale. Moderate to vigorous physical activity, recreational screen time, and sleep duration was dichotomized as binary variable based on the Canadian 24-h Movement Guidelines (37, 38).

Statistical analysis

Prior to formal data analysis, missing data was coped with by using complete case analysis and the procedure

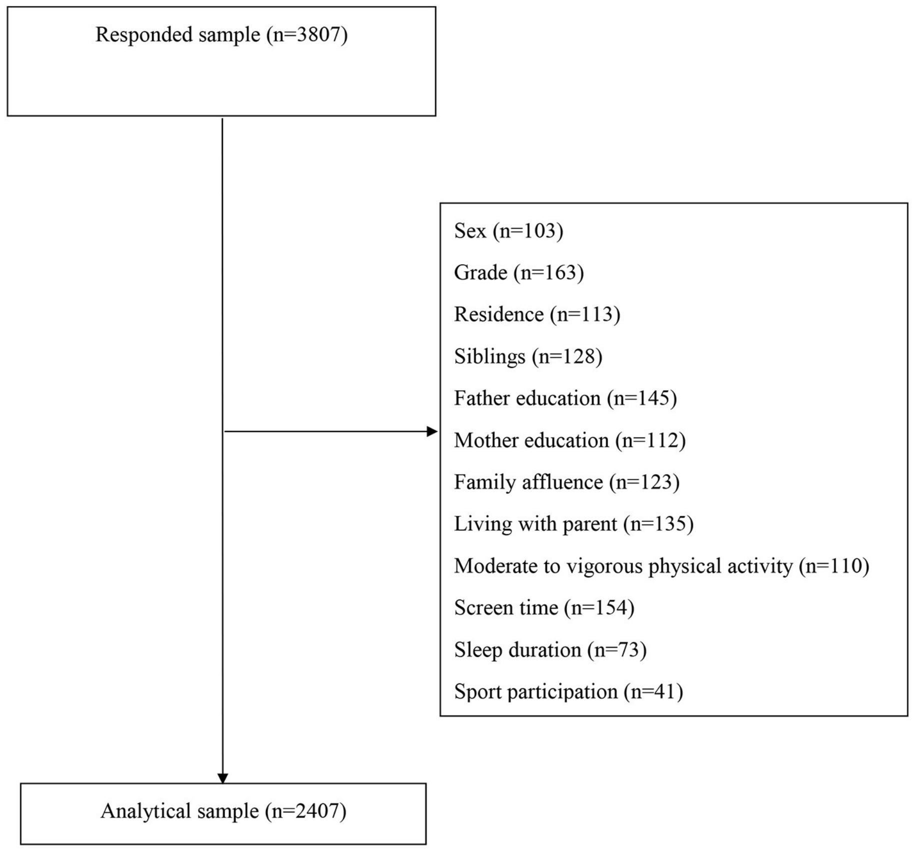

FIGURE 1
The procedure used for cleaning invalid and missing data in this study.

can be found at Figure 1. All the statistical analysis was performed using SPSS 26.0 Version. Descriptive statistics (mean/standard deviation and percentage) were used to report sample characteristics. Mean with standard deviation was for continuous variables (e.g., age) while the percentage was for categorical variables (e.g., grade, residence). Partial correlation was used to explore the associations among sports participation, MSE, AC, and HRPF indicators after controlling for all the sociodemographic factors, moderate to vigorous physical activity, screen time, and sleep duration. To estimate the associations of sports participation (reference group: never), MSE (reference group: <3 times per week), and AC (0 days) with HRPF indicators, five separate models were established (model 1 for general physical fitness; model 2 for cardiorespiratory fitness; model 3 for muscular strength; model 4 for speed and agility; model 5 for flexibility). Entered in the model, sports participation, MSE, and AC were entered the model while controlling for all the other covariates. Generalized linear models with ordinal logistic regression were used to achieve the association estimation. The statistical significance was set up as $p < 0.05$.

Results

Table 1 presents the sample characteristics. The mean age of all the study participants was 13.82 (±2.1), with boys accounting for 52.7%. More information on the study participants can be found in Table 1. In terms of sports participation, MSE, AC and self-reported HRPF indicators, 59.7% of the participants reported never engaging in any sports activities, whilst only 7.6% participated in sports more than three times per week. In addition, 23.4% met the MSE guideline. About 40% of study participants selected Active commuting for going to school or going home on weekdays.

The results from the partial correlation between sports participation, adherence to the MSE guideline, Active commuting, and HRPF indicators are shown in Table 2 after controlling for all the covariates. Specific results indicate that sports participation was correlated with all the indicators of self-reported HRPF (r ranged from 0.16–0.24, $p < 0.001$). Adherence to the MSE guideline was also associated with all the indicators of self-reported HRPF (r ranged from 0.13–0.23, $p < 0.001$). Active commuting was correlated with HRPF

TABLE 1 Sample characteristics of this study.

	n/Mean	%/SD
Age	13.82	2.1
Sex		
Boy	1,268	52.7
Girl	1,139	47.3
Siblings		
Yes	1,184	49.2
No	1,223	50.8
Living with parents		
Yes	2,018	83.8
No	389	16.2
Grade		
4	355	14.7
5	334	13.9
7	353	14.7
8	415	17.2
10	515	21.4
11	435	18.1
Residence		
Rural	277	11.5
Suburban	526	21.9
Urban	1,604	66.6
Father education level		
Middle school or below	623	25.9
High school	595	24.7
Undergraduate	772	32.1
Graduate	137	5.7
Unknown	280	11.6
Mother education level		
Middle school or below	770	32.0
High school	512	21.3
Undergraduate	732	30.4
Graduate	114	4.7
Unknown	279	11.6
Family affluence	5.09	1.5
MVPA guideline		
Not meet	2,250	93.5
Meet	157	6.5
Screen guideline		
Not meet	1,368	56.8
Meet	1,039	43.2
Sleep guideline		
Not meet	1,674	69.5
Meet	733	30.5
Sport participation		
Never	1,436	59.7
1-3 times per week	370	15.4
1-2 times per week	419	17.4
3 or more times per week	182	7.6

(Continued)

TABLE 1 Continued

	n/Mean	%/SD
MSE guideline		
Not meet	1,844	76.6
Meet	563	23.4
Active commuting on a weekday (go to school)		
0	1,077	44.7
1 day	128	5.3
2 days	132	5.5
3 days	91	3.8
4 days	80	3.3
5 days	899	37.3
Active commuting on a weekday (after school)		
0	970	40.3
1 day	144	6.0
2 days	129	5.4
3 days	100	4.2
4 days	67	2.8
5 days	997	41.4
Overall physical fitness		
Very poor	78	3.2
Poor	297	12.3
Average	1,254	52.1
Good	581	24.1
Very good	197	8.2
Cardiorespiratory fitness		
Very poor	90	3.7
Poor	341	14.2
Average	1,140	47.4
Good	621	25.8
Very good	215	8.9
Muscular strength		
Very poor	85	3.5
Poor	380	15.8
Average	1,239	51.5
Good	549	22.8
Very good	154	6.4
Speed/Agility		
Very poor	63	2.6
Poor	305	12.7
Average	1,120	46.5
Good	667	27.7
Very good	252	10.5
Flexibility		
Very poor	166	6.9
Poor	530	22.0
Average	1,031	42.8
Good	491	20.4
Very good	189	7.9

SD, standard deviation; MVPA, moderate to vigorous physical activity; MSE, muscle strengthening exercise.

indicators, except for flexibility. This result is also displayed in the association between active commuting for home and HRPF indicators.

Following control of all the covariates in the current study results from the regression models suggested that sports participation (Figure 2) and adherence to the MSE guideline (Figure 3) were significantly associated with HRPF indicators in the study participants. Specifically, compared with participants who were never involved in sports participation, those reporting 1–3 times per month, 1–2 times per week, and 3 or more times per week had a greater likelihood of general physical fitness (OR = 1.86, 95% CI: 1.49–2.33; OR = 1.77, 95% CI: 1.41–2.21; OR = 4.67, 95% CI: 3.36–6.49). Similar results were also found in the association between sports participation and other HRPF indicators. However, no dose-dependent association was found between sports participation and HRPF indicators, except for muscular strength. As for the association between MSE and HRPF indicators, study participants meeting the MSE guideline were more likely to report higher levels of HRPF (OR for general physical fitness = 2.02, 95% CI: 1.66–2.47; OR for cardiorespiratory fitness = 2.01, 95% CI: 1.65–2.44; OR for muscular strength = 2.23, 95% CI: 1.82–2.72; OR for speed and agility = 1.85, 95%CI: 1.52–2.26; OR for flexibility = 1.60, 95% CI: 1.32–1.93). In the regression model, no significant association was found between Active commuting and HRPF indicators (all $p > 0.05$; data not shown) in the results.

Discussion

The primary aim of the current study is to examine the association between several types of physical activity and self-reported physical fitness (e.g., overall physical fitness, cardiorespiratory fitness) in adolescents aged 11–17. It was found that participating in sports and MSE are positively associated with higher levels of self-reported physical fitness indicators in adolescents. However, AC was not found to be associated with any self-reported physical fitness indicators.

A growing body of evidence has confirmed the positive associations between participating in sports and HRPF indicators in children and adolescents. For example, the Physical Activity Health Longitudinal (PAHL) study reported that adolescents who regularly participate in sports had higher levels of physical fitness (field-based assessments) (26). A longitudinal study suggested that those who participate in sports outperformed those who do not when measuring cardiorespiratory fitness (field-based assessments) (39). Participating in sports was also favourably associated with muscular strength (self-reported questionnaire) (40).

This convincing evidence supports the present research findings. It is, therefore, expected that children and adolescents who participate in sport more frequently can increase their PA levels (41), which in turn improves levels of physical fitness indicators. However, compared with some other studies that investigated the context of participating in sports (e.g., in school or out-of-school) (42), the present study failed to categorise the contexts in which participation occurred. This limits the current study to further explore the contextual health promotion effectiveness of participating in sports in children and adolescents. Future studies should fill the research gaps. Regarding the associations between participating in sports and physical fitness indicators (except for muscular strength), a no dose-response association was found, which may go beyond expectations. A possible reason for this may be due to measurement bias resulting from self-reported measures on sports participation and physical fitness indicators. Of note, odds ratios for the association between participating in sports three or more times and physical fitness indicators were larger than other levels of sports participation. This may imply that participating in sports at a specific frequency can help improve physical fitness indicators in children and adolescents.

As an important component of physical activity, MSE has been confirmed to be associated with a variety of health benefits (43, 44), including promoting mental health (45, 46) and physical fitness improvement (47, 48). It is, therefore, suggested that researchers encourage individuals to participate in more MSE. For children and adolescents, engaging in more muscle promoting activity contributes to higher levels of muscular fitness, including muscular strength and endurance (13). This supports the current study findings that MSE is associated with muscular strength. Moreover, evidence has suggested that MSE can increase other physical fitness indicators. Morrow et al. (49) found that adherence to the MSE guideline was more likely to produce greater levels of cardiorespiratory fitness. The present study also provides evidence for supporting previous, well-recognised guidelines that children and adolescents should engage in MSE at least three times a week, as this study is the very first to examine the association between meeting the MSE guidelines and various physical fitness indicators (albeit self-reported). Collectively, promoting MSE in children and adolescents should be a priority for future health promotion initiatives.

In addition to cardiorespiratory fitness and muscle strength, the current study also suggests that participating in sports and muscle-strengthening exercises are positively associated with speed, agility, and flexibility. Currently, there is no evidence concerning the associations between these two types of physical activity with speed, agility, and flexibility, so it is impossible to find comparable evidence. One explanation for the research findings is that participating in sports and muscle-strengthening exercises might make children and adolescents feel fitter, leading them to report higher levels of these two attributes.

Somewhat inconsistently with previous studies (21), the results found that AC was not associated with any self-reported HRPF indicators. Indeed, as AC is associated with higher

TABLE 2 Partial correlation between sports participation, muscle strengthening exercise, active commuting and self-reported health-related physical fitness.

	1	2	3	4	5	6	7	8	9
1. Sports participation	1.00								
2. Muscle strengthening exercise	0.25***	1.00							
3. AC in weekday (school)	0.10***	0.06**	1.00						
4. AC in weekday (home)	0.08***	0.06**	0.80***	1.00					
5. General physical fitness	0.24***	0.21***	0.07***	0.06**	1.00				
6. Cardiovascular fitness	0.22***	0.20***	0.07***	0.07**	0.57***	1.00			
7. Muscular strength	0.21***	0.23***	0.04	0.05*	0.47***	0.43***	1.00		
8. Speed and agility	0.21***	0.19***	0.07***	0.05*	0.51***	0.43***	0.43***	1.00	
9. Flexibility	0.16***	0.13***	0.02	0.00	0.27***	0.24***	0.24***	0.27***	1.00

AC, active commuting. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

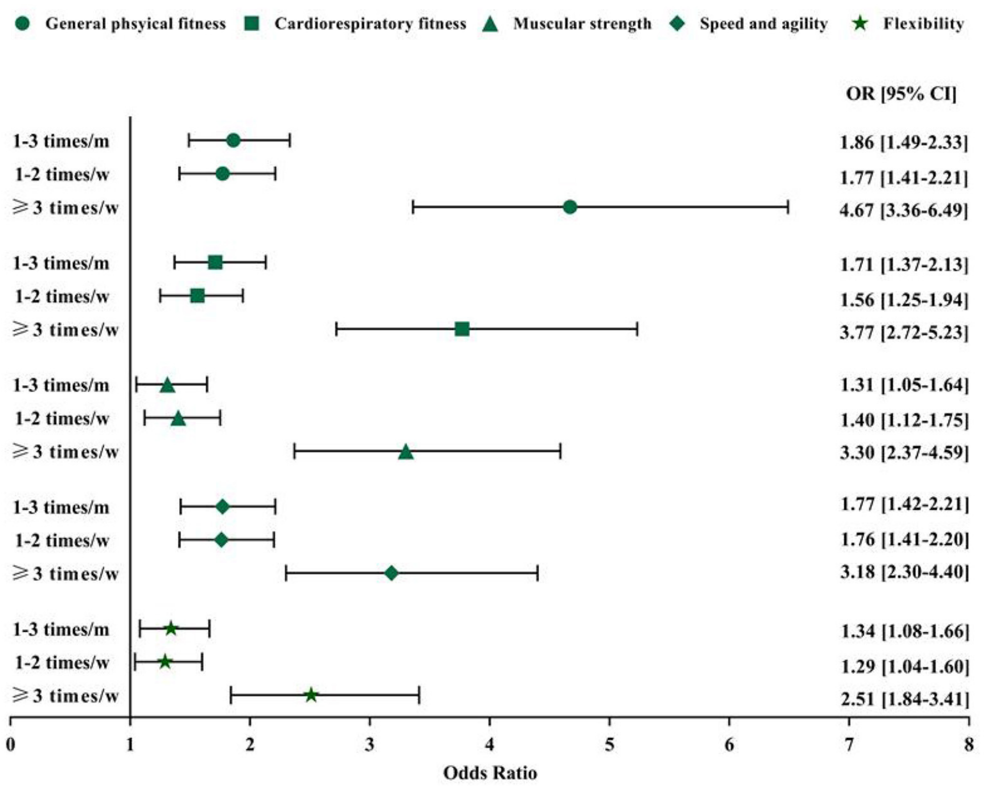

FIGURE 2
Association between frequency of sports participation and self-reported health-related physical fitness indicators. Model controlled for age, sex, siblings, living with parents or not, grade, residence, father and mother education level, and perceived family affluence, moderate to vigorous physical activity, recreational screen time and sleep duration. m, month; w, week; OR, odd ratio; CI, confidence interval. Reference group: never.

levels of physical activity, it is likely that AC may lead to greater physical fitness among children and adolescents. A systematic review found that AC was positively associated with cardiorespiratory fitness in children and adolescents (21). In contrast, the present study does not support this review. Also, the current study suggests that AC is not associated with other HRPF indicators. We assumed several possible reasons to interpret why AC is not associated with HRPF indicators, including the lower intensity of AC (e.g., walking) in children and adolescents; and self-reported HRPF is subject to measurement and recalls bias; and that the measurement of AC is not well-validated. For example, in specific, although children and adolescent actively commuted between school and home, its duration and intensity may be restricted, which may

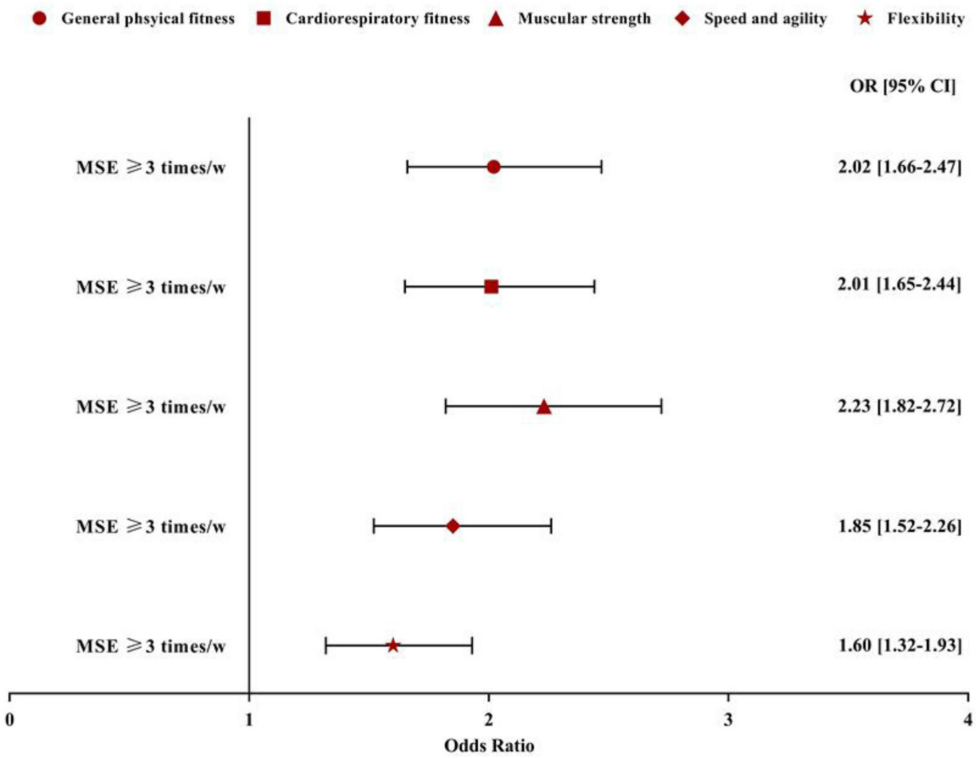

FIGURE 3
Association between muscle strengthening exercise and self-reported health-related physical fitness indicators. Model controlled for age, sex, siblings, living with parents or not, grade, residence, father and mother education level, and perceived family affluence, moderate to vigorous physical activity, recreational screen time and sleep duration. MSE, muscle-strengthening exercise; w, week; OR, odd ratio; CI, confidence interval. Reference group: no more than 3 times/week.

not trigger the threshold of increasing children and adolescents' fitness level. Owing to the rare comparable evidence in this study, more observational and intervention studies are needed to explore and further confirm the roles of AC in physical fitness in children and adolescents.

Study limitations and strengths

This study has some limitations inherent in its design, measuring, and participants. First, owing to the study's cross-sectional design, the study could draw no causal conclusions. In other words, the directionality of the association between participating in sports and physical fitness indicators could not be determined. Second, this study employed self-reported measures to collect data on all the variables, which are subject to recall bias and social desirability of the participants. However, it should also be acknowledged that using objective measures would be offering a solution for studies with a large sample size. Third, as this study adopted a convenient and non-probabilistic sampling method, the research findings may be more regionally than nationally replicable. Finally, BMI was not included, which should be mentioned in the current study as a limitation. Given these limitations, future studies are encouraged to generate stronger evidence. Despite these limitations, this study still has some strengths. This study is the first to assess the associations between participating in sports and self-reported physical fitness indicators, which therefore broadens the literature. Also, the sample size in this study was large, so sufficient statistical power was achieved. Finally, this study controlled for many covariates to accurately estimate the association between participating in sports and self-rated physical fitness.

Practical implications

- As self-reported physical fitness is recognised as an important marker of health status, a regular assessment or surveillance of self-reported physical fitness should be incorporated into a large health surveillance system.
- Encouraging participation in sports and MSE is recommended.

Conclusion

This study offers some evidence concerning the associations between some types of physical activity and self-reported, health-related physical fitness in children and adolescents, highlighting the roles of participating in sports and muscle-strengthening exercises in improving self-reported physical fitness. Future studies should confirm or negate the present research findings.

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 author.

Ethics statement

The study protocol and procedure were approved by the Institutional Review Board (IRB) of the Shanghai University of Sport with a Grant Number of 102772021RT071. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

CS: writing—original draft. SC and JY: formal analysis. LW, KL, JH, HS, and SC: writing—review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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References

1. Haskell WL, Kiernan M. Methodologic issues in measuring physical activity and physical fitness when evaluating the role of dietary supplements for physically active people. *Am J Clin Nutr.* (2000) 72:541S–50S. doi: 10.1093/ajcn/72.2.541S

2. Chen Z, Chi G, Wang L, Chen S, Yan J, Li S. The combinations of physical activity, screen time, and sleep, and their associations with self-reported physical fitness in children and adolescents. *Int J Environ Res Public Health.* (2022) 19:5783. doi: 10.3390/ijerph19105783

3. Ortega FB, Ruiz JR, Castillo MJ, Sjöström M. Physical fitness in childhood and adolescence: a powerful marker of health. *Int J Obes.* (2008) 32:1–11. doi: 10.1038/sj.ijo.0803774

4. Van Andel GE, Austin DR. Physical fitness and mental health: a review of the literature. *Adapt Phys Act Quart.* (1984) 1:207–20.

5. Rauner A, Mess F, Woll A. The relationship between physical activity, physical fitness and overweight in adolescents: a systematic review of studies published in or after 2000. *BMC Pediatr.* (2013) 13:19. doi: 10.1186/1471-2431-13-19

6. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Rep.* (1985) 100:126–31.

7. Gray C, Gibbons R, Larouche R, Sandseter EBH, Bienenstock A, Brussoni M, et al. What is the relationship between outdoor time and physical activity, sedentary behaviour, and physical fitness in children? A systematic review. *Int J Environ Res Public Health.* (2015) 12:6455–74. doi: 10.3390/ijerph120606455

8. Janssen I, LeBlanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *Int J Behav Nutr Phys Act.* (2010) 7:40. doi: 10.1186/1479-5868-7-40

9. Eisenmann JC, Wickel EE, Welk GJ, Blair SN. Relationship between adolescent fitness and fatness and cardiovascular disease risk factors in adulthood: the Aerobics Center Longitudinal Study (ACLS). *Am Heart J.* (2005) 149:46–53. doi: 10.1016/j.ahj.2004.07.016

10. Eddolls WTB, McNarry MA, Lester L, Winn CON, Stratton G, Mackintosh KA. The association between physical activity, fitness and body mass index on mental well-being and quality of life in adolescents. *Qual Life Res.* (2018) 27:2313–20. doi: 10.1007/s11136-018-1915-3

11. Bermejo-Cantarero A, Álvarez-Bueno C, Martínez-Vizcaino V, Redondo-Tébar A, Pozuelo-Carrascosa DP, Sánchez-López M. Relationship between both cardiorespiratory and muscular fitness and health-related quality of life in children and adolescents: a systematic review and meta-analysis of observational studies. *Health Qual Life Outcomes.* (2021) 19:127. doi: 10.1186/s12955-021-01766-0

12. Marques A, Santos DA, Hillman CH, Sardinha LB. How does academic achievement relate to cardiorespiratory fitness, self-reported physical activity and objectively reported physical activity: a systematic review in children and adolescents aged 6–18 years. *Br J Sports Med.* (2018) 52:1039. doi: 10.1136/bjsports-2016-097361

13. García-Hermoso A, Ramírez-Campillo R, Izquierdo M. Is muscular fitness associated with future health benefits in children and adolescents? A systematic review and meta-analysis of longitudinal studies. *Sports Med.* (2019) 49:1079–94. doi: 10.1007/s40279-019-01098-6

14. Lin Y, Yan J. Muscle-strengthening activities and sociodemographic correlates among adults: findings from samples in mainland China. *Int J Environ Res Public Health.* (2020) 17:2266. doi: 10.3390/ijerph17072266

15. Führer T, Kliegl R, Arntz F, Kriemler S, Granacher U. An update on secular trends in physical fitness of children and adolescents from 1972 to 2015: a systematic review. *Sports Med.* (2021) 51:303–20. doi: 10.1007/s40279-020-01373-x

16. Haskell WL, Montoye HJ, Orenstein D. Physical activity and exercise to achieve health-related physical fitness components. *Public Health Rep.* (1985) 100:202.

17. Vanhees L, De Sutter J, Geladas N, Doyle F, Prescott E, Cornelissen V, et al. Importance of characteristics and modalities of physical activity and exercise in defining the benefits to cardiovascular health within the general population:

recommendations from the EACPR (Part I). *Eur J Prev Cardiol.* (2012) 19:670–86. doi: 10.1177/2047487312437059

18. Aubert S, Barnes JD, Abdeta C, Abi Nader P, Adeniyi AF, Aguilar-Farias N, et al. Global matrix 30 physical activity report card grades for children and youth: results and analysis from 49 countries. *J Phys Act Health.* (2018) 15:S251–73. doi: 10.1123/jpah.2018-0472

19. Huang C, Memon AR, Yan J, Lin Y, Chen S-T. The associations of active travel to school with physical activity and screen time among adolescents: do individual and parental characteristics matter? *Front Public Health.* (2021) 9:719742. doi: 10.3389/fpubh.2021.719742

20. Chaput J-P, Willumsen J, Bull F, Chou R, Ekelund U, Firth J, et al. WHO guidelines on physical activity and sedentary behaviour for children and adolescents aged 5–17 years: summary of the evidence. *Int J Behav Nutr Phys Act.* (2020) 17:141. doi: 10.1186/s12966-020-01037-z

21. Lubans DR, Boreham CA, Kelly P, Foster CE. The relationship between active travel to school and health-related fitness in children and adolescents: a systematic review. *Int J Behav Nutr Phys Act.* (2011) 8:5. doi: 10.1186/1479-5868-8-5

22. Larouche R, Saunders TJ, John Faulkner GE, Colley R, Tremblay M. Associations between active school transport and physical activity, body composition, and cardiovascular fitness: a systematic review of 68 studies. *J Phys Activity Health.* (2014) 11:206–27. doi: 10.1123/jpah.2011-0345

23. Henriques-Neto D, Peralta M, Garradas S, Pelegrini A, Pinto AA, Sánchez-Miguel PA, et al. Active commuting and physical fitness: a systematic review. *Int J Environ Res Public Health.* (2020) 17:2721. doi: 10.3390/ijerph17082721

24. Ren T, Yan J, Sun Q. Sociodemographic correlates of organized sports participation in a sample of middle school students in China. *Front Public Health.* (2021) 9:730555. doi: 10.3389/fpubh.2021.730555

25. Chen S, Li X, Yan J, Ren Z. To be a sportsman? Sport participation is associated with optimal academic achievement in a nationally representative sample of high school students. *Front Public Health.* (2021) 9:730497. doi: 10.3389/fpubh.2021.730497

26. Agata K, Monyeki MA. Association between sport participation, body composition, physical fitness, and social correlates among adolescents: the PAHL study. *Int J Environ Res Public Health.* (2018) 15:2793. doi: 10.3390/ijerph15122793

27. Chen S-T, Guo T, Yu Q, Stubbs B, Clark C, Zhang Z, et al. Active school travel is associated with fewer suicide attempts among adolescents from low-and middle-income countries. *Int J Clin Health Psychol.* (2021) 21:100202. doi: 10.1016/j.ijchp.2020.11.001

28. Gu J, Chen S-T. Association between active travel to school and depressive symptoms among early adolescents. *Children.* (2020) 7:41. doi: 10.3390/children7050041

29. Smith JJ, Eather N, Weaver RG, Riley N, Beets MW, Lubans DR. Behavioral correlates of muscular fitness in children and adolescents: a systematic review. *Sports Med.* (2019) 49:887–904. doi: 10.1007/s40279-019-01089-7

30. Ortega FB, Ruiz JR, España-Romero V, Vicente-Rodriguez G, Martínez-Gómez D, Manios Y, et al. The International Fitness Scale (IFIS): usefulness of self-reported fitness in youth. *Int J Epidemiol.* (2011) 40:701–11. doi: 10.1093/ije/dyr039

31. Español-Moya MN, Ramírez-Vélez R. Psychometric validation of the International FItness Scale (IFIS) in Colombian youth. *Rev Esp Salud Publica.* (2014) 88:271–8. doi: 10.4321/S1135-57272014000200009

32. Sánchez-López M, Martínez-Vizcaíno V, García-Hermoso A, Jiménez-Pavón D, Ortega FB. Construct validity and test–retest reliability of the International Fitness Scale (IFIS) in Spanish children aged 9–12 years. *Scand J Med Sci Sports.* (2015) 25:543–51. doi: 10.1111/sms.12267

33. Howie EK, Guagliano JM, Milton K, Vella SA, Gomersall SR, Kolbe-Alexander TL, et al. Ten research priorities related to youth sport, physical activity, and health. *J Phys Activity Health.* (2020) 17:920–9. doi: 10.1123/jpah.2020-0151

34. Xin F, Zhu Z, Chen S, Chen H, Hu X, Ma X, et al. Prevalence and correlates of meeting the muscle-strengthening exercise recommendations among Chinese children and adolescents: results from 2019 Physical Activity and Fitness in China—the youth study. *J Sport Health Sci.* (2022) 11:358–6. doi: 10.1016/j.jshs.2021.09.010

35. Bao R, Chen S, Kastelic K, Drenowatz C, Li M, Zhang J, et al. Reliability of international fitness scale (IFIS) in Chinese children and adolescents. *Children.* (2022) 9:531. doi: 10.3390/children9040531

36. Liu Y, Wang M, Tynjälä J, Lv Y, Villberg J, Zhang Z, et al. Test-retest reliability of selected items of Health Behaviour in School-aged Children (HBSC) survey questionnaire in Beijing, China. *BMC Med Res Methodol.* (2010) 10:1–9. doi: 10.1186/1471-2288-10-73

37. Tremblay MS, Carson V, Chaput J-P, Gorber SC, Dinh T, Duggan M, et al. Canadian 24-hour movement guidelines for children and youth: an integration of physical activity, sedentary behaviour, and sleep. *Appl Physiol Nutr Metabol.* (2016) 41(6 Suppl. 3):S311–27. doi: 10.1139/apnm-2016-0151

38. Tremblay MS, Carson V, Chaput J-P. Introduction to the Canadian 24-hour movement guidelines for children and youth: an integration of physical activity, sedentary behaviour, and sleep. *Appl Physiol Nutr Metabol.* (2016) 41(6 Suppl. 3):iii–iv. doi: 10.1139/apnm-2016-0203

39. Telford RM, Telford RD, Cochrane T, Cunningham RB, Olive LS, Davey R. The influence of sport club participation on physical activity, fitness and body fat during childhood and adolescence: the LOOK longitudinal study. *J Sci Med Sport.* (2016) 19:400–6. doi: 10.1016/j.jsams.2015.04.008

40. Loprinzi PD, Cardinal BJ, Cardinal MK, Corbin CB. Physical education and sport: does participation relate to physical activity patterns, observed fitness, and personal attitudes and beliefs? *Am J Health Promot.* (2018) 32:613–20. doi: 10.1177/0890117117698088

41. Hulteen RM, Smith JJ, Morgan PJ, Barnett LM, Hallal PC, Colyvas K, et al. Global participation in sport and leisure-time physical activities: a systematic review and meta-analysis. *Prevent Med.* (2017) 95:14–25. doi: 10.1016/j.ypmed.2016.11.027

42. Silva G, Andersen LB, Aires L, Mota J, Oliveira J, Ribeiro JC. Associations between sports participation, levels of moderate to vigorous physical activity and cardiorespiratory fitness in children and adolescents. *J Sports Sci.* (2013) 31:1359–67. doi: 10.1080/02640414.2013.781666

43. Bennie JA, Shakespear-Druery J, De Cocker K. Muscle-strengthening exercise epidemiology: a new frontier in chronic disease prevention. *Sports Med Open.* (2020) 6:40. doi: 10.1186/s40798-020-00271-w

44. Bennie J, Smith J, Marvos Y, Biddle S, Kolbe-Alexander T. The neglected guideline: resistance exercise and public health. *J Sci Med Sport.* (2019) 22:S9. doi: 10.1016/j.jsams.2019.08.051

45. Bennie JA, De Cocker K, Biddle SJH, Teychenne MJ. Joint and dose-dependent associations between aerobic and muscle-strengthening activity with depression: a cross-sectional study of 1.48 million adults between 2011 and 2017. *Depress Anxiety.* (2020) 37:166–78. doi: 10.1002/da.22986

46. Bennie JA, Ding D, De Cocker K. Dose-dependent associations of joint aerobic and muscle-strengthening exercise with obesity: a cross-sectional study of 280,605 adults. *J Sport Health Sci.* (2021). doi: 10.1016/j.jshs.2021.01.002

47. Bennie JA, De Cocker K, Pavey T, Stamatakis E, Biddle SJH, Ding D. Muscle strengthening, aerobic exercise, and obesity: a pooled analysis of 17 million US adults. *Obesity.* (2020) 28:371–8. doi: 10.1002/oby.22673

48. Bennie JA, Ding D, Khan A, Stamatakis E, Biddle SJ, Kim J. Run, lift, or both? Associations between concurrent aerobic–muscle strengthening exercise with adverse cardiometabolic biomarkers among Korean adults. *Eur J Prevent Cardiol.* (2020) 27:738–48. doi: 10.1177/2047487318817899

49. Morrow JR, Tucker JS, Jackson AW, Martin SB, Greenleaf CA, Petrie TA. Meeting physical activity guidelines and health-related fitness in youth. *Am J Prev Med.* (2013) 44:439–44. doi: 10.1016/j.amepre.2013.01.008

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Concurrent validity of the combined HRV/ACC sensor and physical activity diary when monitoring physical activity in university students during free-living days

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The purpose of this research was to determine if the scientific research device combined heart rate variability combined with an acceleration sensor (Firstbeat Bodyguard 2, BG2) was valid and reliable for time spent in different intensity zones in free-living. A total of 55 healthy participants performed 48-h physical activity (PA) monitoring with BG2, ActiGraph GT3X+ (GT3X+), and completed Bouchard Physical Activity Diary (Bouchard) every night. In the available studies, GT3X+ is considered the gold standard scientific research device for PA monitor. We compared BG2 and Bouchard with GT3X+ by difference, correlation, and agreement of PA and energy expenditure (EE) in free-living. The results showed that BG2 estimated PA more accurately than Bouchard, with a modest correlation ($r > 0.49$), strong agreement ($\tau > 0.29$), and they had the lowest limits of agreement when estimating moderate to vigorous physical activity (MVPA). The EE estimated by Bouchard was the highest among the three methods, and the correlation and agreement between the three methods were high. Our findings showed that the BG2 is valid and reliable for estimating time spent in different intensity zones in free-living, especially in MVPA.

KEYWORDS

physical activity, energy expenditure, validity, intensity, free-living

Introduction

Physical activity (PA) that produces physical energy expenditure (total energy expenditure or TEE) is defined as any movement that results in a physiological response. Regular PA reduces the risk of mortality and morbidity, regardless of other alterations in lifestyle (1). It is recommended that adults between the ages of 18 and 64 years engage in 150–300 mins of moderate-intensity aerobic activity per week or 75–150 min of high-intensity aerobic activity per week in accordance with the 2020 WHO Guidelines (2). Although energy expenditure (EE) is a significant factor in PA and energy balance, maintaining a specific volume of moderate-to-vigorous physical exercise activity (MVPA) is more important, which is regarded as one of the recommended approaches for preventing cardiovascular risk (3). In comparison, people tend to ignore intensity when completing the recommended amount of exercise (4), which might lead to the phenomenon where people reach the recommended EE under continuous low-intensity PA. Therefore, MVPA in our daily activities should be emphasized considering the benefits of cardiorespiratory fitness.

Currently, various wearable microtechnologies such as accelerometer (ACC), pedometer, and heart rate monitor have been common in PA monitoring, among which ACC-based sensors have been widely utilized within scientific research (5). Specifically, the Actigraph GT3X+ accelerometer is recognized as a reliable tool for adults under free-living conditions to achieve such purpose (6). However, because of their signal detection and data processing techniques, they inevitably result in bias in estimated EE and time of different activity intensities (7, 8). Due to the limitation of wearing position, ACCs often ignore lower limb-based movements, such as climbing stairs, pedaling, etc. Therefore, many studies have also developed corresponding algorithms based on the type of PA (9). Previous studies assessing free-living intensity-specific PA and sedentary (SD) had observed variations in ACC's inter-instrument reliability across intensity categories. The greatest variation has been shown with coefficients of variation (CV) for SD (CV = 10.5%), MPA (CV = 13.5%), and VPA (CV = 12.3%) and very VPA (CV = 18.2%) (10). Trost et al. classified 12 different physical activities into seven categories (lying down, sitting, standing, walking, running, basketball, and dancing), using machine learning techniques, and the classification accuracy for the hip worn accelerometer was 91.0% ± 3.1%. However, it offers modest accuracy in dancing (64.1% for hip and 69.4% for wrist), and approximately 25% of the dancing trials were misclassified as standing plus activities (11). Such results indicate that a single monitoring system might not be able to distinguish between dance and activities requiring upright posture and arm movement (e.g., sweeping the floor). Therefore, future studies should explore the viability of multiple monitor systems.

Firstbeat Bodyguard 2 (BG2, Firstbeat Technologies Ltd, Jyväskylä, Finland) is a body physiology modeling sensor based on the HRV and tri-axial ACC data, calibrated for personal information such as date of birth, gender, height, weight, maximum HR, and minimum HR. BG2 is able to deeply differentiate between mental stress and PA by combining techniques to further improve the analytical recognition ability of PA. Thus, combining technologies should theoretically improve the accuracy of EE estimates and calculate activity time at different intensities with greater precision (12). The BG2 is a commercially available device that provide reliable R–R interval and movement data and could be used in both free-living and lab scenarios. Preliminary studies have demonstrated the advantages of integrating physiological measures, such as heart rate variability combined with an acceleration sensor (HRV/ACC) in the estimation of TEE (13). Nonetheless, no available study has focused on the accuracy of the time spent in different intensities by BG2.

Besides, many studies used activity diaries conveniently for PA estimation. Despite this, diary estimates tend to be biased compared with the real life. Activity diaries are less effective for intensity estimation because of the inherent method limitations and participants' comprehension biases (14).

Based on the above-mentioned rationale, this study aimed to (i) compare the intensity-specific PA time spent estimated by BG2 and Bouchard with that of GT3X+ to evaluate the concurrent validity of BG2; (ii) compare the estimated EE by three methods relatively. It was hypothesized that combining HRV/ACC data exhibited higher consistency on time spent in different intensity zones. As the study takes into account the free-living scene, it is expected that the findings of the study will inform researchers with a more appropriate alternative to monitor PA in generally population.

Methods and measures

Participants

This study recruited 102 healthy adults (58 men and 62 women) who signed a written informed consent before experiment. The inclusion criteria before experiment were as follows: (i) all participants with good sleep (PSQI score < 5); (ii) have no injury history affecting PA in the past 6 months; (iii) do not participate in another biomedical study during the experiment; and (iv) avoid consuming alcohol or caffeinated foods, or any drugs that affect HRV were included in the study. And the exclusion criteria after experiment were as follows: (i) failure to complete the daily Bouchard (more details are shown in study protocol); (ii) the percentage of valid data from GT3X+ was <80%; (iii) the error percentage of BG2 data was >25% according to the suggestion of manufacturer. A total of 55 physically active participants (28 men: age 22.9 ± 2.7 years, height 177.9 ± 6.2 cm, weight 74.7 ± 9.8 kg, and BMI 23.5 ± 2.2 kg/m^2; 27 women: age 22.2 ± 2.5 years, height 164.1 ± 5.7 cm, weight 58.2 ± 8.0 kg, and BMI 21.6 ± 2.6 kg/m^2) were finally included in this study. The Experimental Ethics Committee approved the study for Sports Science at Beijing Sport University

(Registration number 2022056H). Participants were informed of the procedures and purpose of the study.

Study protocol

In December 2021, 48-h PA monitoring has completed for this study, winter (average air temperature: −4 to 5°C and relative humidity: 18–33%). During free-living testing, participants wore GT3X+ and BG2. Figure 1 shows how the devices should be worn and a screenshot of the data. The participants were required to wear the devices throughout the day, except during bathing, swimming, and sleep. Devices were modeled according to the manufacturer's instructions and configured for the individual's age/date of birth, sex, and name before testing. Moreover, participants need to finish the Bouchard nightly with recall and auxiliary records.

Accelerometer (GT3X+) is a type of tri-axial ACC that is commonly used by researchers (15). SD and PA may be measured based on activity counts in an epoch with a set of intensity thresholds, i.e., activity counts classified by time intervals (epoch length) (9). Participants wore a GT3X+ (sampling rate 30 Hz) attached to an elastic waistband around the side of the dominant hip (16). Subjects were monitored for 48 consecutive hours of PA data using a GT3X+, and the data were initially collated and graded using its companion software, Actilife 6.13. At first, Troiano Adult's (2008) criteria were chosen as the basis for classifying PA, where 0–99 counts/min is considered SD, 100 to 2,019 counts/min is LPA, and ≥2,020 counts/min is MVPA, using this criterion to calculate SD time, LPA time, MVPA time and the proportion of each component, as shown in Table 1. Second, Freemason VM3 Combination (2011) formula is chosen to set the PA energy (PAEE).

Combined HRV/ACC sensors (BG2) could monitor beat-to-beat heart rate that targeted for long-term monitoring of HRV and PA (17). It is attached to the body through two electrodes placed under the right clavicle and on the left lower lateral area of the ribcage. Following the recording, registered data are transferred to a computer and analyzed using dedicated software (Firstbeat Sports; v4.5.0.2.) (18).

The subjects wore a BG2 to monitor their PA for 48 h. The data were initially collated and graded using Firstbeat SPORTS software and analyzed and calculated according to the following criteria to obtain indicators such as time in PA at different intensities and TEE calculated by HRmax and activity level (0–10). Different intensity zones are divided as follows: 30–49% light intensity; 50–69% moderate intensity; and ≥70% high intensity to vigorous intensity (19).

Physical activity diary (Bouchard) used in this study and it is one of the most commonly used diaries and involves recording. Bouchard consisting of 96 15-min blocks per day (24 h) during two consecutive days (48 h) (20). Participants were asked to record the main activity in each 15-min block and rate the action on a scale of intensity (1–9, 1 being the lowest and 9 the highest intensity). Each numeric activity code refers to a specific energy cost and converted to a metabolic ratio of expended energy (MET). Total diary EE was calculated as the amount of time in each period multiplied by the correspondent MET and the estimated basal metabolic ratio (BMR). BMR was calculated using the prediction formulas by sex, age, weight, and height. The formula is EE (kcal) for a particular type of PA = EE standard for that type of activity [kcal/(kg−15 min)] × total period (number of sessions) for that type of activity; TEE (kcal /d) = $\sum$ 2 days of EE for every kind of PA/2. The participants complete the Bouchard every night before going to sleep. Classification of exercise intensity intervals based on Bouchard that Categorical values 1, 2 are considered SD; Categorical values 3, 4 are considered LPA; and Categorical values 5–9 are considered MVPA.

Quality control: The enumerators in this study were trained in a uniform and rigorous manner, and double-entry was used. All the types of electronic equipment were purchased from the same batch. Questionnaires and diaries were checked for omissions at the time of collection, and if any were completed on the spot. Subjects were asked to check their equipment while wearing the sensor, and record their activity every hour in the group *via* instant messaging to improve the accuracy of the recording to some extent.

Data processing and analysis

The TEE was automatically exported in BG2, and TEE was calculated according to the formula in Bouchard. PAEE in BG2 and Bouchard were estimated by assuming a fixed percentage for the thermic effect of food (10% of TEE) and a standard resting EE (REE) of 25 kcal/kg/day [PAEE = (TEE × 0.9) – REE] (21). PAEE was automatically exported in GT3X+. Yet, the TEE in GT3X+ was also calculated by the same prediction equations.

Statistical analysis

Data were tested for normality using mean ± SD for descriptive analysis. The correlations between three methods by the Pearson correlation coefficient were classified as having no relationship Strength of the correlation was interpreted as 0.0–0.1 trivial; 0.1–0.3 small; 0.3–0.5 moderate; 0.5–0.7 large; 0.7–0.9 very large and 0.9–1.0 nearly perfect (22). The differences between the three methods by using paired *t*-test. Cohen's *d* was used as effect size statistics for the paired *t*-test and was calculated and interpreted according to the following thresholds: 0.2 trivial; 0.6 small; 1.2 moderate; 2.0 large; 4.0 very large; and ≥4.0 extremely large (22). The agreement between three methods by Kendall's tau-b and ICC. Kendall's tau-b were classified as 0.10–0.19 weak; 0.20–0.29

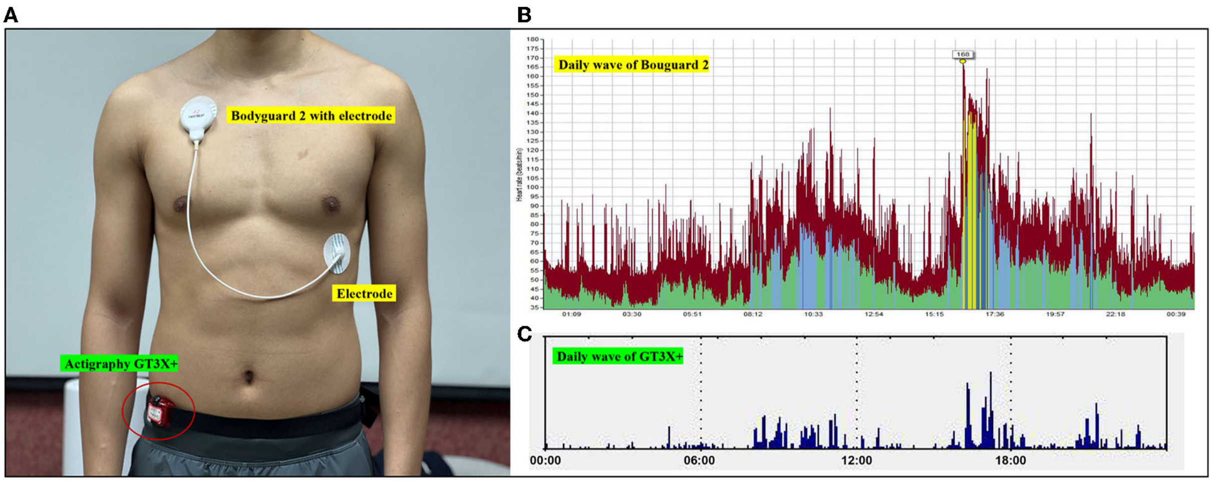

FIGURE 1
(A) Photographs of participants wearing BG2 and GT3X+ during free-living. **(B)** Screenshot of the software program used to acquire PA parameters for BG2. **(C)** Screenshot of the software program used to acquire PA parameters for from GT3X+.

TABLE 1 Correlation and agreement of PA parameters in BG2 and Bouchard compared with GT3X+.

		Pearson (r)	Kendall's tau-b (τ)	ICC (95%CI)
SD (min/d)	Bouchard vs. GT3X+	0.48	0.29**	0.33 (0.08 to 0.54)
	BG2 vs. GT3X+	0.49	0.34**	0.08 (−0.06 to 0.26)
LPA (min/d)	Bouchard vs. GT3X+	−0.02	0.06	−0.01 (−0.28 to 0.25)
	BG2 vs. GT3X+	0.53	0.37**	0.06 (−0.05 to 0.21)
MVPA (min/d)	Bouchard vs. GT3X+	0.40	0.22*	0.16 (−0.07 to 0.39)
	BG2 vs. GT3X+	0.55	0.29**	0.48 (0.25 to 0.66)
TEE (kcal/d)	Bouchard vs. GT3X+	0.90	0.71**	0.87 (0.74 to 0.93)
	BG2 vs. GT3X+	0.84	0.64**	0.83 (0.73 to 0.90)
PAEE (kcal/d)	Bouchard vs. GT3X+	0.79	0.50**	0.71 (0.48 to 0.84)
	BG2 vs. GT3X+	0.52	0.34**	0.55 (0.34 to 0.71)

P-values in Kendall's tau-b indicates statistical significance ($^{*}P < 0.05$ and $^{**}P < 0.01$).

moderate; 0.30 or above strong. The ICC is a value between 0 and 1, where values below 0.5 indicate poor reliability, between 0.5 and 0.75 moderate reliability, between 0.75 and 0.9 good reliability, and any value above 0.9 indicates excellent reliability (23).

The statistical analysis was performed using IBM SPSS Statistics 26.0. The significance level is defined as $P < 0.05$. The Bland–Altman plots using the Medcalc 19.6.4 compared the consistency of the three methods were generated (24).

Results

The differences of time spent in different intensity zones and EE during the free-living by three methods were shown in Figure 2. The correlation and agreement of PA parameters between Bouchard, GT3X+ and BG2 were show in Table 1. The Bland–Altman plots for time spent in different intensity zones and EE during the free-living by three methods were shown in Figure 3.

Differences of PA in free-living between three methods

The BG2 and Bouchard were significantly lower than GT3X+ in SD estimation ($P < 0.01$, ES > -0.34). BG2 was significantly higher than GT3X+ in LPA ($P < 0.01$, ES $= -2.95$), while Bouchard showed no significant difference in this regard. For MVPA, Bouchard was significantly higher than that measured by GT3X+ ($P < 0.01$, ES $= 0.66$), while

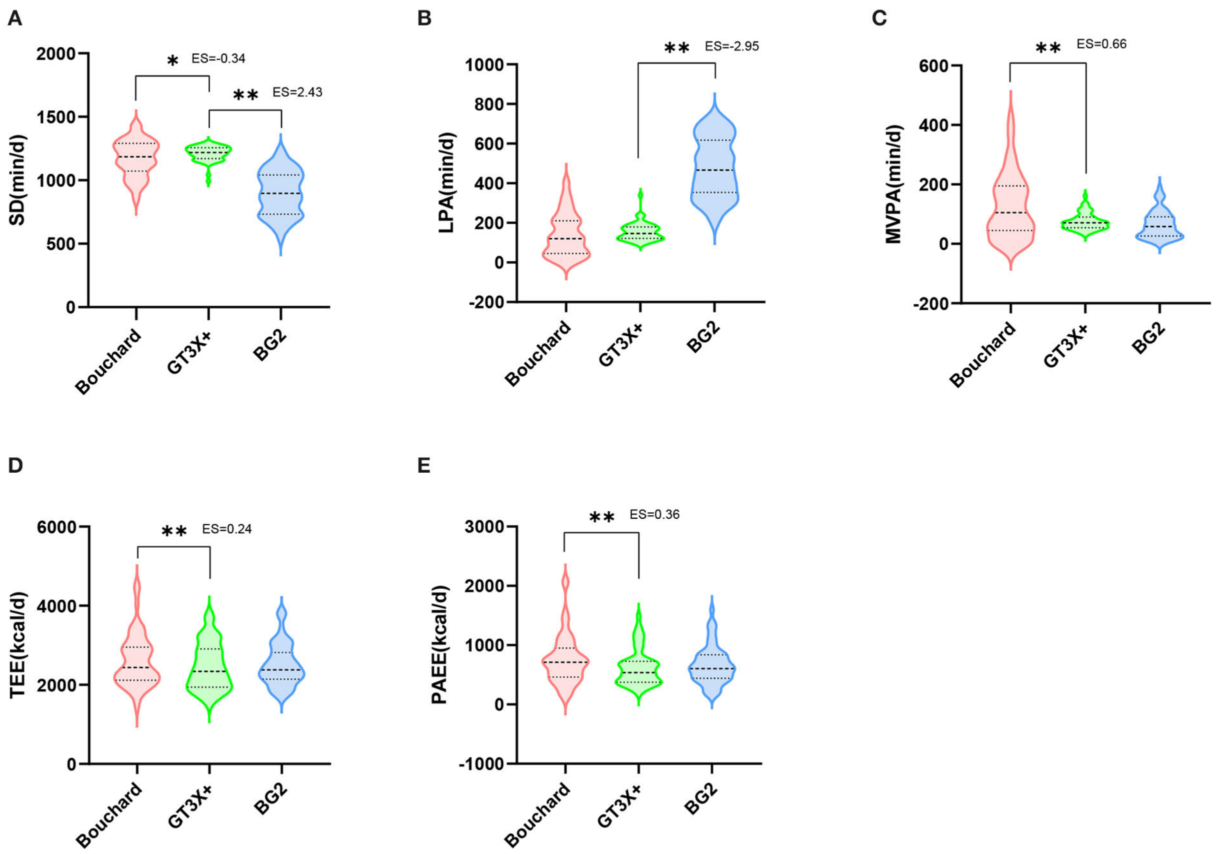

FIGURE 2
The differences of SD, LPA, MVPA, TEE, and PAEE during the free-living by three methods. The thicker dashed line represents the median, and the thinner dashed line represents the inter quartile range. Two-tailed paired *t*-test *P*-values indicate statistical significance (*$P < 0.05$ and **$P < 0.01$).

BG2 has no significant difference with GT3X+. Similarly, BG2 showed no significant difference from GT3X+ in TEE and PAEE estimation, whereas Bouchard was significantly higher than that observed in GT3X+ ($P < 0.01$, ES > 0.24).

Correlation and agreement of PA in free-living between three methods

For the time spent in different intensity zones, the correlation of BG2 is higher than Bouchard in both LPA and MVPA. BG2 has a moderate correlation compared with the GT3X+ ($r > 0.49$), whereas Bouchard has a trivial correlation ($r = -0.02$) in LPA. Similarly, the agreement of BG2 with GT3X+ ($\tau = 0.37$, ICC $= 0.06$) is clearly higher than Bouchard in LPA ($\tau = 0.06$, ICC $= -0.01$). A similar pattern was observed in MVPA that BG2 ($r = 0.55$, $\tau = 0.29$, ICC $= 0.48$) showed relatively better correlation, agreement and ICC values than Bouchard ($r = 0.40$, $\tau = 0.22$, ICC $= 0.16$).

Discussion

This study is the first to examine the accuracy of the BG2 and Bouchard for estimating PA in healthy adults during free-living. The current results indicate that estimating time spent in different intensity zones estimated by BG2 was quite reproducible and valid in a large sample of the healthy adults, especially for MVPA. Therefore, it is of good reference value to compare the accuracy of BG2 based on the PA monitoring results.

The results showed that BG2 is capable of accurately monitoring and accumulating time spent in different intensity zones during free-living. The estimation of PA monitoring by BG2 is accurate compared with GT3X+, which proves its appropriateness for research in a real free-living environment. Compared with GT3X+, BG2 estimated lower level of SD and higher level of LPA, whereas MVPA were comparable. Such results may be due to the fact that BG2 is more sensitive to LPA activity in terms of wearing location. In specific, GT3X+ is worn on the hip, the acceleration detected by the device is

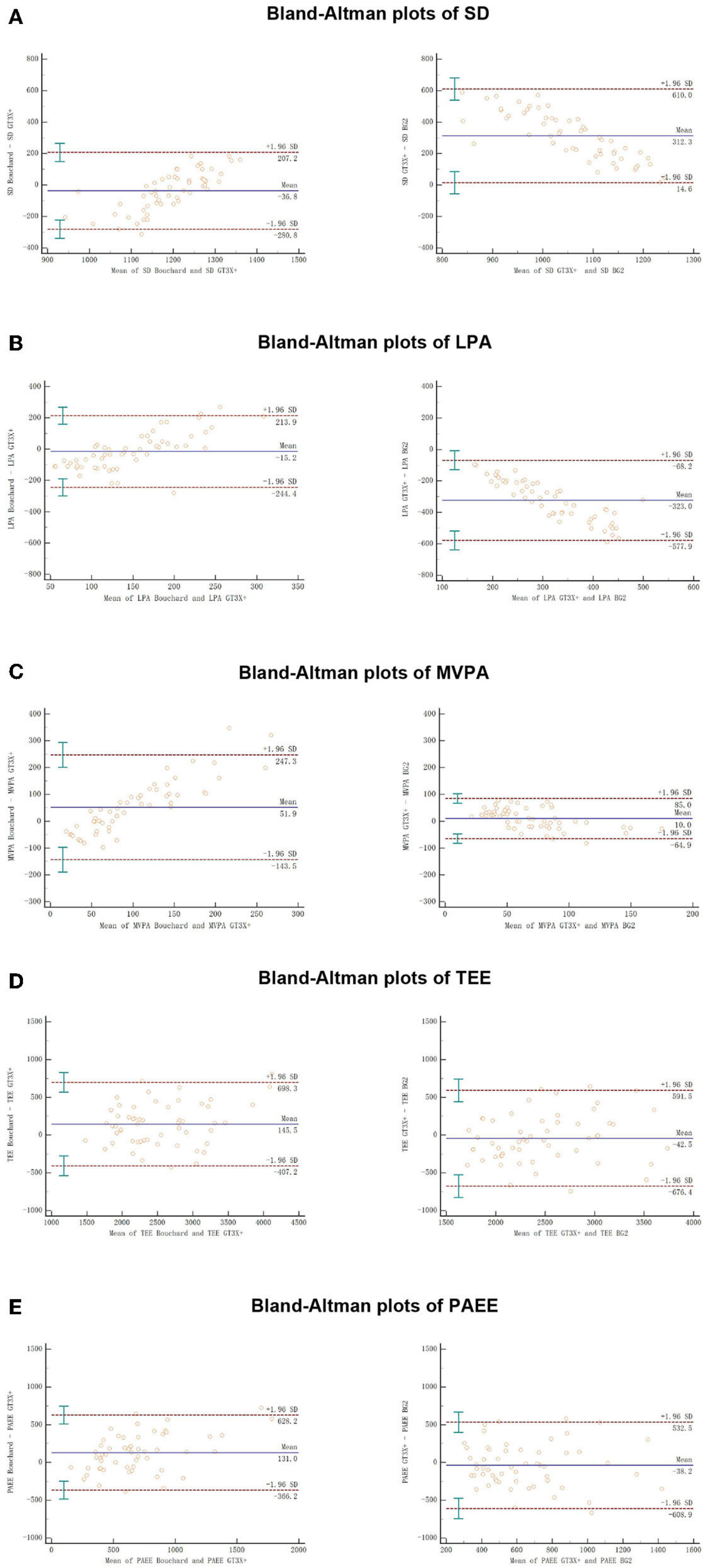

FIGURE 3
The Bland–Altman plots for SD, LPA, MVPA, TEE, and PAEE during the free-living by three methods. Solid lines show the mean difference between methods, and dotted lines show the 95% CI of the limits of agreement (Mean ± 1.96 SD); error bars are 95% CIs.

mainly from the movements of lower quadrant, whereas BG2 is worn on chest, where more slight upper body movement (i.e., sweeping, mopping, washing clothes, upper body resistance training) might be included in LPA (25). So, the magnitude of the measurement bias also varied depending on the PA types (26, 27). In addition, BG2 integrates the HRV data with individual calibrations of HRV responses to free-living physical activities so as to eliminate individual differences in EE caused by physiological differences of participants such as aerobic fitness (28). The difference shown in BG2 measurements may also be caused by HRV correction of ACC counts. The SD time was difficult to be distinguished from LPA when the participants were standing or engaging in some very light activity with GT3X+. In contrast, BG2 can accurately classify SD and LPA time based on the HRV, thus potentially correcting the less accurate estimation of GT3X+. Similarly, the slight measurement difference in MVPA by BG2 may also be related to the correction effect of HRV. As for the comparison of GT3X+ with BG2 in time spent in different intensity zones, the systematic bias between relationships is a negative correlation. That means the lower intensity, the more significant difference between BG2 and GT3X+ measurements, which indicates that BG2 seems to be better corrected when measuring the lower intensity activities.

The results of Bouchard compared with GT3X+ are lower estimated in SD and higher estimated in MVPA, similar to other research. Previous studies have shown that questionnaire-based monitoring tools that the duration and intensity of MVPA recorded by subjects may be higher than objective measures of PA, such as doubly labeled water (DLW) (29, 30). This may be due to differences in understanding and seriousness of the questionnaire among participants. In particular, it was participants' comprehension of different walk speeds in levels 4 and 5 that directly led to the increases in TEE and PAEE. Bouchard is a recall questionnaire in which subjects may make subjective errors when reflecting the intensity and duration of their PA. In addition, as Bouchard uses a fixed interval of 15 min, the total amount of time the subject fills out may differ from the amount of time spent engaging in PA.

In this study, the estimation of Bouchard is the highest in TEE and PAEE, while GT3X+ and BG2 showed no significant difference. Such finding was concordant with previous studies that analyzed the consistency between self-reported levels of PA (similar to Bouchard) and single ACC (21, 31). However, previous studies (32–34) showed high-percentage error and wide limits of agreement in EE estimation using Actigraph when compared with the golden standard tests, while only a few studies showed good validity in predicting EE in controlled treadmill activities or using light intensity stepping exercise (35, 36). Therefore, it remains inconclusive to determine which method was better due to the lack of the gold standard method of EE estimation in the study. It only might be inferred that EE estimated by BG2 is closer to GT3X+.

The BG2 appears to monitor PA under free-living accurately. Despite this, there are still a few limitations: (i) the differences between races are not accounted for in the existing algorithms; (ii) poor contact can cause noise or signal loss, especially during moderate-to-high intensity PA. We also need to handle the poor signal contact of BG2 between the electrode pads and the skin in use; (iii) it was requested that participants remove the equipment while showering and swimming, which might affect measurement results; (iv) BG2 is also susceptible to interference from static electricity in free-living or other metal-based appliances. There also needs to be machine learning or video recognition to verify the activity monitoring using BG2 and the assessment of EE estimate of BG2 using calorimetry in further studies.

In conclusion, by comparing the three methods for the estimation of different PA intensities and EE, BG2 showed comparable results with GT3X+ in both EE and MPVA, and therefore, researchers may use BG2 in future studies for relevant areas. However, there were large discrepancies between SD and LPA prediction. With the potential limitations and drawbacks of using the accelerometer in PA quantification reported by previous studies, it is speculated that a more accurate SD and LPA measurement would be guaranteed when HRV data were combined in BG2. On the other hand, although EE estimation between the three methods was very similar, it only provided an approximate estimation instead of high-precision measurement. Future studies using different populations and the comparison with the gold standard EE test are needed.

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 Experimental Ethics Committee approved the study for Sports Science at Beijing Sport University (Registration Number 2022056H). The patients/participants provided their written informed consent to participate in this study.

Author contributions

Conceptualization: HaocL, QL, YH, DB, HaoyL, and YC. Data curation and writing–original draft: HaocL and QL. Formal analysis and investigation: HaocL, QL, YL, and YW. Writing–review and editing: DB, HaoyL, and YC. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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References

1. Gregg EW, Cauley JA, Stone K, Thompson TJ, Bauer DC, Cummings SR, et al. Relationship of changes in physical activity and mortality among older women. *JAMA.* (2003) 289:2379–86. doi: 10.1001/jama.289.18.2379

2. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br J Sports Med.* (2020) 54:1451–62. doi: 10.1136/bjsports-2020-102955

3. Kraus WE, Powell KE, Haskell WL, Janz KF, Campbell WW, Jakicic JM, et al. Physical activity, all-cause and cardiovascular mortality, and cardiovascular disease. *Med Sci Sports Exerc.* (2019) 51:1270–81. doi: 10.1249/mss.0000000000001939

4. Dowd KP, Szeklicki R, Minetto MA, Murphy MH, Polito A, Ghigo E, et al. A systematic literature review of reviews on techniques for physical activity measurement in adults: a dedipac study. *Int J Behav Nutr Phys Act.* (2018) 15:15. doi: 10.1186/s12966-017-0636-2

5. Troiano RP, McClain JJ, Brychta RJ, Chen KY. Evolution of accelerometer methods for physical activity research. *Br J Sports Med.* (2014) 48:1019–23. doi: 10.1136/bjsports-2014-093546

6. Lee IM, Shiroma EJ. Using accelerometers to measure physical activity in large-scale epidemiological studies: issues and challenges. *Br J Sports Med.* (2014) 48:197–201. doi: 10.1136/bjsports-2013-093154

7. Bonomi AG, Westerterp KR. Advances in physical activity monitoring and lifestyle interventions in obesity: a review. *Int J Obes (Lond).* (2012) 36:167–77. doi: 10.1038/ijo.2011.99

8. Plasqui G, Westerterp KR. Physical activity assessment with accelerometers: an evaluation against doubly labeled water. *Obesity (Silver Spring).* (2007) 15:2371–9. doi: 10.1038/oby.2007.281

9. Migueles JH, Cadenas-Sanchez C, Ekelund U, Delisle Nyström C, Mora-Gonzalez J, Löf M, et al. Accelerometer data collection and processing criteria to assess physical activity and other outcomes: a systematic review and practical considerations. *Sports Med.* (2017) 47:1821–45. doi: 10.1007/s40279-017-0716-0

10. Aadland E, Ylvisåker E. Reliability of the actigraph Gt3x+ accelerometer in adults under free-living conditions. *PLoS ONE.* (2015) 10:e0134606. doi: 10.1371/journal.pone.0134606

11. Trost SG, Zheng Y, Wong WK. Machine learning for activity recognition: hip versus wrist data. *Physiol Meas.* (2014) 35:2183–9. doi: 10.1088/0967-3334/35/11/2183

12. Robertson AH, King K, Ritchie SD, Gauthier AP, Laurence M, Dorman SC. Validating the use of heart rate variability for estimating energy expenditure. *Int J Human Mov Sports Sci.* (2015) 3:19–26. doi: 10.13189/saj.2015.030203

13. Villars C, Bergouignan A, Dugas J, Antoun E, Schoeller DA, Roth H, et al. Validity of Combining heart rate and uniaxial acceleration to measure free-living physical activity energy expenditure in young men. *J Appl Physiol.* (2012) 113:1763–71. doi: 10.1152/japplphysiol.01413.2011

14. Helmerhorst HJ, Brage S, Warren J, Besson H, Ekelund U. A systematic review of reliability and objective criterion-related validity of physical activity questionnaires. *Int J Behav Nutr Phys Act.* (2012) 9:103. doi: 10.1186/1479-5868-9-103

15. Wijndaele K, Westgate K, Stephens SK, Blair SN, Bull FC, Chastin SF, et al. Utilization and harmonization of adult accelerometry data: review and expert consensus. *Med Sci Sports Exerc.* (2015) 47:2129–39. doi: 10.1249/mss.0000000000000661

16. Neugebauer JM, Collins KH, Hawkins DA. Ground reaction force estimates from actigraph Gt3x+ hip accelerations. *PLoS ONE.* (2014) 9:e99023. doi: 10.1371/journal.pone.0099023

17. Bogdány T BS, Szemerszky R, Köteles F. Validation of the firstbeat teambelt and bodyguard2 systems. *Magyar Sporttudományi Szemle.* (2016) 17:5–12.

18. Palmer AR, Distefano R, Leneman K, Berry D. Reliability of the Bodyguard2 (firstbeat) in the detection of heart rate variability. *Appl Psychophysiol Biofeedback.* (2021) 46:251–8. doi: 10.1007/s10484-021-09510-6

19. Strath SJ, Kaminsky LA, Ainsworth BE, Ekelund U, Freedson PS, Gary RA, et al. Guide to the assessment of physical activity: clinical and research applications: a scientific statement from the American Heart Association. *Circulation.* (2013) 128:2259–79. doi: 10.1161/01.cir.0000435708.67487.da

20. Bouchard C, Tremblay A, Leblanc C, Lortie G, Savard R, Thériault G, et al. Method to assess energy expenditure in children and adults. *Am J Clin Nutr.* (1983) 37:461–7. doi: 10.1093/ajcn/37.3.461

21. Wickel EE, Welk GJ, Eisenmann JC. Concurrent validation of the bouchard diary with an accelerometry-based monitor. *Med Sci Sports Exerc.* (2006) 38:373–9. doi: 10.1249/01.mss.0000183344.46077.bb

22. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc.* (2009) 41:3–13. doi: 10.1249/MSS.0b013e31818cb278

23. Koo TK Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med.* (2016) 15:155–63. doi: 10.1016/j.jcm.2016.02.012

24. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet.* (1986) 1:307–10.

25. Kossi O, Lacroix J, Ferry B, Batcho CS, Julien-Vergonjanne A, Mandigout S. Reliability of actigraph Gt3x+ placement location in the estimation of energy expenditure during moderate and high-intensity physical activities in young and older adults. *J Sports Sci.* (2021) 39:1489–96. doi: 10.1080/02640414.2021.1880689

26. Ellis K, Kerr J, Godbole S, Staudenmayer J, Lanckriet G. Hip and wrist accelerometer algorithms for free-living behavior classification. *Med Sci Sports Exerc.* (2016) 48:933–40. doi: 10.1249/mss.0000000000000840

27. Leenders NY, Sherman WM, Nagaraja HN, Kien CL. Evaluation of methods to assess physical activity in free-living conditions. *Med Sci Sports Exerc.* (2001) 33:1233–40. doi: 10.1097/00005768-200107000-00024

28. Keytel LR, Goedecke JH, Noakes TD, Hiiloskorpi H, Laukkanen R, van der Merwe L, et al. Prediction of energy expenditure from heart rate monitoring during submaximal exercise. *J Sports Sci.* (2005) 23:289–97. doi: 10.1080/02640410470001730089

29. Shephard RJ, Aoyagi Y. Measurement of human energy expenditure, with particular reference to field studies: an historical perspective. *Eur J Appl Physiol.* (2012) 112:2785–815. doi: 10.1007/s00421-011-2268-6

30. Prince SA, Adamo KB, Hamel ME, Hardt J, Connor Gorber S, Tremblay M, et al. Comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *Int J Behav Nutr Phys Act.* (2008) 5:56. doi: 10.1186/1479-5868-5-56

31. Matthews CE, Freedson PS. Field trial of a three-dimensional activity monitor: comparison with self report. *Med Sci Sports Exerc.* (1995) 27:1071–8. doi: 10.1249/00005768-199507000-00017

32. Reilly JJ, Kelly LA, Montgomery C, Jackson DM, Slater C, Grant S, et al. Validation of actigraph accelerometer estimates of total energy expenditure in young children. *Int J Pediatr Obes.* (2006) 1:161–7. doi: 10.1080/17477160600845051

33. Lee JM, Kim Y, Welk GJ. Validity of consumer-based physical activity monitors. *Med Sci Sports Exerc.* (2014) 46:1840–8. doi: 10.1249/mss.0000000000000287

34. Hills AP, Mokhtar N, Byrne NM. Assessment of physical activity and energy expenditure: an overview of objective measures. *Front Nutr.* (2014) 1:5. doi: 10.3389/fnut.2014.00005

35. Chang CH, Hsu YJ Li F, Tu YT, Jhang WL, Hsu CW, et al. Reliability and validity of the physical activity monitor for assessing energy expenditures in sedentary, regularly exercising, non-endurance athlete, and endurance athlete adults. *PeerJ.* (2020) 8:e9717. doi: 10.7717/peerj.9717

36. Wetten AA, Batterham M, Tan SY, Tapsell L. Relative validity of 3 accelerometer models for estimating energy expenditure during light activity. *J Phys Act Health.* (2014) 11:638–47. doi: 10.1123/jpah.2011-0167

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Causal effects and functional mechanisms of the Internet on residents' physical fitness-An empirical analysis based on China family panel survey

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Introduction: Physical fitness is an essential part of a healthy lifestyle that concerns the overall health of the nation. Research on the relationship between the Internet and physical fitness has long been caught in the dilemma of "media mobilization" and "media suppression," and previous studies have rarely examined the causal relationship and functional mechanism.

Methods: This study selected the data of 23,989 samples successfully followed in all three surveys of the China Family Panel Survey (CFPS) from 2014 to 2018 to explore the correlation and causal inference between the Internet and physical fitness by using the Time Fixed Effects Model and cross-lagged models, respectively; meanwhile, the data of 24,687 samples in CFPS 2020 to examine the functional mechanism of the Internet's effect on residents' physical fitness behavior by the KHB method.

Results: We obtained three valuable conclusions as follows: First, there is a significant correlation between the Internet and physical fitness behavior. Second, the Internet use is the cause for the increase in fitness frequency, and there is a rival relationship between Internet duration and fitness time. Third, under regular prevention and control of the COVID-19 epidemic, social capital and health risk perceptions are the functional mechanisms of the Internet influencing fitness behavior, and the mediating effect of psychological health risk perceptions is higher than that of social capital.

Discussion: It's necessary to create an intelligent, informative, and digital sports public service system by enriching and optimizing sports media and facilitating the Internet to serve residents' physical fitness better. The new concept of "Internet plus Fitness" will be of great significance in the implementation of the "Healthy China Initiative."

KEYWORDS
Internet, health, physical fitness, causal effect, mediation effect

Introduction

Since the outbreak of COVID-19, due to physical isolation, vaccination, and other control measures, China has accomplished a remarkable achievement in the fight against the epidemic which has maximally protected the lives and health of the residents. However, the continuous mutation of the virus has caused the outbreak to repeatedly rise in the country. The negative impact of isolation on physical and mental health is increasingly prominent, despite the fact that it remains a important way of blocking the spread of the epidemic. Given this context, promoting active physical fitness by establishing the concept of "everyone is the first responsible for his or her own health" (1) should be one of the major contents of the regular prevention and control of the epidemic.

Among the current studies, the factors influencing residents' physical fitness behavior include macro social environment factors such as sports policy and system, public sports funding, service system, and public space supply (2–4), as well as micro-social hierarchy factors such as income, education and occupational status (5, 6), and also individual factors such as perceptions, attitudes and behavioral motivations toward physical fitness (7).

The Internet has played an essential role in residents' fitness behavior during the home quarantine of the epidemic. On one hand, while physical isolation has to some extent weakened the social environment and hierarchical advantages of sports, it has strengthened the impact of the Internet on residents' physical fitness behavior (8–10). On the other hand, Physical fitness strategies promoted by the Internet are undoubtedly the most effective way to address health risks and defend against crises (11). According to a survey among 21,118 residents conducted by the Zhejiang Provincial Sports Bureau on the status of physical fitness during the epidemic, 81.54% participated in physical exercise, which is a 10.23% increase from before the epidemic. 40.48% of residents engaged in home fitness 3 times a week, and 70.03% of them exercised for more than 15 min. Most residents reckoned that physical exercise contributes a lot to enhancing immune ability, promoting confidence in defending epidemics, and conquering psychological fears (12). With the regular prevention and control of the epidemic, what will be the relationship between Internet and residents' physical fitness behavior? Will the online medium play a sustainable role in elevating the physical fitness level of the population? The answer is of great practical importance in regular prevention and control of the epidemic and the protection of the physical and psychological health of the residents.

Previous studies focusing on the relationship between the Internet and residents' physical fitness behaviors have achieved some results, but have also been challenged. Firstly, research on the influence of Internet on physical fitness or sports participation has developed into two opposing theoretical perspectives which are "media mobilization" (13–15) and "media suppression" (16–18). Scholars holding the "media mobilization" argue that the Internet has shaped the social environment of sports, extended the ways of sports participation (19–21), consolidated and broadened the ways of accumulating sports social capital (22, 23), and thus influenced the residents' perceptions, attitudes and behaviors toward the value of physical fitness. Researchers holding the "media suppression" promote that the increase in time spent on the Internet comes at the cost of less time spent on physical fitness (14). The residents' physical fitness behavior is influenced by various factors such as age, gender, education level, urban and rural areas, and social class. The regression estimation method of traditional cross-sectional data pays inadequate attention to the endogeneity issue, resulting in ambiguous causal relationship between the Internet and physical fitness behaviors, and it is questionable to discuss the relationship between Internet and residents' fitness behaviors only by using "media mobilization" and "media suppression." Secondly, as most studies have been conducted only to assess the positive or negative effects of the Internet on physical fitness, the relationship between the two has long been discussed only in terms of "mobilization" and "suppression," with less research on the more profound mechanisms. Since the outbreak of COVID-19 epidemic, several studies have theoretically examined the role of social risk (11), social anxiety (24), and social interaction (10) in the process of the Internet influencing the physical fitness behavior of the residents, but these studies have not sufficiently tested the theory.

With the regular prevention and control of the epidemic, physical fitness is still an essential method in protecting the physical and psychological health of the residents. To examine the functional mechanism and relationship of the Internet in affecting the residents is of great theoretical value and practical meaning. Therefore, this study concentrates on residents' physical fitness behavior and utilizes the micro-panel data of China Family Panel Studies (CFPS) in 2014, 2016, 2018, and 2020 to analyze the influence and functional mechanisms of the Internet. The purpose of this study was to: (1) examine whether there exists a relationship between the Internet and residents' behaviors of physical fitness; (2) explore what the specific relationship is; (3) find the functional mechanism through which the Internet influence residents' physical fitness behavior.

Literature review

Social compensation and time displacement

Currently, the results of empirical studies on the impact of the Internet on the residents' physical fitness behaviors vary significantly. Some studies concluded that the overall effect of the Internet on physical fitness is positive (13, 16); while others indicated the opposite (25), and some studies suggested that there was no significant relationship between the two (18). Theoretically speaking, the influence of the Internet on residents' physical fitness has effects of both social compensation and time displacement. Scholars holding the view of social compensation argue that, as a critical way to obtain information resources in modern society, the Internet has more dominance in shaping the sports environment, acquiring sports knowledge, skills, spectating and other resources, which to a certain extent compensates for the dilemma of insufficient sports resources possessed by the underprivileged and assists in improving residents' sports and fitness awareness, concepts and behaviors (26). Media effects theory promotes that the media sports integrated by the Internet and sports has both social and individual communication effects: at the social level, sports media can generate the effects of sports environment cognition, sports fitness value formation and maintenance, and sports social behavior demonstration; at the individual level, sports media can cause changes in residents' sports cognition, sports attitudes, and sports behaviors, and this effect continuously accumulates, deepens and expands. However, the theory also reveals that there exists no direct relationship among individual cognition, attitude and behavior (27). In other words, the Internet medium can change residents' perceptions and attitudes toward physical fitness, without necessarily affecting their fitness behaviors. Consequently, media effects theory can account for the rapid development of sports media and the widespread use of smart sports devices in China without changing the physical fitness behavior of the residents, especially the youth group. Internet may be a positive, but not decisive, factor influencing residents' fitness behavior.

As an effective way of social interaction, the Internet is an alternative form of social capital acquisition (28, 29), indirectly influencing residents' physical fitness behavior. Social capital theory suggests that resources embedded in interpersonal social relationship networks play an important role in the achievement of individual behavioral goals, and that interpersonal interactions in real society are the principal way to obtain social capital, while online social networking, although different from the real social interactions, can also establish interpersonal relationships and may even obtain more superior and extensive social capital accumulation (30). As many types of research reveals, social capital accumulated from interactions in real society has a positive effect on residents' physical fitness behaviors (31, 32). However, with the continuous development of Internet information technology, depending on Internet social media to obtain social capital is gradually becoming a principal way to promote residents' physical fitness levels. Bian and Lei concluded that online socialization expands the characteristic heterogeneity, hierarchical breadth, and status of social interaction groups, thus contributing to the consolidation and expansion of both in-group and out-group social capital (33). They proposed the concept of online epidemic prevention social capital and verified the capital acquired by residents through the Internet medium during the epidemic had a significant positive effect on residents' physical fitness (34). Based on big data from 7 countries worldwide, Lu used methods of computational sociology to further empirically confirm the effectiveness of online social networking in enhancing the online fitness behavior of the residents, which has a positive effect on epidemic prevention and the health of the residents (10). In addition, in a study based on data from the 2012 China General Social Survey, Wang suggested that online media can not only expand the network size of social relationships, but also provide individuals with more social support and emotional comfort, which in turn is conducive to cultivating residents' physical exercise habits (35). Therefore, residents' behavior of Internet use may have exceeded the single function of searching for sports and fitness information and transferring resources, and become a critical tool for acquiring social capital, thus indirectly influencing residents' sports participation.

Scholars who support the time displacement effect claim that time spent on Internet crowds out time for physical fitness with negative effects on residents' fitness behavior. The time displacement effect hypothesis states that the total amount of disposable time is limited and there is a zero-sum relationship between the time occupied by various behaviors (36). On this basis, Robinson propose the functional equivalence hypothesis, which suggests that media with the same function or providing the same satisfaction are most likely to be displaced by new media (37). With the universalization and development of Internet technology, network media have a significant time displacement effect on mass media such as TV, radio, newspapers and books (38, 39), but the effect on individual behavior is associated with the type of daily activities (37). Some studies suggested that the Internet medium has a time displacement effect on children and adolescents' physical fitness behavior (40, 41). What's more, the effect of time displacement was also examined in research of the relationship between network media and social capital (42, 43). For instance, Putnam suggested that in1970's, hidden behind the phenomenon of "bowling alone" in the US is the fact that digital media have occupied people's public living space, resulting in less time for human interaction and social capital loss (44). However, it is still uncertain whether the time displacement effect of the Internet weakens the impact of social capital on physical fitness.

Above all, the Internet has a dual effect on residents' physical fitness behavior. In terms of the time displacement effect, there may be a time competition relationship between Internet and physical fitness, i.e., the increase in the duration of Internet use will crowd out the time of physical fitness. However, in regard to the social compensation effect, the Internet has a positive impact on residents' physical fitness behavior, in other words, the social compensation effect of the Internet media is reflected as a tool both for transferring sports information resources and obtaining social capital. Existing studies still have some limitations: firstly, studies mainly use cross-sectional data, which makes it difficult to examine the causal relationship between the Internet and physical fitness behavior; secondly, previous studies have focused on only one dimension of physical fitness frequency, time, and effectiveness, and rare studies have examined the effect of the Internet from multiple dimensions simultaneously; thirdly, different from the previous circumstances, the social interactions of Chinese residents are subject to the development of the epidemic under the regular prevention and control, and the existing studies have not examined and responded to the effects of social capital mechanisms. In addition, another significant reason for the influence of the Internet on physical fitness behavior is the transformation of residents' health anxiety and perceptions during the epidemic.

Health risk perception

With the progress of industrialization and urbanization in China, the characteristics of a "risk society" are emerging, and various "social risks" such as environmental pollution, food safety, and infectious diseases are reinforced by the Internet increasing the perceived health risks of the residents (45). In exploring the relationship between media use and individual behavior from the perspective of risk communication, scholars have proposed theories like "social amplification of risk" (46), "protection motivation theory" (47), and "media credibility" (48). However, the basic analytical framework of these theories is based on the logic of "information-perception-behavior." Thus, "perception" is an essential link between "information" and "behavior," in other words, health perception may be another pathway through which the Internet influence residents' physical fitness behavior.

To begin with, there is either a weakening or strengthening relationship between the Internet and health perceptions. According to studies on the weakening relationship, in contrast to traditional societies, people's perception of modern society is mainly obtained by the media, and the social amplification effect of the media on risk increases the level of social risk perception (49), and also the level of health risk perception (50). At the beginning of the outbreak, physical isolation allowed the Internet media to become an effective way for residents to follow the development of the epidemic, but the public and even experts had little knowledge and measures to effectively prevent and control the virus. The negative information that was amplified during the dissemination of the Internet media caused excessive public panic and health concerns, and the negative emotions of anxiety significantly increased the level of risk perception of residents' physical and mental health status, and even resulted in irrational crowds behaviors such as the "crazy purchasing of food and vegetables" and the "rush for Shuanghuanglian and Banlangen." Despite the fact that official media propaganda on epidemic prevention and control knowledge and measures has reduced the risk of social amplification effect of the Internet (48). However, once the new epidemic rebounded in a certain area, the social amplification effect of online media would again be prominent and influence the level of risk perception and health behavior of the residents. Research on strengthening relationships argues that Internet will facilitate residents' health perceptions. Compared to the social amplification theory of risk from the communicator's perspective, the "use and satisfaction" theory considers the exposure or use of media from the audience's position as a deliberate action based on one's own needs to meet specific individual needs (51). In a study on health perceptions of the elderly, He and Yuan found that the use of Internet media can satisfy the need for emotional communication and thus have a significant positive impact on the physical and psychological health perceptions of the elderly (52). Wang identified that the use of online media can reduce stress and tension from daily issues, help individuals access more health information and medical resources, and thus improve their perception of health (35). Despite the fact that some studies have questioned this view (53), it is undeniable that media socialization was an effective complement to daily social activities during the epidemic, which contributed to a decrease in loneliness and emotional enrichment among the elderly population (54, 55).

Moreover, the impact of health risk perception on physical fitness has also been focused on and discussed by scholars. The behavioral theory holds that health perceptions, attitudes, motivation, self-efficacy, and self-identity are all major factors influencing physical activity and can predict, to varying degrees, individual physical fitness levels (56). The Health Belief Model proposes that individuals have the confidence and ability to change undesirable behaviors when they are in fear of the current malpractice and are convinced that they will derive more benefit (56). With the arrival of the "risk society" and the fast-paced lifestyle, people are increasingly aware of the importance and urgency of health, and the perception of health status has become an crucial subjective factor influencing individual sports participation in the "post-epidemic" era (11, 57). Huang et al. theoretically explores the logic between the social mindsets triggered by Internet media during the epidemic, such as public panic and anxiety, and the action of physical fitness, suggesting that the health concerns of the public and the introspection of their own behavior are rational expressions of the social action of physical fitness to resolve social anxiety (24). It is suggested that health risk perceptions significantly promote physical activity among adolescents (58) and play an important mediating role in the relationship between self-efficacy and physical activity (59). Based on the above analysis, this study consider that the health risk perception may be another important mechanism through which the Internet influence physical fitness behavior.

Materials and methods

Data sources

The research data in this paper comes from the China Family Panel Studies (CFPS) database, conducted by Institute of Social Science Survey, Peking University and the survey was conducted every 2 years since 2010. In the four surveys from 2014 to 2020, CFPS collected data from three levels, individual, household, and community, among which the data of respondents' physical fitness, Internet use, social participation, health status evaluation, and demographic characteristics provided precious information for this study to explore the causal analysis and mechanism of Internet use and physical fitness. Unfortunately, only individual-level data of CFPS2020 are available, which cannot be effectively matched with household-level data in other surveys, and the questionnaires on Internet use and physical fitness behavior are designed with a different format from other surveys. Hence, in order to reduce the measurement error and ensure the authenticity and reliability of the results, this study selected the data of 23,989 samples successfully followed in all three surveys of CFPS from 2014 to 2018 to explore the causal effect of the relationship between the Internet and physical fitness; meanwhile, the data of 24,687 samples in CFPS 2020 to examine the mechanism of the Internet's effect on residents' physical fitness behavior. The characteristic of the selected data is consistent with the assumptions of cross lagged models, which are contemporaneity, smoothness, and period effects. First, the CFPS data used in this paper contain data for three periods, 2014, 2016, and 2018. Second, each variable is measured at the same scale and occurs within the same period. Cross lagged models are an important method of causal inference and are widely used in panel data analysis. Michael W. Kearney describes the principles for this method of causal inference in detail in his article Cross Lagged Panel Analysis.

Variable selection

Dependent variable

The current academic measurement of physical fitness includes three main dimensions: frequency, time, and effectiveness, and the selected dependent variables are the frequency, duration, and effectiveness of residents' physical fitness. The question in the questionnaire of CFPS2014, 2016, and 2018 is "How many times have you participated in physical fitness in the past week?" and "How long did you participate in physical activity in total?"; the range of answers for the frequency of fitness is 0 to 21 times/week, and the range of answers for the time of fitness is 0.1 to 105 h/week. However, there were no results on fitness effectiveness in the survey. The CFPS 2020 survey inquired about the frequency, time, and effectiveness of physical fitness in the past year. The answer to the question of frequency is "(1) <1 time per month on average," "(2) More than 1 time per month on average, but <1 time per week," "(3) 1–2 times per week on average," "(4) times per week on average," "(5) times per week and above on average," "(6) 1 time per day on average," "(7) Twice a day and above on average," and "(8) Never participate." This study re-codes and re-assigns the above answers, options 1 and 8 are assigned as 0 "Never participate," options 2 and 3 are assigned as 1 "Low," options 4 and 5 are assigned as 2 "Middle," and options

6 and 7 are assigned as 3 "High." The duration of physical fitness ranges from 1 to 300 min per day. The answer of effectiveness is "breathing and heart rate do not change much," "increased breathing, heart rate, slight sweating," and "Shortness of breath, significantly faster heartbeat, more sweating," which are coded and assigned as (1) "average," (2) "good," and (3) "excellent," respectively.

Independent variable

The independent variable of this study is whether to use the Internet, including mobile Internet access and computer Internet access. A respondent is considered to be using the Internet medium if he or she uses any of the methods to access the Internet and is assigned as 1. If not, assigned as 0. The independent variable is defined as "Internet use." Meanwhile, CFPS 2014–2018 investigated residents' average time spent online per week, while CFPS 2020 surveyed residents' time spent online per day. Therefore, this study standardizes the unit of Internet access time as "hours per week" and takes its logarithmic value, which is defined as Internet duration.

Mediator variable

The selected mediator variables are social capital and health risk perception, as is showed in Table 1. Participation in social organizations is an important indicator of an individual's social capital, which is measured by the question "which of the following organizations do you currently participate in?". A total of 5 social organizations were selected, and respondents will be assigned as 1 if they were a member of any of these organizations, and 0 if they were not. This study refers to Sherbourne's measure of assessing health risk perception and selects the question "Do you think your health is excellent, very good, good, not bad, or poor" (60). Also, eight questions from the Center for Epidemiological Studies-Depression (CES-D) scale are selected and summed to measure the perception of psychological health risk. The higher the two variables indicate a higher level of health risk perception. It should be clarified that the CFPS 2014 does not include the CES-D depression scale.

Controlled variables

Referring to the previous literature, this study selects control variables including age, gender, marital status, years of education, household income per capita, urban-rural residence, and BMI, among which the per capita household income is logarithmically processed. The results of the coding value and descriptive statistics of each variable are shown in Table 1.

Model selection

Table 1 shows the changing trends in Internet use, time spent and physical fitness behavior of Chinese residents. Compared with 2014, the percentage of Internet use among residents in 2020 has increased by 18.27% and the average weekly usage time has risen over 50%. The frequency and time of physical fitness among residents also show an upward trend from 2014 to 2018, but the proportion of residents who do not participate in physical fitness is close to 66% in 2020, and <15.6% insist on daily fitness. There also exists slight fluctuations in the social capital and health perceptions possessed by residents around the time after the outbreak of the COVID-19 epidemic, but the overall trend is on the rise. In addition, it is noteworthy that variables that shift over time are not entirely individual and may be influenced by changes over time in sample size or other factors. Under such circumstances, conventional mixed regression models may not accurately estimate the relationship between Internet and physical fitness behavior, resulting in incorrect research findings. Therefore, this study firstly applies the Time Fixed Effects Model to address the problem of omitted variables that vary with individuals and control for the effect of confounding structural variables that vary with year. Then, this study utilizes the Cross Lagged Panel Model to examine the causal relationship between the Internet and physical fitness behavior by maximum likelihood estimation method. Finally, this study verifies the mediating role of social capital and health perceptions in the relationship between the Internet and physical fitness behavior through the KHB model.

Results

Time fixed effects model

To examine the effects and duration of Internet use on the frequency and time of physical fitness residents, respectively, six models were constructed and the effects of time-varying factors and confounding bias caused by individual factors were controlled for by incorporating time dummy variables and relevant individual factors for the survey years, and the regression results are shown in Table 2. In terms of fitness frequency, the results of model 1 indicate that Internet use can positively influence fitness frequency compared with residents who do not use the Internet; the results of models 2 and 3 show that there is no linear but non-linear relationship between the Internet duration and fitness frequency, and fitness frequency presents a trend of first decreasing and then increasing with the rise in using duration. This suggests that Internet use has a social compensation effect on residents' physical fitness behavior. In regard to fitness time, the results of model 4 demonstrate that Internet use does not significantly increase fitness time compared to residents without using the Internet; however, the results of model 5 show that Internet use duration has a significant positive correlation with fitness time, yet a non-linear relationship between the two is not found in model 6, suggesting that the time displacement effect of Internet use on residents' physical fitness behavior is not verified. The above results reveal the relationship between residents' Internet use and physical fitness behavior and the differences in their effects. However, the relationship may be influenced by unobserved omitted variables, such as spatial differences in Internet penetration in China (60, 61), and thus no accurate judgment can be made about the causal relationship.

Cross lagged panel model

This study employs a cross lagged panel model to further estimates the causal relationship between Internet use and physical fitness behavior. The model is currently an important method widely used to explore causality. Based on panel data of two or more periods, it estimates the cross-period effects of variables on the basis of the predicted contemporaneous correlations between variables and self-correlation of variables (i.e., controlling for contemporaneous

TABLE 1 Descriptive statistical results of variables.

Categories	Variable	2014 (*N* = 22,471)	2016 (*N* = 22,540)	2018 (*N* = 21,707)	2020 (*N* = 23,872)
Dependent variable	Frequency	1.85 (2.93)	2.18 (3.08)	2.68 (3.29)	
	Never participate = 0				63.64
	Low = 1				15.03
	Middle = 2				7.45
	High = 3				15.6
	Time	1.58 (0.98)	1.67 (0.98)	1.70 (0.98)	3.86 (0.65)
	Effectiveness				
	Average = 1				20.21
	good=2				48.89
	Excellent = 3				30.9
Independent variable	Internet use				
	Not use = 0	71.34	61.66	52.31	34.01
	Use=1	28.66	38.34	47.69	65.99
	Internet duration	2.03 (0.99)	2.09 (1.07)	2.16 (1.07)	4.81 (1.33)
Mediator variable	Social capital (participate in organization = 1)	14.99	26.99	22.16	26.28
	Physical Health risk perception (1–4)	2.98 (1.25)	3.11 (1.23)	3.13 (1.24)	2.81 (1.20)
	Psychological health risk perception (8–32)	—	13.20 (3.91)	13.56 (4.05)	13.44 (4.03)
Controlled variables	Age (9–100)	46.29 (16.38)	48.39 (16.32)	50.30 (16.38)	42.51 (18.29)
	Gender (male = 1)	49.4	49.41	49.37	50.42
	Marital status (married = 1)	80.82	81.47	76.11	70.54
	Years of education (0–24)	7.28 (4.69)	7.35 (4.80)	7.52 (4.91)	8.61 (4.58)
	Household income per capita	9.04 (1.18)	9.39 (0.99)	9.56 (1.20)	—
	Urban = 1	44.46	45.84	48.11	49.82
	BMI (1–4)	2.28 (0.71)	2.32 (0.72)	2.36 (0.72)	2.31 (0.78)

effects and time-period variance), in other words, it determines the causal effects between the independent variables by estimating the significance of the effect parameter β1 of the dependent variable in the previous period on the dependent variable in the latter period and the effect parameter β2 of the dependent variable in the previous period on the independent variable in the latter period (62). The assumptions of the model include: each measured variable occurs at the same time period; the relationship between variables remains consistent over time (especially for three and more periods), and the length of the period should not be set too long or too short, etc. According to the assumptions of the model, the variables of "Internet use," "Internet duration" and fitness "frequency" and "time" with the same measurement scale in the survey data of 2014, 2016, and 2018 were selected for this study, and other characteristic variables that could cause confounding bias within the same period were controlled. After accepting the autocorrelation of inter- and intra-group variables across time, the estimated results of the causal relationship between residents' Internet use and physical fitness behavior are shown in the Figures 1, 2.

The analysis results of Internet use and fitness frequency are presented in Figure 1. At first, both Internet use and fitness frequency show significant autocorrelations, with stronger positive correlations between Internet use than fitness frequency in the two consecutive periods. Secondly, the results of the model analysis constructed with three temporal points of Internet use and fitness frequency reveal that the first and second measure of Internet use significantly predict the second and the third measure of fitness frequency ($\beta_{t-1} = 0.221$, $p < 0.001$; $\beta_{t-2} = 0.201$, $p < 0.001$). While the first measure of fitness frequency does not significantly predict the second measure of Internet use ($\beta_{t-1} = -0.001$, $p > 0.1$), and the impact of the second measure of fitness frequency on the third measure of Internet use was only negative significant at the 0.1 level ($\beta_{t-2} = -0.002$, $p < 0.1$). This is consistent with the results of the previous analysis, thereby further suggesting that Internet use is responsible for the increase in the frequency of fitness among residents.

The results of the analysis of Internet duration and fitness time are illustrated in Figure 2. Similar to fitness frequency, fitness time and Internet duration indicate a significant autocorrelation. In terms of causal direction, the first measure of Internet duration negatively predicts the second fitness time at a significant level of 0.1 ($\beta_{t-1} = -0.032$, $p < 0.1$), while the second measure of Internet duration has a non-significant effect on the third measure of fitness time

TABLE 2 The influence of Internet on the frequency and time of residents' physical fitness.

Variable	Fitness frequency			Fitness time		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Internet use	0.278***			0.007		
Internet duration		−0.004	−0.098*		0.055***	0.029
Internet duration squared			0.026*			0.008
Social capital	0.270***	0.122**	0.122**	0.004	−0.03	−0.029
Physical health risk perception	−0.058***	−0.045*	−0.045*	−0.016*	0.009	0.009
Psychological Health risk perception	0.001	−0.022***	−0.022***	−0.006**	−0.008*	−0.008*
Age	−0.048	−0.125**	−0.124**	0.019	0.029	0.03
Age squared	0.001***	0.003***	0.003***	0	0	0
Gender (male = 1)	−0.069	−0.376	−0.367	−0.075	1.470***	1.476***
Marital status (Married = 1)	−0.160*	−0.267**	−0.264**	−0.089*	−0.12	−0.117
Years of education	−0.063***	−0.025	−0.026	−0.021*	−0.027*	−0.027*
Household income per capita	−0.026	0.01	0.01	0.022**	0.026	0.026
Urban = 1	0.093	0.091	0.093	0.031	0.049	0.049
BMI	0.037	−0.011	−0.013	0.019	−0.011	−0.012
2016	0.148*	0.411***	0.406***	0.145***	0.126	0.125
2018	0.494***	0.586***	0.579***	0.162**	0.106	0.103
Intercept	1.956	3.086*	3.112*	1.096	−0.379	−0.386
R2	0.033***	0.100***	0.110***	0.048***	0.018***	0.018***
N	66,708	25,443	25,443	27,934	12,746	12,746

Standard errors have been omitted for simplicity of presentation.
*p < 0.1, **p < 0.05, ***p < 0.01.

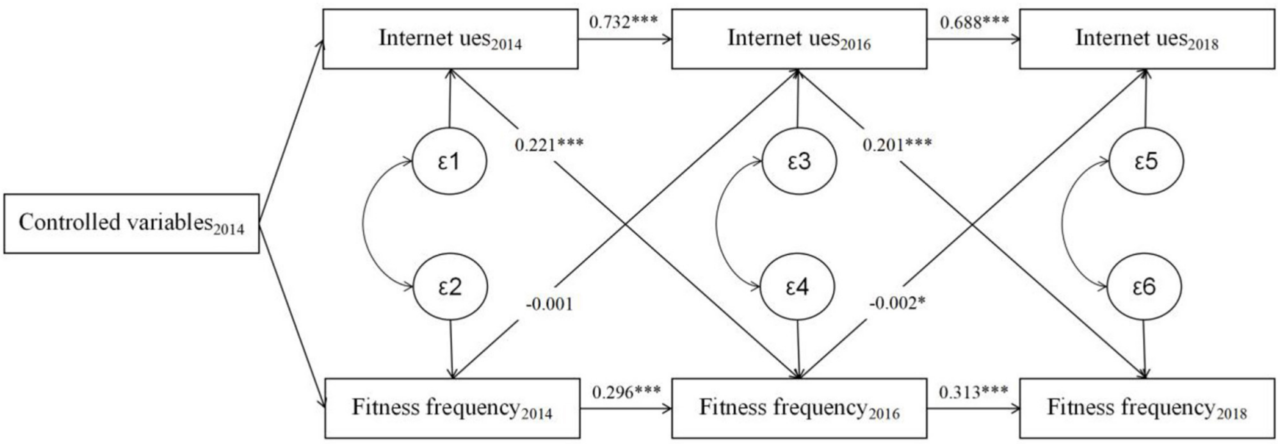

FIGURE 1
The estimation of the cross lagged panel model of the internet use and physical fitness frequency.

($\beta_{t-2} = 0.008$, $p > 0.1$). However, the first and second measures of fitness time significantly and negatively predict the second and third measures of Internet duration ($\beta_{t-1} = -0.107$, $p < 0.001$; $\beta_{t-2} = -0.133$, $p < 0.001$), suggesting that the decrease in fitness time is responsible for the increase in Internet duration; in other words, the increase in physical fitness time significantly reduces Internet duration.

The results of the cross lagged model verified the causal relationship between Internet and physical fitness behavior, thus further indicating the existence of social compensation and time displacement effect of Internet on physical fitness behavior. Firstly, there is a rivalry between fitness time and Internet duration, where an increase in the former reduces the latter. Secondly, compared to residents who do not use Internet, users' social compensation effects

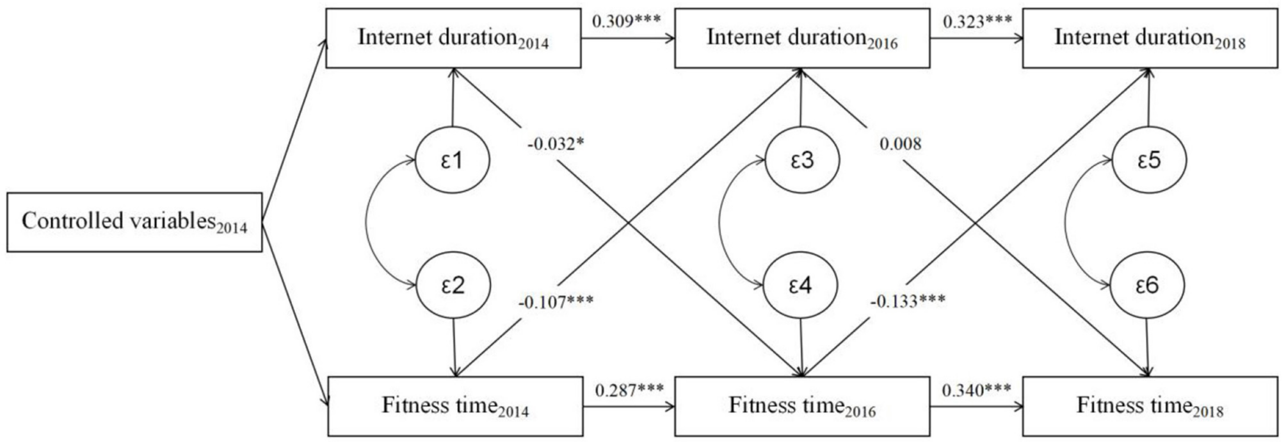

FIGURE 2
The estimation of the cross lagged panel model of the internet duration and physical fitness time.

have a positive impact on their physical fitness behavior. This study will further analyze the mechanism of the social compensation effect brought by the Internet on physical fitness behavior.

Functional mechanism of Internet use in influencing residents' physical fitness behavior

Based on the previous theoretical discussion and the CFPS2020 cross-sectional data, this study verified the role of social capital and health risk perceptions in influencing the physical fitness behavior of residents through the Internet in the context of regular epidemic prevention and control. Since fitness frequency and effectiveness are ordered categorical variables in the CFPS2020, this paper first applied Ologit estimation method to construct a multivariate nested model to examine the relationship between Internet use, social capital, health risk perception and physical fitness behavior, and then conducted a mediating effect test by KHB analysis. The advantage of KHB analysis is that it can be adopted in mediating effects analysis of nonlinear logistic regression models to compare the estimated coefficients of the same sample of nested models, so as to effectively estimate and test the mediating effects (63).

As indicated in Table 3, Internet use can also significantly increase residents' fitness frequency and effectiveness after controlling for the same individual characteristic variables in the previous section. Specifically, the frequency and effectiveness of fitness are 91.3 and 17.1% higher for residents who use the Internet than for non-users. After adding social capital and health risk perceptions to models 1 and 5, respectively, the results of models 2 and 6 indicate that social capital has a significant positive effect on the increase of fitness frequency of residents, but not on the effectiveness. Models 3 and 7 suggest that the lower the perception of psychological health risks, the higher the frequency of fitness; the higher the perception of physical and psychological health risks, the better the fitness effectiveness is. As can be seen from Models 4 and 8, when both social capital and health risk perception variables are included, residents with higher social capital and psychological health risk perceptions have higher fitness frequency. Higher the physical and psychological health risk perceptions result in better fitness, but social capital has no significant effect on the fitness effect. With the use of Internet, the odds ratio of fitness frequency among residents decreased by 1.9%, but there is an increase of 1.7% in the odds ratio of fitness effectiveness. The result suggests a possible mediating effect of social capital and health risk perceptions between Internet use and residents' fitness behavior, which will be further examined by this study through KHB analysis method.

The results of the KHB test for the mediating variables and their decomposition effects are listed in Table 4. Social capital and health risk perceptions exert mediating effects in the relationship between Internet use and fitness frequency, but no mediating effect is found in the effect of Internet use on fitness effectiveness. After simultaneously including the three mediating variables of social capital, physical and psychological health risk perceptions in the main effects model, the direct effect of Internet use on fitness frequency is significantly reduced by 0.0159, resulting in indirect effects of 0.0046, 0.0003 and 0.0106, at the individual contribution rate of 30.56, 0.22, and 69.27%, respectively. The contribution rate of psychological health risk perception is higher than that of social capital, and the rate of physical health risk perception is the lowest. After adding the three mediating variables separately in the main effects model, only the mediating effect of psychological health risk perception is significant with a separate contribution rate of 2.16%, while the mediating effect of the rest was not significant. The results indicate that the social compensation effect of Internet use on residents' fitness behavior is mainly reflected in the increase of social capital and the decrease of health risk perceptions, while under the regular prevention and control of the epidemic, residents' psychological health risk perceptions are a critical mechanism for media use to affect fitness behavior.

Discussion

In this study, we applied the first 3 years of CFPS data to explore the casual effect of Internet use and residents' physical fitness. With the data from CFPS2020, we further explored the

TABLE 3 The influence of the Internet on the frequency and fitness effect of residents' physical fitness under regular epidemic prevention and control.

Variable	Fitness frequency				Fitness effectiveness			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Internet use	1.913***	1.910***	1.896***	1.894***	1.171**	1.171**	1.188**	1.188**
Social capital		1.304***		1.332***		0.98		0.985
Health risk perception								
Physical Health risk perception			0.987	0.988			1.065***	1.065***
Psychological health risk perception			0.894***	0.895***			1.249***	1.249***
Age	0.923***	0.921***	0.928***	0.927***	1.007	1.007	0.990	0.991
Age squared	1.001***	1.001***	1.001***	1.001***	1.000***	1.000***	1.000**	1.000**
Gender (male = 1)	1.071**	1.076***	1.053*	1.059**	1.292***	1.292***	1.341***	1.341***
Marital status (Married = 1)	0.685***	0.713***	0.664***	0.690***	0.945	0.942	1.008	1.006
Years of education	1.570***	1.494***	1.552***	1.477***	0.946*	0.949*	0.977	0.979
Urban = 1	1.740***	1.737***	1.725***	1.722***	1.094**	1.094**	1.109**	1.109**
BMI	1.065***	1.066***	1.063***	1.063***	1.225***	1.225***	1.229***	1.229***
R2	0.055***	0.057***	0.057***	0.058***	0.033***	0.033***	0.041***	0.041***
N	23,872	23,872	23,872	23,872	9,073	9,207	9,207	9,207

The coefficient estimate is Exp.
Standard errors have been omitted for simplicity of presentation.
*p < 0.1, **p < 0.05, ***p < 0.01.

functional mechanism of the Internet on residents' physical fitness behavior under the regular prevention and control of the COVID-19 epidemic from two dimensions: social capital and health risk perception. We obtained three valuable conclusions as follows: First, there is a significant correlation between the Internet and physical fitness behavior. Second, the Internet use is the cause for the increase in fitness frequency, and there is a rival relationship between Internet duration and fitness time. Third, under regular prevention and control of the COVID-19 epidemic, social capital and health risk perceptions are the functional mechanisms of the Internet influencing fitness behavior, and the mediating effect of psychological health risk perceptions is higher than that of social capital.

During 2014–2018, Chinese residents' Internet use and physical fitness behavior both showed an increasing trend, with the proportion of people using mobile devices such as cell phones and computers to access the Internet increasing from 28.66 to 65.99%, and the duration of usage increasing from 11.7 to 25 h per week. Physical fitness frequency and time increased from 1.8 times/week and 7.8 hours/week in 2014 to 2.7 times/week and 9.0 h/week in 2018, respectively, but the proportion of people who participated in 1 time or more decreased in 2020, and fitness time maintained at 1 h/time. The results of the fixed effects model confirms the "media mobilization theory" (14, 15) proposed in previous studies. Both Internet use and duration have a significant positive effect on fitness behavior, but there is no significant difference in the time spent on fitness whether or not they use Internet; nor do increase the time spent on Internet significantly raise the frequency of fitness. Thus, it can be seen that the effect of the Internet on fitness behaviors may vary in findings due to differences in concept measurement, which may partially explain the "media suppression theory" that has been upheld by previous empirical studies (16, 17).

In contrast to previous studies, the CFPS data used in this study allowed us to explore the causal relationship between the Internet and fitness behaviors. The results of the cross-lagged panel model reveal that the use of Internet significantly and positively predicts the frequency of fitness; while the Internet duration negatively predicts the fitness time and vice versa. This demonstrates that the influence of Internet use on fitness behavior has both a "time displacement effect" and a "social compensation effect." In terms of fitness time, as the total amount of time is limited, increasing the time spent on Internet use will inevitably be at the cost of decreasing the time spent on fitness, and in turn, increasing the time spent on fitness will also certainly reduce the time spent on Internet use, therefore, this study supports the "time displacement effect hypothesis" of the Internet. Internet media also has an important "social compensation effect" on fitness frequency. Previous studies have suggested that the social compensation mechanism of the Internet is mainly reflected in its significant role in shaping the social environment of sports, accessing fitness information and resources, and altering fitness attitudes and motivation (19, 20). The disadvantaged can use the Internet to compensate for the insufficient possession of social sports resources and thus promote their fitness behavior (26). However, this study suggests that with the extensive use of Internet information technology, residents' Internet use behavior may have exceeded the single function of searching or delivering sports information, and may be more likely to become an effective tool for social interaction and health risk perception, further shaping residents' fitness behavior.

Although it has been shown that epidemic prevention social capital formed through the Internet during the physical isolation of the COVID-19 epidemic had a significant effect on physical fitness (9, 10, 34). This study show that when the mediating effects of social capital and health risk perceptions were examined simultaneously,

TABLE 4 Mediating effects test based on the KHB.

Variable	Fitness frequency			Fitness effectiveness		
	Social capital	Physical health risk perception	Psychological health risk perception	Social capital	Physical health risk perception	Psychological health risk perception
Total effects	0.649***	0.649***	0.649***	0.171**	0.171**	0.171**
Direct effects	0.644***	0.649***	0.635***	0.158**	0.175**	0.189***
Indirect effects	0.005	0	0.014**	0	−0.004	−0.018
Separate contribution rate	—	—	2.16%	—	—	—
Individual contribution effect	0.005	0.0003	0.0106	—	—	—
Individual contribution rate	30.56%	0.22%	69.21%	—	—	—

Standard errors have been omitted for simplicity of presentation.
**$p < 0.05$, ***$p < 0.01$.

the contribution of social capital in the total mediating effect is 30.56%, which is lower than the 69.27% contribution of psychological health risk perceptions. When the mediating effects of social capital and health risk perceptions are examined separately, the mediating effect of social capital is not significant, while the mediating effect of psychological risk perceptions is, but only accounted for 2.16% of the total. This study suggests that online and face-to-face social interaction are two forms of social capital accumulation, and that the Internet is an effective way for residents to interact with the outside world and to achieve social capital during the epidemic isolation period, however, as for the regular prevention and control of the epidemic, real social interaction may still be the main way to maintain and develop social capital. Therefore, due to the impact of the regular prevention and control of COVID-19 epidemic, the mediating role of social capital in influencing fitness behavior through online media is diminished. The mediating effect of psychological health risk perceptions is stronger than that of physical health risk perceptions, and although the separate contribution of physical health risk perceptions is not significant, the mediating effect of psychological health risk perceptions is. On one hand, the health threat of the epidemic is intensified by the "amplification effect of the risk society" of the Internet, which in turn motivates residents to pay more attention to healthy lifestyles, especially physical fitness; on the other hand, the psychological impacts of the epidemic are more extensive, longer-lasting, and more easily perceived than the physical ones. With the virus becoming less severe and the effective implementation of China's epidemic prevention and control policy, the daily life of residents gradually returns to normal and the perception of physical health risk will gradually decrease, but the perception of psychological health risk could hardly diminish in a short period of time.

There are some limitations to be interpreted. First, due to data limitations, we could only measure the concept of "Internet" in two dimensions: "Internet use" and "Internet duration," which would generalize the findings of this study. Second, the sample of this study included three social groups adolescents, middle age, and the elderly. Thus, this study examined the causal relationship and mechanism of action between online media and residents' fitness behavior from a general perspective without considering the issue of age heterogeneity. For this reason, the total mediating effect of social capital and health risk perception was low when the mediating effect was tested.

Despite these limitations, our study revealed the causal relationship and functional mechanism between the Internet and physical fitness in terms of theoretical derivation and data validation. Therefore, it also provides practical recommendations for future work. First, We should accelerate the deep integration of "Internet + fitness" and optimize the function of sports media in promoting scientific fitness knowledge, skills and methods. Sports media is an achievement of integrating and developing the Internet and sports and has played an essential role in sports communication. However, the current content of sports media communication is based on the broadcast of major international and domestic sports events. Very little content is disseminated for scientific sports and fitness knowledge, skills and methods. Although we can search for the fitness content we need in online media, it lacks authority and may have a negative impact on residents' physical fitness. Second, we need to reasonably allocate time for Internet use, avoid the time displacement effect, promote the effect of social capital accumulation and avoid the effect of health risk perception. With the rapid growth of global Internet penetration, the online medium has become an essential way of online services such as online shopping, payment, education, medical care, and social interaction in developed and developing countries. However, the total amount of individuals' time is limited, and prolonged physical behavior on the online medium shortens the time spent on physical fitness. Compared to the time displacement effect of the Internet, the social capital accumulation effect facilitates residents' fitness behavior. Although this study found that the mediating effect of risky health perceptions was greater than that of social capital in Internet influences on physical fitness during the particular period of COVID-19, as the impact of the epidemic continues to decrease, social capital could still be an essential functional mechanism for the Internet to influence physical fitness behavior.

Conclusion

This study explored the causal relationship and functioning mechanism of Internet and physical fitness behavior. We found that there is a significant correlation between the Internet and physical fitness behavior, the Internet use is the cause for the increase in fitness frequency, and there is a rival relationship between Internet duration and fitness time. Moreover, under regular prevention and control of the COVID-19 epidemic, social capital and health risk perceptions are the functional mechanisms of the Internet influencing fitness behavior, and the mediating effect of psychological health risk perceptions is higher than that of social capital. At the same time, we also observed a relatively moderate effect of Internet on fitness behavior. Therefore, how to further create an intelligent, informative and digital sports public service system *via* enriching and optimizing sports medium, and facilitate the Internet to better serve the residents' physical fitness is a theoretical and practical topic that should be focused in the future.

Data availability statement

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

Ethics statement

The studies involving human participants were reviewed and approved by Ethics Committee of the School of Xi'an Jiaotong University. The patients/participants provided their written informed consent to participate in this study.

Author contributions

LZ: conceptualization. CL and LZ: data collection, writing–original draft, and writing–review and editing. CY: methodology and supervision. ZL: writing–review and editing. YZ: supervision. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

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

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References

1. Committee HCAP. *Healthy China Initiative (2019–2030)* (2019). Available online at: http://www.gov.cn/xinwen/2019-07/15/content_5409694.htm (accessed January 4, 2023).

2. Charlotte VT. Macro-environmental factors associated with leisure-time physical activity: a cross-national analysis of EU countries. *Scand J Public Health.* (2011) 39:419–26. doi: 10.1177/1403494810396553

3. Li DM. Realistic dilemma and development countermeasures of mass fitness public sports space supply in China. *J Shenyang Sport Univ.* (2022) 41:83–9.

4. Ruseski JE, Maresova K. Economic freedom, sport policy, and individual participation in physical activity: an international comparison. *Contemp Econ Policy.* (2014) 32:42–55. doi: 10.1111/coep.12027

5. Andersen PL, Bakken A. Social class differences in youths' participation in organized sports: what are the mechanisms? *Int Rev Sociol Sport.* (2018) 54:921–37. doi: 10.1177/1012690218764626

6. Xu W, Zhu YJ. The trend of sports participation stratification and Its Influencing factors. *J Sports Res.* (2020) 34:77–86. doi: 10.15877/j.cnki.nsic.20200305.001

7. Chang G, Liu J. Analysis of factors related to adolescents' physical activity behavior based on multichannel LSTM model. *Comput Intel Neurosc.* (2022) 2022:1–8. doi: 10.1155/2022/1022421

8. Bian YJ. Epidemic-specific social capital and its impact on physical activity and health status. *J Sport Health Sci.* (2020) 9:426–9. doi: 10.1016/j.jshs.2020.07.009

9. Bian YJ, Miao XL, Lu XL, Ma XL, Guo XX. The emergence of a COVID-19 related social capital: the case of China. *Int J Sociol.* (2020) 50:419–33. doi: 10.1080/00207659.2020.1802141

10. Bian YJ, Lu XL. The anti-pandemic effect of online fitness and online social networking:an empirical analysis of cross-national big data. *J Xi'an Phys Educ Univ.* (2021) 38:641–51. doi: 10.16063/j.cnki.issn1001-747x.2021.06.001

11. Wang ZH. Consensus crisis and self-enlightenment: value dimension of mass sports participation in the post-pandemic era. *J Shenyang Sport Univ.* (2022) 39:1–8.

12. China GAOS. *Research Report on the Home Fitness Status of Urban and Rural Residents in Zhejiang Province During Covid-19 Epidemic*. Available online at: https://www.sport.gov.cn/n20001280/n20745751/n20767239/c21469502/content.html (accessed January 4, 2023).

13. Bauman A, Chau J. The role of media in promoting physical activity. *J Phys Activity Health.* (2009) 6:196–210. doi: 10.1123/jpah.6.s2.s196

14. Braumüller B. Young adults'perceptions of the relevance of interaction on social online networks for sports activities. *Eur J Sport Soc.* (2020) 17:231–49. doi: 10.1080/16138171.2020.1792072

15. Hayes M. Social media and inspiring physical activity during COVID-19 and beyond. *Manag Sport Leis.* (2020) 27:14–21. doi: 10.1080/23750472.2020.1794939

16. Kaiser-Jovy S, Scheu A, Greier K. Media use, sports activities, and motor fitness in childhood and adolescence. *Wien Klin Wochenschr.* (2017) 129:464–71. doi: 10.1007/s00508-017-1216-9

17. O'Connor TM, Chen T, Baranowski J, Thompson D, Baranowski T. Physical activity and screen-media–related parenting practices have different associations with children's objectively measured physical activity. *Child Obes.* (2013) 9:446–53. doi: 10.1089/chi.2012.0131

18. Sarah S, Filip M, Alexander W, Hajo Z. Do media use and physical activity compete in adolescents? Results of the MoMo study. *Plos ONE.* (2015) 10:1–14. doi: 10.1371/journal.pone.0142544

19. Boyle R, Haynes R. Sport, public relations and social media. In: *Routledge Handbook of Sport and New Media.* London: Routledge (2014).

20. Cavill N, Bauman A. Changing the way people think about health-enhancing physical activity: do mass media campaigns have a role? *J Sport Sci.* (2004) 22:771–90. doi: 10.1080/02640410410001712467

21. Wilson B. New media, social movements, and global sport studies: A revolutionary moment and the sociology of sport. *Sociol Sport J.* (2007) 24:457–77. doi: 10.1123/ssj.24.4.457

22. Bian YJ. Social capital and grassroots sport. *J Shanghai Univ Sport.* (2020) 44:1–11. doi: 10.16099/j.sus.2020.04.001

23. Bian YJ, Lu XL. Theoretical construction and practical significance of sport social capital. *J Shanghai Univ Sport.* (2022) 46:1–11. doi: 10.16099/j.sus.2021.12.26.0005

24. Huang YL. Sociological review of relieving social anxiety through sports action during the epidemic of COVID-19. *J Chengdu Sport Univ.* (2020) 46:8–15. doi: 10.15942/j.jcsu.2020.04.002

25. Booker CL, Skew AJ, Kelly YJ, Sacker A. Media use, sports participation, and well-being in adolescence: cross-sectional findings from the UK household longitudinal study. *Am J Public Health.* (2015) 105:173–9. doi: 10.2105/AJPH.2013.301783

26. Zhang L, Li CT, Zeng YH, Ma B, Jin YZ. Impact of network media use on the sports participation behavior of Chinese residents—an empirical study based on CGSS2017 data. *J Phys Educ.* (2022) 29:54–61. doi: 10.16237/j.cnki.cn44-1404/g8.2022.05.014

27. Liu HL. *Mass Communication Theory: Paradigms and Schools*. Beijing: China Renmin University Press. (2008).

28. Huang RG, Luo TY, Gui Y. The impact of the internet on social capital: an empirical study based on internet access activities. *Jianghai Acad J.* (2013) 55:227–33.

29. Zhang QS, Wang XG. Media usage and social capital accumulation: based on media effects perspective. *Chin J Commun.* (2021) 43:139–58. doi: 10.13495/j.cnki.cjjc.2021.10.007

30. Lin N. *Social Capital-A Theory of Social Structure and Action*. Shanghai: Shanghai People's Publishing House. (2005). p. 18.

31. Ueshima K, Fujiwara T, Takao S, Suzuki E, Iwase T, Doi H, et al. Does social capital promote physical activity? A population-based study in Japan. *PLoS ONE.* (2010) 5:1–6. doi: 10.1371/journal.pone.0012135

32. Zhang XL, Huang Q. The theoretical analysis of the influence and action path of social capital on physical fitness. *J Xi'an Phys Educ Univ.* (2018) 35:657–62.

33. Bian YJ, Lei M. Between virtual and social realities: the transformation of online and offline forms of social capital. *Jilin Univ J Soc Sci Edn.* (2017) 57:81–91.

34. Miao XL, Bian YJ. Epidemic-specific social capital, physical activity and health status. *J Shanghai Univ Sport.* (2020) 44:1–12. doi: 10.16099/j.sus.2020.12.001

35. Wang YC, Wang XY. The positive influence of internet on personal health and its formation mechanism: the role of social network. *J East China Univ Sci Technol.* (2022) 37:66–80.

36. Robinson JP, Godbey G. *Time for Life: The Surprising Ways Americans Use Their Time*. University Park, MD: Penn State Press (1997).

37. Robinson JP, Kestnbaum M, Neustadtl A, Alvarez A. Information technology and functional time displacement. *IT Soc.* (2002) 1:21–36. doi: 10.1093/acprof:oso/9780195312805.003.0005

38. Ha L, Fang L. Internet experience and time displacement of traditional news media use: an application of the theory of the niche. *Telemat Inform.* (2012) 29:177–86. doi: 10.1016/j.tele.2011.06.001

39. Yu GM, Xu ZH, Zhao XQ. Impact of the internet on time spent on traditional media. *Mod Commun.* (2013) 35:105–10.

40. Braumüller B, Hartmann-Tews I. Jugendliche als mediatisierte Stubenhocker? Eine Analyse der Zusammenhänge zwischen sportlichem und medialem Handeln von Jugendlichen aus Geschlechterperspektive. *J Child Adolesc Res.* (2017) 12:11–2. doi: 10.3224/diskurs.v12i1.05

41. Marshall SJ, Biddle SJ, Gorely T, Cameron N, Murdey I. Relationships between media use, body fatness and physical activity in children and youth: a meta-analysis. *Int J Obesity.* (2004) 28:1238–46. doi: 10.1038/sj.ijo.0802706

42. Kraut R, Kiesler S, Boneva B, Cummings J, Helgeson V, Crawford A. Internet Paradox Revisited. *J Soc Issues.* (2002) 58:49–74. doi: 10.1111/1540-4560.00248

43. Nie NH, Erbring L. Internet and society: a preliminary report. *IT Soc.* (2002) 1:275–83.

44. Putnam RD. *Bowling Alone: America's Declining Social Capital*. The city reader. Routledge. (2015). p. 188–96.

45. Sun HX, Shi X. Public health crises, global economic environment shocks and population risk perceptions. *Shanghai Ins Mon.* (2021) 37:19–22.

46. Kasperson RE, Renn O, Slovic P, Brown HS, Emel J, Goble R, et al. The social amplification of risk: a conceptual framework. *Risk Anal.* (1988) 8:177–87. doi: 10.1111/j.1539-6924.1988.tb01168.x

47. Witte K, Berkowitz JM, Cameron KA, McKeon JK. Preventing the spread of genital warts: Using fear appeals to promote self-protective behaviors. *Health Educ Behav.* (1998) 25:571–85. doi: 10.1177/109019819802500505

48. Li XJ, Liu QL. An extended model of risk transmission from a media credibility perspective - a national survey based on the Covid-19 epidemic. *Mod Commun.* (2021) 43:33–40.

49. Nick P, Roger E, Paul S. *The Social Amplification of Risk*. Beijing: China Labour Social Security Publishing Houses (2010).

50. Xu YH, Lai DP. Internet use, risk perception and urban residents' health. *J Party Sch Cent Comm CPC.* (2021) 25:110–1. doi: 10.14119/j.cnki.zgxb.2021.01.009

51. Lu H. Uses and gratifications: a theorv as a label. *J Int Commun.* (2011) 33:11–8. doi: 10.13495/j.cnki.cjjc.2011.02.012

52. He GP, Yuan S. Effects of media use and social interaction on self-perceived health of the elderly. *China J Commun J.* (2022) 15:67–82.

53. Deetjen U. The lifestyle paradox: adverse effects of Internet use on self-rated health status. *Inf Commun Soc.* (2018) 21:1322–36. doi: 10.1080/1369118X.2017.1313293

54. Bonsaksen T, Ruffolo M, Leung J, Price D, Thygesen H, Schoultz M, et al. Loneliness and its association with social media use during the COVID-19 outbreak. *Soc Media Soc.* (2021) 7:1–10. doi: 10.1177/20563051211033821

55. Kim YK, Fingerman KL. Daily social media use, social ties, and emotional wellbeing in later life. *J Soc Pers Relat.* (2022) 39:1794–813. doi: 10.1177/02654075211067254

56. Glanz K, Bishop DB. The role of behavioral science theory in development and implementation of public health interventions. *Annu Rev Publ Health.* (2010) 31:399–418. doi: 10.1146/annurev.publhealth.012809.103604

57. Wang ZH. Discipline and punishment: body discipline and cognitive turn under the background of COVID-19 pandemic. *J Beijing Sport Univ.* (2022) 43:1–13. doi: 10.19582/j.cnki.11-3785/g8.2020.03.001

58. Lee SM, Jeong HC, So WY, Youn HS. Mediating Effect of Sports Participation on the Relationship between Health Perceptions and Health Promoting Behavior in Adolescents. *Int J Environ Res Public Health.* (2020) 17:6744–56. doi: 10.3390/ijerph17186744

59. Arribas-Galarraga S, Luisde CI, Luisde CG, Urrutia-Gutierrez S. Mediation effect of perceived fitness on the relationship between self-efficacy and sport practice in Spanish adolescents. *Int J Environ Res Public Health.* (2020) 17:8800–8. doi: 10.3390/ijerph17238800

60. Ware JE, Sherbourne A. The MOS 36-item short form health survey. *Med Care.* (1992) 30:473–83. doi: 10.1097/00005650-199206000-00002

61. Wang M, Wang QM, Wan B. Spatial difference of internet popularization in China and analysis on its influencing factors. *Stat Dec.* (2018) 34:101–4. doi: 10.13546/j.cnki.tjyjc.2018.07.023

62. Kearney MW. Cross lagged panel analysis. In: *The SAGE Encyclopedia of Communication Research Methods*. Thousand Oaks, CA: SAGE Publications (2017).

63. Kohler U, Karlson KB, Holm A. Comparing coefficients of nested nonlinear probability models. *Stata J.* (2011) 11:420–38. doi: 10.1177/1536867X1101100306

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Socioeconomic disparities and inequality of mass sports participation: Analysis from Chinese General Social Survey 2010–2018

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Background: With industrialization, urbanization, and modernization, mass sports have entered people's daily lives to maintain their health status. However, less attention has been paid to the heterogeneity and inequality of access to mass sports, especially in developing countries. This study aims to analyze the factors that affect mass sports participation in developing countries represented by China, and explain the changing trends and inequality in the class differentiation and mobility of public sports participation.

Methods: The study selected the Chinese General Social Survey (CGSS) data in 2010 and 2018 as the research samples, and used an ordered Probit model and sub-sample regression to analyze the factors and trends of Chinese residents' mass sports participation and the influencing factors. By stratified three-stage probability sampling, the study obtained 4,940 valid responses, including 1,014 in CGSS 2010 and 3926 in CGSS 2018.

Results: First, in terms of social factors, urban residents have a higher frequency of sports participation than rural residents. Second, regarding family factors, residents with higher social classes are more likely to participate in sports than those with lower social classes. Third, in terms of self-induced factors, the elderly are more motivated to exercise than the young. Residents with public-sector jobs, high incomes, and higher education levels are keener to participate in sports. Fourth, residents' mass sports participation rate has generally shown an upward trend over time. Fifth, with time changes, the sports participation rate varies between urban and rural areas, between ethnic minorities and Han ethnic, between old and young age groups, and between higher and lower education levels will continue to shrink, but differences between social classes will further increase over time.

Conclusions: Our analysis demonstrated that hidden inequality existed in accessing mass sports participation in developing countries, and the self-induced characteristics were significantly correlated with the quality of sports participation. Future public sports policies should address the inequity to ensure equal access to affordable qualified personal mass sports.

KEYWORDS

mass sports participation, inequality, CGSS, China mass sports, socioeconomic disparities

1. Introduction

With the improvement of social and economic levels, human values gradually surpass the pursuit of a single economic dimension, and pay more attention to multi-dimensional experiences such as social, psychological and physical health (1). When health sociologists observe changes in perceptions, they find that socioeconomic factors such as social status, education and income level of individuals are closely related to the attainment of physical health (2–8). The inequality of sports participation caused by social class distinction has attracted scholars' attention.

From the perspective of sports sociology, sports access or mass sports participation can be regarded as one of the most common social phenomena in modern society and one of the crucial ways for ordinary members of society to achieve socialization (9). Earlier, Kenyon (9) and other scholars refined the meaning of sports participation. He believed that sports participation covered the level of sports cognition, emotional tendency, direct participation, and indirect participation related to social class characteristics (10). Therefore, under this background, some scholars believe that the inequality of mass sports participation is due to the existence of class divisions. The way of sports participation, as a means of class division, is not only reflected in the choice of sports events, but also limited sports participation (10–13). With the development of democracy, sports participation is no longer restricted by class divisions, but by sports itself, which makes the inequality of sports participation appear in another form (14, 15). For example, the upper class or more affluent group excludes others through expensive consumption or strict membership in golf and rowing clubs, while the working class is attracted by exciting sports such as boxing, wrestling, and dog running (16). At the same time, a strict distinction has been made between professional and amateur athletes, which does not release the inequality of participation (14, 17).

Up to now, sports participation has been gradually decoupled from the political class. Economic or willingness analyzes of new technologies are beginning to be applied to sports participation (18, 19). The development of blockchain and other technologies has effectively protected personal sports and health data (20, 21). Sports participation bears more weight on individual development and family health living. Under this trend, sports participation is divided more finely. On a global scale, scholars have divided sports participation into mass and elite/professional sports participation (22). More specifically, three forms of sports participation have been formed: competitive sports participation, school sports participation, and mass sports participation (23–25). Among them, competitive sports focus on stimulating human beings. To maximize the potential of physical fitness and psychological endurance, it emphasizes starting from all human beings, regardless of ethnicity and race, so when we discuss participation in competitive sports, we emphasize individual-level talent. Schools' physical education is a form of physical education related to school sports participation (23, 24, 26). It pays more attention to the methods of physical education, the position and development prospects of physical education in quality education, and the discussion of school sports participation pays more attention to the influence of the social level. Mass sports participation is the generalization of residents' daily exercise habits and amateur sports acquisition, which is usually closely related to lifestyle, healthy exercise, etc., so the discussion on mass sports participation needs to consider both the individual level and the social level (27).

Based on the above classification, this article chooses to focus on sports participation in mass sports. Compared with competitive and school sports, mass sports are more closely related to each of us. Meanwhile, due to economic improvement, residents are paying more and more attention to healthy lifestyles, and mass sports can include as many samples as possible. Research on mass sports participation can better reflect the changes in mass exercise methods and the development of health policies.

Hence, the research will start with the specific factors that affect mass sports participation and answer two progressive questions:

(1) Does the inequality of mass sports participation in developing countries (China) exist? If it exists, what are the specific influencing factors; if it does not, clarifies the presentation form of mass sports participation.
(2) With the changes of the times, what kind of changing trend does mass sports participation in developing countries show? Has inequality improved amid this trend?

By sorting out residents' sports participation tendencies, we find that social structures, such as class, status, prestige, power, etc., affect the socialization of sports participation to a certain extent (28–31). In fact, there have been discussions of sports participation from the perspective of social stratification theory. In the late twentieth century, scholars noticed that sports participation as a means of social stereotyping was widely used throughout society and played a role as a maker of social inequality in social stratification (28, 32). Giddens (33) once stated that the liberation of the individual is the freedom obtained by breaking free from the constraints of inequality. Inequality theory has become a direction that public sociologists and scholars engaged in a social policy called on government authorities to promote public participation in sports (17, 34–36). Sports have become a powerful weapon for reform in project promotion and sports facility construction.

In sociology, scholars have also linked public sports participation with social structure and individual agency along the perspective of social stratification theory (14, 32, 37–39). Social structure, that is, we usually understand various external environmental factors that are independent of the individual but can restrict the individual, while individual agency emphasizes the individual's ability to independently choose and carry out actions (40). It is undeniable that the social structure is independent of the individual and is indeed a factor that cannot be ignored in the changing times. The individual initiative will also check, balance, and influence the social structure. However, this distinction divides the individual and society. In fact, the distinction between the micro-level and the macro-level does not have such a large span. Similarly, the social structure at the macro level does not always directly act on individuals through external factors, but often looks for some intermediaries, such as government organizations (governments) and some public profit organizations (hospitals) that we cannot ignore.

Scholars' research in recent years has also found that the family has a non-negligible influence on the behavior and habits of adults, and the way family upbringing will affect the individual's lifestyle in adulthood (2, 39, 41, 42). Therefore, in order to ensure the scientific nature of the research, this study believes that discussions such as family annual income and family social class also need to be included in the frame design.

Specifically, in this study, the author attempts to classify the factors that affect mass sports participation into social factors, family factors and self-induced factors, and accordingly put forward the following hypotheses:

H1: Inequality in mass sports participation exists in developing countries (China).

> *H1a: Social factors have a significant impact on mass sports participation.*
> *H1b: Family factors have a significant impact on mass sports participation.*
> *H1c: Self-induced factors have a significant impact on mass sports participation.*

H2: As times change, inequality in mass sports participation in developing countries will improve.

2. Methods

2.1. Setting and data resources

The data in this paper comes from the Chinese General Social Survey (CGSS). CGSS is the earliest national, comprehensive and continuous academic survey project in China, implemented by the China Survey and Data Center of Renmin University of China. Since 2003, the project has basically guaranteed to conduct continuous cross-sectional surveys on more than 10,000 households in various provincial units in mainland China once a year. 2003–2008 is the first phase of the CGSS project. A total of 5 annual surveys were completed (exclude 2007), and 5 sets of high-quality annual data were produced. 2010-2019 is the second phase of the CGSS project. As of the article writing, 7 annual survey data (2010, 2011, 2012, 2013, 2015, 2017, 2018) have been released, the latest year of data available is 2018.

This article explores Chinese residents' sports participation and its influencing factors. Considering that with the evolution of the times, Chinese citizens' attitudes toward physical participation have changed, this article will also attempt to deeply explore the changing trends of the effects of various influencing factors. The authors selected the CGSS data in 2010 and 2018 as the research samples. CGSS 2010 and 2018 contain several parts, including core modules (basic information), class consciousness, social stratification, income and consumption, religion, environment, and health. After removing missing values and outliers, the study obtained 4940 valid observation samples, including 1014 in CGSS 2010 and 3926 in CGSS 2018.

2.2. Sampling method

2.2.1. Stratified three-stage probability sampling

The CGSS is a national large-scale survey project which targets all urban and rural households in 31 provinces, autonomous regions, and municipalities directly under the Central Government (excluding Hong Kong, Macao, and Taiwan). CGSS 2010 and 2018 adopt stratified three-stage probability sampling. As shown in Table 1, the sampling units of each stage are slightly different.

For the mandatory layer, choosing streets as the primary sampling unit can refine the sampling frame and make the sample points relatively scattered, which is conducive to collecting general information and avoids sample bias due to too thick a sampling frame. For the selection layer, considering that there are many districts, county-level cities, and counties in the whole country, it is more appropriate to use them as the primary sampling unit.

Based on past survey experience, the target sample size for the survey is set at 12,000 households, of which 2,000 are compulsory and 10,000 are selected. The sample size allocations covered in the subsequent sections are all based on the target sample size.

2.2.2. Sample size

For the mandatory layer, the total sample size is 2,000 households. Specifically, 40 primary sampling units (streets) are selected, and two secondary sampling units (neighborhood committees) are chosen from each primary sampling unit (PSU). The third stage of sampling contains 25 households, which were selected from SSU.

For the selection layer, the total sample size is 10,000 households. Specifically, 100 PSUs (districts, county-level cities, counties) are selected, and 4 SSUs (neighborhood committees, village committees) are chosen from each PSU. Each neighborhood committee (village committee) selects 25 households.

Hence, a total number of 140 PSUs and 480 SSUs were drawn in this survey.

Considering that the answer rate in the survey is difficult to reach 100%, this plan adopts the method of expanding the sample size by using the expansion coefficient to enlarge the sample size of the third stage. According to the survey experience in previous years, due to various reasons, the answer rate of residents in the municipal districts of developed cities is 50%. That is, the expansion coefficient is around 2, so 50 households are selected from each second-level unit in the mandatory layer, and the contact sample size of this layer is expanded to 4,000.

The response rate of the residents in the selected layer is higher than that of the mandatory layer. In general, based on the experience in the previous year, the response rate of urban residents is around 65%, and the response rate of rural residents is higher than that of urban residents, roughly about 85%. Therefore, for the selection layer, 38 households were selected for each neighborhood committee, and 30 households were selected for each village committee.

This survey's final contact sample size is 17,664, of which 4,000 are mandatory, and 13,664 are selection. In the mandatory layer, when the number of primary and secondary units remains unchanged, the number of contact samples in each secondary unit increases to 50 households. In the selection layer, the number of primary units is 100, and the number of secondary units in each primary unit is 4. The contact sample size in each sampling neighborhood committee was expanded to 38 households, while in each sampling village committee was expanded to 30 households. Therefore, the contact sample size of the selection layer was 13,664, of which 7,904 were urban residents and 5,760 were rural residents.

2.3. Variable selection

2.3.1. Dependent variable: Sports participation

The dependent variable in this paper is residents' sports participation. Unlike the previous studies, which defined sports participation as a dummy variable—whether or not to participate in physical exercise; this study believes that the previous method limits the study to qualitative analysis. In fact, there are also significant

TABLE 1 Stratified three-stage probability sampling.

	Primary sampling unit (PSU)	Secondary sampling unit (SSU)	Third stage sampling unit
Mandatory layer	Street	Neighborhood committee	Households
Lottery layer	District, county-level city, county	Neighborhood committee, village committee	Households

TABLE 2 The measurement of the independent variable—social factors (CGSS 2018).

Social factors	Question and assign	Frequency	Percentage
Gender	**A2. What is your gender?**		
	female = 0	6,441	53.01
	male = 1	5,708	46.99
Household registration	**A18. Your current household registration status is**		
	Rural household registration = 1	6,994	54.70
	Urban household registration = 0	3,123	24.42
	Resident household (formerly rural household registration) = 0	1,010	7.90
	Resident household (formerly urban household registration) = 0	1,628	12.73
	Military status = None	5	0.04
	No account = None	5	0.04
	Other = None	22	0.17
Ethnicity	**A4.Your ethnicity is**		
	Han = 0	11,829	92.74
	Montgomery = 1	36	0.28
	Man = 1	97	0.76
	Hui = 1	235	1.84
	Zang = 1	7	0.05
	Zhuang = 1	145	1.14
	Wei = 1	3	0.02
	Other = 1	403	3.16

CGSS2010 and CGSS2018 have the same variable measurement methods in the related questions, the data of CGSS2010 will not be listed in detail.

differences in the frequency of participation among groups that participate in physical activity. Therefore, this article will focus on the number of participants. For example, taking the 2010 questionnaire as an example, this research selects the following questions:

> *“B4: How many times a week do you do physical exercise for at least 20 minutes or more? Here refer to those exercises that make sweat or breathe faster.”*

According to the answer, define the dependent variable sports participation and set the five frequencies of “I do not exercise”, “several times a year or even less”, “several times a month”, “several times a week” and “exercise every day” as 1, 2, 3, 4, 5. Similarly, in the 2018 questionnaire, the number of specific exercises was classified as the above five frequencies for assignment.

2.3.2. Independent variable

Considering the diversification of factors influencing sports participation, whether or not to participate in physical exercise and the frequency of participation are often the result of the combined action of multiple factors. The past literature introduces a series of factors that may affect the dependent variable as independent variables from three aspects: social factors, family factors, and self-induced factors. (1) Social factors include household registration, gender, and ethnicity; (2) Family factors include family income and social class of the households at the age of 14; (3) Self-induced factors include age, occupation, individual income, education level, marital status, and religious beliefs. In addition, considering that the changes in the times may impact on sports participation, the study also introduces time virtual variables; the specific variable selection and assignment are shown in Tables 2–4.

2.4. Model building

2.4.1. Descriptive statistics

The descriptive statistics of the main variables in this paper are shown in Table 5. The dependent variable in the study is sports participation. Regarding the frequency of sports participation, the average value in 2010 was 2.550, which rose to 2.740 in 2018. In the nine-year duration, the enthusiasm of Chinese residents to

TABLE 3 The measurement of the independent variable—family factors (CGSS 2018).

Family factors	Question and assign	Frequency	Percentage
A Family income	***A62.What was your family's total household income in 2017?*** ***hundred thousand*** ***thousand*** ***ten*** [_______|_______|_______|_______|_______|_______|_______|_______] ***million*** ***ten thousand*** ***hundred*** ***one***		
	Family income = ln(a62 + 1)		
Social class	**A4.When you were 14, what social class did you think your family was in?**		
	One point = 1	2,123	17.17
	Two points = 2	2,407	19.46
	Three points = 3	2,499	20.21
	Four points = 4	1,731	14.00
	Five points = 5	2,177	17.60
	Six points = 6	636	5.14
	Seven points = 7	301	2.43
	Eight points = 8	172	1.39
	Nine points = 9	39	0.32
	Ten points = 10	64	0.52
	Don't know = None	196	1.58
	Refuse to answer = None	21	0.17

CGSS2010 and CGSS2018 have the same variable measurement methods in the related questions, the data of CGSS2010 will not be listed in detail.

participate in sports has increased. However, the median of 2010 and 2018 is 2, which means that although the enthusiasm of Chinese residents to participate in sports has increased, it is still not high overall. The standard deviations are 1.721 and 1.747, respectively, which means that there is a big difference in the frequency of residents' sports participation in the two periods.

The independent variables of this study consist of three dimensions:

(1) Social factors dimension includes household registration, gender, and ethnicity. In 2010, the average household registration was 0.603; that is, 60.3% of the households were registered as urban residents. In 2018, this figure rose to 65.5%, which is generally consistent with China's urbanization process. In 2010, the gender average was 0.509; that is, 50.9% of the respondents were female. In 2018, this figure was 54.8%, and the proportion of female respondents increased slightly. In 2010, the average ethnicity value was 0.081, showing that about 8.1% of the respondents were ethnic minorities, and this figure dropped to 5.8% in 2018.
(2) Family factors dimension includes family income and the social class of the respondents when they were 14 years old. Among them, the average value of social class in 2010 was 3.037; that is, the majority of interviewees believed that their native families belonged to the middle and lower classes. In 2018, this number rose to 3.517, indicating that most interviewees had jumped in class. In 2010, the average value of household income after logarithm removal was 10.45; in 2018, it rose to 10.93, and the standard deviations were relatively large, indicating that the family income of different resident groups varies considerably.
(3) Self-induced factors dimension includes factors related to individuals, such as age, occupation, individual income, education level, marital status, and religious belief. In 2010, the average age was 53.24, and in 2018 it rose to 59.08, reflecting the acceleration of the aging process in China. In terms of occupation, based on social experience and previous research, influenced by the socialist system with Chinese characteristics, people generally believe that occupations that work for the state (or are paid by the state) are more stable. This type of occupation is habitually called *work in the system* in China. In 2010, the average occupation value was 0.163; that is, about 16.3% of the respondents were working in the system. In 2018, this figure rose to 20.2%. For individual income in 2010 and 2018, the mean value after taking the logarithm is 8.647, and the standard deviation is slight different, indicating that the income difference of resident groups has changed little. The average education level in 2010 was 8.547, and it rose to 9.145 in 2018, with a median of 9, which means that the intermediate education level of the interviewed households is about junior high school. The average value of marital status in 2010 was 0.829, indicating that 82.9% of the interviewed households were married; this figure dropped to 74.9% in 2018, which also explained the decline in the marriage registration rate. It should be noted that in statistics, remarriage with spouse is considered as a type of marital change, so this indicator is not included in the statistics of married. Meanwhile, considering that the sample size of remarried with spouse is small (n = 200), its impact on the statistical results can be ignored. The average value of religious belief in 2010 was 0.122, indicating that religious believers accounted for 12.2% of the total sample, and this figure dropped to 11.6% in 2018.

TABLE 4 The measurement of the independent variable- self-induced factors (CGSS 2018).

Self-induced factors	Question and assign	Frequency	Percentage
Individual income	***A8a.What was your total individual income for last year (2017)?*** ***hundred thousand thousand ten*** [_______|_______|_______|_______|_______|_______|_______|_______] ***million ten thousand hundred one***		
	Income = ln(a8a+1)		
Age	**A3a. What is your date of birth?[____|____|____|____]year[____|____]month[____|____]day**		
	Age = 2018-a3a		
Marital status	**A69.What is your current marital status?**		
	Single = 0	1,204	9.91
	Cohabitation = 0	254	2.09
	First marriage with spouse = 1	8,882	73.11
	Remarried with spouse = 0	200	1.65
	Separated but not divorced = 0	68	0.56
	Divorce = 0	301	2.48
	Widowed = 0	1240	10.21
Education level	**A7a.Your current highest education level is**		
	Without any education = 0	1,758	14.50
	Private schools = 6	77	0.64
	Primary schools = 6	2,612	21.54
	Junior high school = 9	3,260	26.89
	Vocational high school = 12	167	1.38
	General high school = 12	1,444	11.91
	Technical secondary school = 12	556	4.59
	Technical school = 12	51	0.42
	University Diploma (adult higher education) = 15	369	3.04
	University Associates (formal higher education) = 15	570	4.70
	Undergraduate (adult higher education) = 16	269	2.22
	Undergraduate (formal higher education) = 16	850	7.01
	Postgraduate and above = 19	142	1.17
Occupation	**A60j.The type of affiliation or company in which your most recent off-farm job was**		
	Party and government organs = 1	170	4.31
	Enterprise = 0	2,012	50.96
	Public institutions = 1	625	15.83
	Social groups, village/neighborhood committees = 0	132	3.34
	Unemployed/self-employed = 0	799	20.24
	Army = 0	34	0.86
	Other = None	95	2.41
	Don't know = None	70	1.77
	Refused to answer = None	11	0.28
Religious	**A5.What is your religion?**		
	No religion = 0	10,852	89.32
	Buddhism = 1	533	4.39
	Taoism = 1	17	0.14

(Continued)

TABLE 4 (Continued)

Self-induced factors	Question and assign	Frequency	Percentage
	Folk beliefs (Mazu, Guan Gong, etc.) = 1	256	2.11
	Islam/Islam = 1	217	1.79
	Catholic = 1	23	0.19
	Christianity = 1	234	1.93
	Other Christian = 1	1	0.01
	Other = None	16	0.13
Time factor	Era	1 in 2018, 0 in 2010	

CGSS2010 and CGSS2018 have the same variable measurement methods in the related questions, the data of CGSS2010 will not be listed in detail.

TABLE 5 Descriptive statistics.

Variable	Mean		Median		Standard deviation		Minimum		Maximum value	
	2010	2018	2010	2018	2010	2018	2010	2018	2010	2018
Sports participation	2.550	2.740	2	2	1.721	1.747	1	1	5	5
Household registration	0.603	0.655	1	1	0.490	0.476	0	0	1	1
Gender	0.509	0.548	1	1	0.500	0.498	0	0	1	1
Ethnicity	0.081	0.058	0	0	0.273	0.233	0	0	1	1
Social class	3.037	3.517	3	3	1.838	1.859	1	1	10	10
Family income	10.45	10.93	10.19	11.00	1.703	2.303	7.474	0	16.12	16.12
Age	53.24	59.08	55	62	16.06	15.63	18	18	96	118
Occupation	0.163	0.202	0	0	0.369	0.402	0	0	1	1
Individual income	8.647	8.678	9.393	10.27	3.579	3.958	0	0	16.12	16.12
Education level	8.547	9.145	9	9	3.624	4	0	0	19	19
Marital status	0.829	0.749	1	1	0.376	0.434	0	0	1	1
Religious belief	0.122	0.116	0	0	0.328	0.321	0	0	1	1

2.4.2. Ordered Probit model

The empirical goal of this paper is to explore the influencing factors of Chinese residents' sports participation. Since the dependent variable in this paper is an ordered discrete variable, when the explained variable is a multivariate ordered discrete variable, the ordered Probit model can better meet the needs of empirical regression. Compared with the traditional ordered Logit model, the ordered Probit model relaxes the assumption of the independence of irrelevant alternatives of the sample data and has broader applicability. Therefore, this paper establishes the ordered Probit model. The equations are as follows:

$$
\begin{aligned}
\mathbf{Y}^{*} = & \sum_{\mathbf{i=1}}^{5} \alpha_{\mathbf{i}} + \beta_1 \mathbf{urban} + \beta_2 \mathbf{sex} + \beta_3 \mathbf{nation} + \beta_4 \mathbf{rank} \\
& + \beta_5 \mathbf{fa\_income} + \beta_6 \mathbf{age} + \beta_7 \mathbf{job} + \beta_8 \mathbf{per\_income} + \beta_9 \mathbf{edu} \\
& + \beta_{10} \mathbf{marry} + \beta_{11} \mathbf{belief} + \beta_{12} \mathbf{time} + \epsilon
\end{aligned}
$$

Among them, Y* is the frequency of resident sports participation in the dependent variable, which is divided into five grades: " I do not exercise", "several times a year or even less", "several times a month", "several times a week", and "exercise every day". α_i is a constant term, there are five categories of dependent variable values, and five constant terms will be generated under the ordered multiple regression. β_i is the regression coefficient of the corresponding i-th influencing factor, and $\varepsilon_i$is the residual term. Set the threshold $\lambda_1 < \lambda_2 < \lambda_3 << \lambda_4 < \lambda_5$, there is the formula:

$$
\mathrm{Y} = \begin{matrix} 1 \; if \; Y^{*} \leq \lambda_1 \\ 2 \; if \; \lambda_1 < Y^{*} \leq \lambda_2 \\ 3 \; if \; \lambda_2 < Y^{*} \leq \lambda_3 \\ \ldots \end{matrix}
$$

The probability of Y looks like this:

$$
\begin{aligned}
&\mathbf{Prob(Y=1|X)} \; = \mathbf{Prob}\ (\mathbf{Y}^{*} \leq \lambda_1 \mathbf{|X}) = \mathbf{Prob}\ (\mathbf{X}\beta^{\mathbf{T}} + \varepsilon_{\mathbf{i}}) \\
&\leq \lambda_1 \mathbf{|X} = \phi\ (\lambda_1 - \mathbf{X}\beta^{\mathbf{T}}) \\
&\mathbf{Prob\ (Y=2|X)} \; = \mathbf{Prob}\ (\lambda_1 < \mathbf{Y}^{*} \leq \lambda_2 \mathbf{|X}) \; = \phi\ (\lambda_2 - \mathbf{X}\beta^{\mathbf{T}}) - \phi\ (\lambda_1 - \mathbf{X}\beta^{\mathbf{T}}) \\
&\mathbf{Prob(Y=3|X)} \; = \mathbf{Prob}\ (\lambda_2 < \mathbf{Y}^{*} \leq \lambda_3 \mathbf{|X}) \; = \phi(\lambda_3 - \mathbf{X}\beta^{\mathbf{T}}) - \phi\ (\lambda_2 - \mathbf{X}\beta^{\mathbf{T}}) \\
&\mathbf{Prob\ (Y=4|X)} \; = \mathbf{Prob}\ (\lambda_3 < \mathbf{Y}^{*} \leq \lambda_4 \mathbf{|X}) = \phi\ (\lambda_4 - \mathbf{X}\beta^{\mathbf{T}}) - \phi\ (\lambda_3 - \mathbf{X}\beta^{\mathbf{T}}) \\
&\mathbf{Prob\ (Y=5|X\ )} \; = \mathbf{Prob}\ (\lambda_4 < \mathbf{Y}^{*} \leq \lambda_5 \mathbf{|X}) = \phi\ (\lambda_5 - \mathbf{X}\beta^{\mathbf{T}}) - \phi\ (\lambda_4 - \mathbf{X}\beta^{\mathbf{T}})
\end{aligned}
$$

In the above formula, ϕ is the standard normal cumulative distribution function.

The study concentrates on the direction and significance of the coefficient β_i of the independent variable. If it is

TABLE 6 Benchmark regression.

	(1) Full sample	(2) Year 2010	(3) Year 2018
Household registration	0.365***	0.471***	0.332***
	(0.044)	(0.100)	(0.049)
Gender	0.057	−0.081	0.088**
	(0.035)	(0.079)	(0.039)
Ethnicity	−0.122	−0.256*	−0.076
	(0.074)	(0.153)	(0.085)
Social class	0.029***	0.002	0.035***
	(0.009)	(0.021)	(0.011)
Family income	0.010	0.018	0.007
	(0.008)	(0.021)	(0.009)
Age	0.006***	0.012***	0.004***
	(0.001)	(0.003)	(0.001)
Occupation	0.099**	0.129	0.093*
	(0.044)	(0.107)	(0.048)
Individual income	0.013***	−0.011	0.021***
	(0.005)	(0.010)	(0.005)
Education level	0.027***	0.046***	0.023***
	(0.005)	(0.012)	(0.005)
Marriage	0.050	0.082	0.043
	(0.039)	(0.100)	(0.043)
Religious belief	0.002	−0.029	0.011
	(0.053)	(0.129)	(0.059)
Era	0.074*		
	(0.042)		
/			
Cut1	1.127***	1.404***	0.961***
	(0.127)	(0.308)	(0.141)
Cut2	1.375***	1.650***	1.211***
	(0.127)	(0.310)	(0.141)
Cut3	1.615***	1.805***	1.472***
	(0.127)	(0.311)	(0.142)
Cut4	1.840***	2.177***	1.664***
	(0.128)	(0.313)	(0.142)
N	0.365***	0.471***	0.332***
R2_p	(0.044)	(0.100)	(0.049)

Standard errors are in brackets, ***, **, *represent significant at the 1, 5, and 10% levels, respectively.

TABLE 7 Robustness test by replacing the dependent variable.

	(1) Full sample	(2) Year 2010	(3) Year 2018
Household registration	0.533***	0.774***	0.479***
	(0.042)	(0.102)	(0.047)
Gender	0.087**	−0.012	0.108***
	(0.034)	(0.080)	(0.038)
Ethnicity	−0.134*	−0.241	−0.097
	(0.075)	(0.176)	(0.084)
Social class	0.036***	0.060***	0.032***
	(0.009)	(0.021)	(0.011)
Household income	0.019**	0.024	0.018**
	(0.008)	(0.020)	(0.008)
Age	0.006***	0.014***	0.004***
	(0.001)	(0.003)	(0.001)
Occupation	0.034	−0.100	0.058
	(0.043)	(0.108)	(0.047)
Individual income	0.009**	0.003	0.013***
	(0.004)	(0.010)	(0.005)
Education level	0.042***	0.048***	0.041***
	(0.005)	(0.012)	(0.005)
Marriage	0.043	0.047	0.045
	(0.039)	(0.104)	(0.042)
Religious belief	−0.035	−0.111	−0.023
	(0.053)	(0.129)	(0.059)
Era	0.222***		
	(0.042)		
/			
Cut1	1.460***	2.057***	1.104***
	(0.122)	(0.311)	(0.135)
Cut2	1.763***	2.436***	1.391***
	(0.122)	(0.312)	(0.135)
Cut3	1.952***	2.710***	1.564***
	(0.123)	(0.315)	(0.135)
Cut4	2.418***	3.001***	2.068***
	(0.124)	(0.318)	(0.136)
N	4870	999	3871
R2_p	0.051	0.088	0.041

Standard errors are in brackets, ***, **, *represent significant at the 1, 5, and 10% levels, respectively.

positive and significant, it means that the factor will promote the increase of the frequency of residents' sports participation; if it is negative and significant, the factor will reduce the frequency of residents' sports participation; if it is insignificant, it means that the factor has no significant relationship with the frequency of residents' sports participation. According to empirical needs, the study will also conduct sub-sample regression on the two-year cross-sectional data in 2010 and 2018 to explore the different changes in the influencing factors in each era.

TABLE 8 Further analysis.

Social factors					
Household registration	0.548***	**Gender**	−0.073	**Ethnicity**	−0.334**
	(0.084)		(0.073)		(0.142)
Era	0.227***	**Era**	−0.010	**Era**	0.055
	(0.075)		(0.060)		(0.043)
Household registration* era	−0.232***	**Gender* era**	0.162**	**Ethnicity* era**	0.280*
	(0.089)		(0.081)		(0.164)
Family Factors					
Social class	0.012		**Family income**	0.139	
	(0.020)			(0.233)	
Era	0.006		**Era**	0.015	
	(0.084)			(0.020)	
Social class* era	0.022		**Family income* era**	0.139	
	(0.022)			(0.233)	
Self-induced factors					
Age	0.012***	**Occupation**	0.232**	**Individual income**	0.000
	(0.002)		(0.099)		(0.010)
Era	0.511***	**Era**	0.103**	**Era**	−0.064
	(0.143)		(0.046)		(0.100)
Age* era	−0.008***	**Occupation* era**	−0.161	**Individual income* era**	0.016
	(0.003)		(0.108)		(0.011)
Education level	0.043***	**Marriage**	0.068	**Religious**	−0.086
	(0.010)		(0.096)		(0.120)
Era	0.245**	**Era**	0.092	**Era**	0.062
	(0.110)		(0.095)		(0.044)
Education level* era	−0.019*	**Marriage* era**	−0.022	**Religious*era**	0.109
	(0.011)		(0.105)		(0.132)

Standard errors are in brackets, ***, **, * represent significant at the 1, 5, and 10% levels, respectively.

3. Results

3.1. Probit regression

According to the sample data, combined with the empirical model established above, an ordered Probit regression is carried out, and robust standard errors are used to overcome the heteroscedasticity problem. The regression results are as follows (see Table 6).

As shown in Table 6, in column (1), the study uses a two-year mixed sample of 2010 and 2018 to test the influencing factors of the dependent variable-sports participation. The results show that in terms of social factors, the household registration coefficient is significantly positive at the 1% significance level while gender and ethnicity coefficients are not; that is, urban residents have a higher frequency of sports participation than rural residents, while men and women participate relatively equal in physical exercise. The ethnicity coefficient is insignificant, indicating no noticeable difference in sports preference between Han and ethnic minorities.

Regarding family factors, the coefficient of social class is significantly positive while the coefficient of family income is not, which means that residents of higher social classes are more motivated to participate in sports than residents of lower social classes; and the family income has little effect.

For self-induced factors, age, individual income, education level and the occupation coefficient are all significantly positive, while religious belief and marital status are not; that is, the elderly are more active in physical exercise than the young, which may be because the elderly have sufficient leisure time. It also indicates that residents who work in the system (those who work for the state), residents with high income, and residents with higher education levels are keener to participate in sports.

The era (whether it is 2018) is significantly positive, indicating that the resident' sports participation in 2018 is more active than that in 2010, and it also shows that the residents' sports participation has changed significantly in the 9-year period; ascension is the main feature.

3.2. Sub-sample regression

The authors also conduct a sub-sample regression to verify whether the influence of various influencing factors on sports participation has changed from 2010 to 2018, the results can be found in Table 6, columns (2) and (3).

For social factors, the results show that from 2010 to 2018, the coefficient of household registration is still significant, but the size of the coefficient gradually decreases, indicating that despite the current enthusiasm of urban residents to participate in sports is more potent than that of rural areas, but the gap with the latter has been narrowing. Meanwhile, it can be seen that gender was insignificant in 2010 but significantly positive in 2018, indicating that in 2010, the frequency of male and female participation in sports had no significant difference, while after 9 years, female's fitness enthusiasm has improved and been significantly higher than that of male. Also, the ethnicity coefficient changed from significant to negative insignificant; in 2010, compared with the Han group, the overall fitness enthusiasm of ethnic minorities was not strong, and after 9 years, the two were nearly indistinguishable.

For family factors, the coefficient of social class was insignificant in 2010, while it was significantly positive in 2018, which also means that with the evolution of the times, people with higher social status have an increasing awareness of physical fitness, and the frequency of participation has also increased.

For self-introduced factors, the age coefficient was significantly positive in 2010 and 2018, but the coefficient was reduced in 2018, showing that young people's enthusiasm for physical exercise increased with time. The occupation coefficient never increased, which shows that practitioners in the system (those who work for the state) have more enthusiasm for fitness. The individual income coefficient is from insignificant to significantly positive, indicating that groups with high income have a greater increase in fitness enthusiasm. When it turns to education level, its coefficient in 2010 and 2018 were both significantly positive in the middle of the year, but the coefficient shrank significantly in 2018, which means that the frequency of fitness among groups with lower education levels is also increasing.

3.3. Robustness check

To verify the validity of the empirical conclusion of the study, that is, whether the empirical conclusion can reveal the correct social phenomenon, or it is only a particular result under the accidental regression, and cannot be generalized as a general conclusion, this paper attempts to conduct a robustness test to check.

Previously, the source of the dependent variable in this paper was the item:

> *"B4: How many times a week do you do physical exercise for at least 20 minutes or more? Here refer to those exercises that make sweat or breathe faster."*

Considering that some sports participants prefer low-intensity exercise without sweating, the author re-selects an item from the questionnaire to replace current dependent variable:

> *"A30i. In the past year, did you often engage in the following activities in your spare time-physical exercise?"*

The five grades of "I do not exercise", "several times a year or even less", "several times a month ", "several times a week", and "exercise every day" are, respectively, assigned to 1–5. The intensity is specified, reflecting the degree of participation more comprehensively. Taking this variable as the new dependent variable, the ordered Probit regression is performed again, and the results are shown in Table 7. The sign and direction of the coefficients are still consistent with the previous regression, indicating that the empirical conclusions of this paper are robust.

3.4. Further analysis

Comparing the two-year data between 2010 and 2018, the influence of most social and self-induced factors shows a certain rigidity. However, the coefficient estimates of the main variables have changed to a certain extent. To test whether the influence of various factors on residents' sports participation has been strengthened or weakened with the evolution of time and social transformation, the authors introduce the multiplication term of each influencing factor and the dummy variable of the era, and conduct an ordered Probit regression analysis again; the results are shown in Table 8.

For social factors, both household registration and era are significantly positive, but the interaction term between those two is significantly negative, which shows that with the development of the times, the impact of household registration on resident' sports participation is weakening. This result may be related to the reform of the household registration system implemented in China in 2014 and the improvement of rural sports facilities in recent years. According to the *Opinions on Further Promoting the Reform of the Household Registration System* promulgated in 2014, Chinese household registration no longer distinguishes between rural and urban household registration. Compared with rural residents, although urban residents have long-term advantages in sports participation, with the evolution of the times, especially the continuous improvement of rural sports facilities and the awakening of rural fitness awareness, the difference will continue to shrink. On the other hand, the regression results also show that the coefficients of gender and era are not significant, but the interaction term is significantly positive, indicating that although there is no significant difference in the frequency of sports participation between men and women, as time progresses, women's fitness levels are higher than men's. The frequency will be increased to a greater extent. Finally, the regression results show that the ethnicity coefficient is significantly negative, while its interaction term with the era is significantly positive, indicating that compared with the Han, ethnic minorities have a lower frequency of sports participation, but with the evolution of the times, ethnic minorities catch up effect is more pronounced.

For family factors, the regression results show that the coefficient of the interaction term between social class and era is significantly positive, which means that under the blessing of time, groups with a higher social class will be more active in sports. On the other hand, family income, era and their interaction items are insignificant, indicating that family income is not a critical indicator affecting sports participation, and the impact of family income on sports participation will not change with the evolution of the times.

As for self-induced factors, although times are changing, these are still the most crucial aspect affecting residents' sports participation. According to the regression results, the coefficients of age and era are both significantly positive, while the interaction term is significantly negative, indicating that the elderly have a higher frequency of sports participation than the young. Still, as the times evolve, young people will also invest more time in physical exercise, and the inter-generational age gap in sports participation will continue to narrow. At the same time, the occupation and era coefficients are both significantly positive, but the interaction term between the two is insignificant, indicating that the group *working in the system* is more active in participating in physical exercise than the group *working outside the system*. The difference tends to shrink, but the trend is not apparent, indicating that the differences in sport participation in and outside the system will persist for a considerable time. Moreover, the education level and era coefficients are both significantly positive, but the interaction term is significantly negative, indicating that the group with a higher education level has a higher frequency of sports participation than the group with a lower education level. However, with the evolution of the times, the latter will pay more and more attention to their health and spend more time participating in physical exercise, and the inter-generational gap in the education level of sports participation will continue to narrow. On the other hand, individual income, religious belief, and marital status do not affect the frequency of sports participation. Its interaction items are also insignificant, indicating that these characteristics are not the decisive factors affecting sports participation, and the evolution of the times will not significantly impact the change's effectiveness.

4. Discussion

4.1. Findings

The specific issue under investigation here is whether mass sports participation behavior appears to be characterized by inequities in terms of social, family, and self-induced factors. Using the two-year sample data of CGSS 2010 and 2018, the authors screened 4940 valid observation samples and conducted an ordered Probit regression in Stata 17 software. The empirical results are studied and the following five conclusions are found.

First, in terms of social factors, urban residents have a higher frequency of sports participation than rural residents.

Second, in terms of family factors, residents with higher social classes are more likely to participate in sports than those with lower social classes.

Third, in terms of self-induced factors, the elderly are more motivated to exercise than the young; residents who work in the system (those who work for the state), residents with high incomes, and residents with higher education levels are keener to participate in sports.

Fourth, Chinese residents' mass sports participation rate has generally shown an upward trend over time.

Last but not least, after the robustness test of the results to verify its validity, the study finds that with time changes, the sports participation rate varies between urban and rural areas, between ethnic minorities and Han ethnic, between old and young age groups, between higher and lower education levels will continue to shrink, but differences between social classes will further increase over time.

4.2. Limitations

Since the study used ordered Probit regression to discuss the influencing factors and changing trends of Chinese residents' sports participation, the author's interpretation of the economic significance of the variable coefficient is mainly based on the current situation and previous research results. It cannot conduct a further in-depth discussion on the impact mechanism.

As shown above, the study also used sub-sample regression to illustrate the changing trends and effects of time. Sub-sample test is a classic method in social science and has been used for a long time, which may not be fashionable enough. Since we have already added interaction terms to our variables in Probit analysis, it is meaningless to multiply variables by interaction terms again, so we still chose sub-sample regression. Nevertheless, to ensure the results' robustness, we also replaced the dependent variable as a supplement in the robustness check section; the results are meaningful and robust. Therefore, we hope future researchers could dig out better and more fashionable methods to replace the sub-sample regression.

Moreover, considering that the study focused on the influencing factors of sports participation rather than discussing a specific independent variable's influence on the dependent variable, the authors carefully selected the sample and adopted a method of replacing the dependent variables to reduce the effect of endogeneity. However, the study cannot deny that there exist more influencing factors in real society other than the variables covered by design, and the endogeneity could not essentially avoid. We can only guarantee the mentioned factors have been thoroughly explained and proven to have a non-negligible impact.

Hence, based on the limitations, the authors hope that future research could design models that include a more comprehensive range of indicators so that discussions on mass sport participation can get further deepened.

5. Conclusion

This paper explores the influencing factors of residents' sports participation, analyzes the role of social, family, and self-induced factors in residents' mass sports participation, and studies the temporal trend of the above factors.

It can be concluded that inequality existed in the access to mass sports on social, family, and self-induced factors. Suppose China and other developing countries would like to reduce the inequality of sports participation caused by social and family factors such as the urban-rural gap and social class disparity, they need to increase investment in rural public sports facilities and fundamentally change residents' awareness of healthy lifestyles.

Meanwhile, considering that self-induced factors are the most critical factors affecting the inequality of mass sports participation, improving the educational level and individual income can also reduce the gap. On the educational aspect, China has implemented a 9-year compulsory education policy since 1986; as of 2018, the average length of educated duration in China is maintained at about nine years, which is very low. Over the past 30 years, given that residents' income levels and educational concepts have changed tremendously, policymakers may consider extending compulsory education to 12 years as most developed countries do. On the individual income aspect, it should distinguish individual income and family income first. Individual income measures the individual's economic level, while family income reflects the family's survival. Although China's economy has developed rapidly in recent years, the fact that the agricultural population accounts for the majority has not changed fundamentally. Measurements based on family statistics need to consider the number of hidden unemployed or non-labor force households in Chinese society. Based on this situation, the relative advantage of the individual income will disappear, because the individual has the obligation and responsibility to help other family members financially. That is to say, the higher overall income of individuals does not mean that the family's total income is also higher. This situation should be more common in developing countries. Therefore, while paying attention to improving personal income, policymakers need to consider the ultimate impact of policies on personal benefits separately.

Inequality of social class will bring socio-political and economic instability. Although mass sports participation is only one indicator of a healthy lifestyle, if the country continues to ignore equal access to mass sports participation, it will eventually affect the stability of the social structure.

As a developing country, China has already reached the upper middle-income status by World Bank definitions. Most developing countries are growing much slower than China and remain relegated to low-income or lower-middle-income status. Based on this consideration, inequality in mass sports participation in China can be seen as an inevitable process that other developing countries will experience in the future, and the discussion of the study using China as a case can provide prior experience to a certain extent. However, China's political system and economic development process differ greatly from most developing countries. Developing countries should fully understand and analyze their national conditions when learning from China's experience.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: http://www.cnsda.org/index.php?r=projects/index.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

Author contributions

YW conceived the study, collected and analyzed the data, and prepared the manuscript draft. HD provided comprehensive editing, interpretation of the data, and manuscript refinement. WL sorted out the literature. JD put forward suggestions for revision. All authors read and approved the final manuscript.

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Conflict of interest

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

Publisher's note

References

1. Wei, JP, Rahim S, Wang SZ. Role of environmental degradation, institutional quality, and government health expenditures for human health: evidence from emerging seven countries. *Front. Public Health.* (2022) 10:870767. doi: 10.3389/fpubh.2022.870767

2. Reiss F, Meyrose AK, Otto C, Lampert T, Klasen F, Ravens-Sieberer U. Socioeconomic status, stressful life situations and mental health problems in children and adolescents: Results of the German BELLA cohort-study. *PLoS ONE.* (2019) 14:e0213700. doi: 10.1371/journal.pone.0213700

3. de Freitas DF, Pritchard M, Shetty H, Khondoker M, Nazroo J, Hayes RD,et al. Ethnic inequities in multimorbidity among people with psychosis: A retrospective cohort study. *Epidemiol Psychiatric Sci.* (2019) 31: E52. doi: 10.1017/S2045796022000385

4. Svendsen MT, Bak CK, Sørensen K, Pelikan J, Riddersholm SJ, Skals RK, et al. Associations of health literacy with socioeconomic position, health risk behavior, and health status: a large national population-based survey among Danish adults. *BMC Public Health.* (2020) 20:565. doi: 10.1186/s12889-020-08498-8

5. Frase RT, Bauldry S. The expansion of higher education and the education-health gradient in the United States. *Soc Curr.* (2022) 9:70–86. doi: 10.1177/23294965211021645

6. Schwandt H, Currie J, von Wachter T, Kowarski J, Chapman D, Woolf SH. Changes in the relationship between income and life expectancy before and during the COVID-19 pandemic, California, 2015-2021. *JAMA.* (2022) 328:360–366. 10952 doi: 10.1001/jama.2022.10952

7. Nessel, K. Balancing mass sports participation and elite sports performance: heterogeneity of the EU countries. *J Phys Educ Sport.* (2021) 21:2. doi: 10.7752/jpes.2021.s2146

8. Schönbach JK, Bolte G, Czwikla G, et al. Equity impacts of interventions to increase physical activity among older adults: a quantitative health impact assessment. *Int J Behav Nutr Phys Act.* (2020) 17:103. doi: 10.1186/s12966-020-00999-4

9. Kenyon, G. S. Sport involvement: A conceptual go and some consequences thereof. In: *Sociology of Sport*. (1969). Chicago: Athletic Institute. p. 77–99.

10. Su Yeon Roh, Ik Young Chang. Gender, social stratification, and differences in sports participation among Korean adults: data from the 2019 Korea National Sports Participation Survey. *J. Mens. Health.* (2022) 18:168. doi: 10.31083/j.jomh1808168

11. Goldsmith PR, Abel R. The dice are loaded: Schools' social class composition and athletic contests. *Socius.* (2022) 8:23780231211069423. doi: 10.1177/23780231211069423

12. Meier A, Hartmann BS, Larson R. A quarter century of participation in school-based extracurricular activities: Inequalities by race, class, gender and age? *J Youth Adolesc.* (2018) 47:1299–316. doi: 10.1007/s10964-018-0838-1

13. Hayhurst LMC, Thorpe H, Chawansky M. *Introducing Sport, Gender and Development: A Critical Intersection, Sport, Gender and Development*. Bingley: Emerald Publishing Limited (2021) 1-32 p.

14. Zhou, J. Chinese active lifestyle development: limitations and countermeasures. *Revista Brasileira De Medicina Do Esporte*. (2022) 28:390–3. doi: 10.1590/1517-8692202228052021_0531

15. Michael Mutz & Johannes Müller. Social stratification of leisure time sport and exercise activities: comparison of ten popular sports activities. *Leisure Stud*. (2021) 40:597–611. doi: 10.1080/02614367.2021.1916834

16. McKibbin, R. *The Sporting Life, Classes and Culture: England 1918-1951*. UK: Oxford University Press (1998) 332-385 p.

17. Stempel C. Sport as high culture in the USA. *Int Rev Sociol Sport*. (2020) 55:1167–91. doi: 10.1177/1012690219870067

18. Li C, Li D, He S, Sun S, Tian Y, Wang Z. The effect of big data-based digital payments on household healthcare expenditure. *Front Public Health*. (2022) 10:922574. doi: 10.3389/fpubh.2022.922574

19. Wang Z, Li M, Lu J, Cheng X. Business Innovation based on artificial intelligence and Blockchain technology. *Inform Process Manage*. (2022) 59:102759. doi: 10.1016/j.ipm.2021.102759

20. Wang, Z, Lu, J, Li, M, Yang, S, Wang, Y, Cheng, X. Edge Computing and Blockchain in Enterprise Performance and Venture Capital Management. *Comput Intell Neurosci*. (2022) 20:2022. doi: 10.1155/2022/2914936

21. Wang Z, Zhang S, Zhao Y, Chen C, Dong X. Risk prediction and credibility detection of network public opinion using blockchain technology. *Technol Forecast Soc Change*. (2023) 187:122177. doi: 10.1016/j.techfore.2022.122177

22. Yang F. Visual Analysis of China's Sports Policy Based on Knowledge Map. *J Shangqiu Normal Univ*. (2022) 38:66–8. doi: 10.1177/2158244020988725

23. Junmin Z, Donghua L, Guosheng S, Lan L, Yun G, Lv M, Xiang F, Tao H. Facing 2030: practical exploration and enlightenment of ioc in promoting sustainable development. *J Shanghai Univ Sport*. (2022) 46:56–64. doi: 10.16099/j.sus.2022.01.05.0004

24. Aiqun L, Wangang L, Changzhu Q, Xiaohong W. The character and value of Chinese Sports spirit in contributing to the great revival of the Chinese nation—review of the seminar on Chinese Sports Spirit and the Great Revival of the Chinese Nation. *J Wuhan Sports University*. (2022) 56:5–11. doi: 10.15930/j.cnki.wtxb.2022.11.001

25. The State Council Information Office of the People's Republic of China. Outline of Building a Powerful Sports Country. Available online at: http://www.gov.cn/zhengce/content/2019-09/02/content_5426485.htm (accessed January 30, 2023).

26. Committee on Physical Activity and Physical Education in the School Environment; Food and Nutrition Board; Institute of Medicine; Kohl HW III, Cook HD. *Educating the student body: taking physical activity and physical education to school*. Washington (DC): National Academies Press (2013)

27. Donnelly P. "Chapter VI. Sport Participation". Thibault, Lucie, et Jean Harvey. *Sport Policy in Canada*. Ottawa: University of Ottawa Press (2013) 177–213 p.

28. Lenartowicz M. Family leisure consumption and youth sport socialization in post-communist Poland: A perspective based on Bourdieu's class theory. *Int Rev Sociol Sport*. (2016) 51:219–37. doi: 10.1177/1012690213516619

29. Nobis T, El-Kayed N. Social inequality and sport in Germany–a multidimensional and intersectional perspective. *Eur J Sport Soc*. (2019) 16:5–26. doi: 10.1080/16138171.2019.1577328

30. Valenti M, Scelles N, Morrow S. The determinants of stadium attendance in elite women's football: Evidence from the UEFA Women's Champions League. *Sport Manage Rev*. (2020) 23:509–20. doi: 10.1016/j.smr.2019.04.005

31. Ma S, Kaplanidou K. Social capital and running: a network social capital perspective. *Sustainability*. (2021) 13:12398. doi: 10.3390/su132212398

32. Gemar A. The social patterning of sport: dispositions in regular sports participation and stratification in Canada. *World Leisure J*. (2021) 63:390–410. doi: 10.1080/16078055.2020.1832910

33. Giddens A. The Consequences of Modernity. *Stanford, 1990*. (1991).

34. Mutz M, van Munster M. Associations of physical activity policies with sports participation in EU countries: higher overall levels, smaller social inequalities, and more positive trends since 2009. *J Phys Activity Health*. (2020) 17:464–70. doi: 10.1123/jpah.2019-0329

35. Skauge M, Seippel Ø. Where do they all come from? Youth, fitness gyms, sport clubs and social inequality. *Sport Soc*. (2022) 25:1506–27. doi: 10.1080/17430437.2020.1840554

36. Hoekman R, Scheerder J. Sport policy practice and outcome: theoretical and empirical approaches. *Eur J Sport Soc*. (2021) 18:103–13. doi: 10.1080/16138171.2021.1926772

37. Wang, W, Wang, Y. A Qualitative Research on the Winter Sports Body-Building Activities of Chinese Residents from the Perspective of Social Stratification. *Revista de Psicología del Deporte (J Sport Psychol)*. (2021) 30:20–9.

38. Reyes, J. Sport omnivorism: Social stratification of sports practice in Chile. *Int Rev Sociol Sport*. (2021) 56:779–803. doi: 10.1177/1012690220959102

39. Munoz-Comet J, Martinez-Pastor JI. The influence of parents' physical activity on participation in sport. How does it affect social class inequality?. *Sociologia*. (2021) 79:e185.

40. Yang, Y, Liu, L. Strategic uncertainty, coordination failure and emergence: A game theory study on agency-structure interactions. *J Theory Soc Behav*. (2019) 49:402–20. doi: 10.1111/jtsb.12215

41. Daines CL, Hansen D, Novilla MLB, Crandall A. Effects of positive and negative childhood experiences on adult family health. *BMC Public Health*. (2021) 21:1–8. doi: 10.1186/s12889-021-10732-w

42. Jaf D, Özdemir M, Skoog, T. Immigrant and Swedish adolescents' involvement in organized sports activities: an expectancy-value approach. *BMC Psychol*. (2021) 9:12. doi: 10.1186/s40359-021-00522-9

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Adjunct tele-yoga on clinical status at 14 days in hospitalized patients with mild and moderate COVID-19: A randomized control trial

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Background: The initial insights from the studies on COVID-19 had been disappointing, indicating the necessity of an aggravated search for alternative strategies. In this regard, the adjunct potential of yoga has been proposed for enhancing the effectiveness of the standard of care with respect to COVID-19 management. We tested whether a telemodel of yoga intervention could aid in better clinical management for hospitalized patients with mild-to-moderate COVID-19 when complemented with the standard of care.

Methods: This was a randomized controlled trial conducted at the Narayana Hrudyalaya, Bengaluru, India, on hospitalized patients with mild-to-moderate COVID-19 infection enrolled between 31 May and 22 July 2021. The patients (n = 225) were randomized in a 1:1 ratio [adjunct tele-yoga (n = 113) or standard of care]. The adjunct yoga group received intervention in tele-mode within 4-h post-randomization until 14 days along with the standard of care. The primary outcome was the clinical status on day 14 post-randomization, assessed with a seven-category ordinal scale. The secondary outcome set included scores on the COVID Outcomes Scale on day 7, follow-up for clinical status and all-cause mortality on day 28, post-randomization, duration of days at the hospital, 5th-day changes post-randomization for viral load expressed as cyclic threshold (Ct), and inflammatory markers and perceived stress scores on day 14.

Results: As compared with the standard of care alone, the proportional odds of having a higher score on the 7-point ordinal scale on day 14 were ~1.8 for the adjunct tele-yoga group (OR = 1.83, 95% CI, 1.11–3.03). On day 5, there were significant reductions in CRP ($P = 0.001$) and LDH levels ($P = 0.029$) in the adjunct yoga group compared to the standard of care alone. CRP reduction was also observed as a potential mediator for the yoga-induced improvement of clinical outcomes. The Kaplan–Meier estimate of all-cause mortality on day 28 was the adjusted hazard ratio (HR) of 0.26 (95% CI, 0.05–1.30).

Conclusion: The observed 1.8-fold improvement in the clinical status on day 14 of patients of COVID-19 with adjunct use of tele-yoga contests its use as a complementary treatment in hospital settings.

KEYWORDS

tele-yoga, COVID-19, hospitalized patients, clinical status, India

Introduction

The rapid global spread of the coronavirus-related pneumonia outbreak, which was described first in December 2019, led to the evolution of one of the most extensive pandemics in human history so far (1–3). Although the mainstay of treatment for patients with COVID-19 pneumonia remains symptomatic and supportive care (4–6), the devastating impact of the pandemic led to a parallel unprecedented quest of identifying new and/or repurposed pharmacological treatments (5–10). Unfortunately, the initial indications from these studies were disappointing, which aggravated the search for strategies based on complementary and alternative medicine (5–11). Amid this uncertainty, several key clinicians and scientists identified and proposed the adjunct potential of yoga for enhancing the effectiveness of standard of care with respect to COVID-19 management in acute settings (12). The authors emphasized the relevance of certain practices of yoga and meditation in helping reduce the severity of COVID-19, including its collateral effects and sequelae (12), further underlining the immunomodulatory, anti-inflammatory, and stress modulatory potential of yoga (13–15). This notion was further strengthened by the findings of a preliminary report wherein tele-yoga intervention was reported to be safe, feasible, and useful in improving individual wellbeing and reducing stress (16). However, the long duration of direct exposure to patients during routinely delivered yoga interventions outweighs the benefit-to-risk ratio of physically delivered yoga interventions. Hence, we deemed the tele-mode of delivering the intervention as a viable and safer option for acute care in hospital settings. With the given background, this clinical trial was conducted to address the necessity of testing the effectiveness of tele-yoga as an adjunct to the standard of care in improving the clinical outcomes for adults hospitalized with COVID-19.

Design and amendments

The protocol was approved by the Institutional Ethics Committee of Narayana Health City and conducted in compliance with the Declaration of Helsinki. The study protocol was approved for funding by the Department of Science and Technology, Government of India. All patients or legally authorized representatives provided written informed consent. Given the uncertainty in the recruitment and random allocation of the study subjects in chaotic hospital settings amid the pandemic, the trial was initially planned as a non-randomized clinical trial wherein an integrative yoga-based supportive care was planned to be administrated as an adjunct intervention for hospitalized patients with COVID-19. However, the protocol was amended on 14 May 2020, based on the emerging feasibility of conducting the randomization trial as emphasized by the clinicians due to the superior design of randomized vs. non-randomized trials. The study was registered at the clinical trial registry of India (CTRI/2020/09/027915, registered on 21/09/2020).

Participants

Given a significant proportion of the requirement for timely hospitalization and management of patients with COVID-19, we recruited hospitalized patients with COVID-19 in this trial. Patients with mild and moderate COVID-19 were referred and managed at the Mazumdar Shaw Medical Center, Narayana Hrudyalaya, Bengaluru, India. SARS-CoV-2 cases, confirmed by polymerase chain reaction (PCR), were included as mild or moderate according to FDA guidance with the following eight symptoms: (17) fever, cough, sore throat, malaise, headache, muscle pain, gastrointestinal symptoms, and shortness of breath with exertion. Detailed eligibility criteria are listed below:

Inclusion criteria

The inclusion criteria are as follows:

- Age 18–60 years old, both genders.
- Willing and able to provide written informed consent prior to performing study procedures.
- Oxygen saturation measured by pulse oximetry (SpO_2) $\geq$ 90% on room air at sea level/with oxygen supplement non-invasively and not requiring intubation (18). The moderate disease definition was based on the $SpO_2 \geq 90\%$ and respiratory rate (RR) between 15 and 30/min.
- SARS-CoV-2 infection confirmed by PCR test $\leq$ 4 days before randomization.

Exclusion criteria

The exclusion criteria are as follows:

- Breastfeeding and pregnant patients were excluded based on their declaration and pregnancy test results when required.
- Patients with $SpO_2 < 90\%$ on room air, a ratio of arterial partial pressure of oxygen to the fraction of inspired oxygen (PaO_2/FiO_2) < 300 mm Hg, a respiratory rate of >30 breaths/min, or lung infiltrates of >50%.
- Patients diagnosed with critical COVID-19: respiratory failure, septic shock, and/or multiple organ dysfunction (MOD) or failure (MOF).
- Already enrolled in another COVID-19 trial or currently on any physiotherapy-based interventions.
- Unable to provide informed consent (e.g., moderate–severe dementia diagnosis).
- Those with more than 4 L per minute of supplemental oxygen (19).

Outcomes

We used the seven-category ordinal scale that has been used in different COVID-19 therapeutic trials (7, 20). The primary outcome was the clinical status on day 14 post-randomization, assessed with a seven-category ordinal scale (the COVID Outcomes Scale) recommended by the World Health Organization (20). The scale consisted of seven mutually exclusive categories: 1, death; 2, hospitalized, receiving extracorporeal membrane oxygenation (ECMO) or invasive mechanical ventilation; 3, hospitalized, receiving noninvasive mechanical ventilation or nasal high-flow oxygen therapy; 4, hospitalized, receiving supplemental oxygen without positive pressure or high flow; 5, hospitalized, not receiving supplemental oxygen; 6, not hospitalized and unable to perform normal activities; and 7, not hospitalized and able to perform normal activities. To distinguish between categories 6 and 7, study personnel assessed the patient's performance of usual activities with questions consistent with validated health status measures (21).

All the patients provided written or electronic informed consent before randomization. The secondary outcome set included the following: scores on the COVID Outcomes Scale on day 7, follow-up for clinical status and all-cause mortality on the 28th-day post-randomization, duration of days at the hospital, 5th-day changes post-randomization for viral load expressed as cyclic threshold (Ct), and inflammatory markers and perceived stress scores on day 14. Other auxiliary markers were HbA1c, blood hemogram, and kidney function markers. All protocol amendments were authorized and approved by the institutional review board or independent ethics committee.

Clinical and laboratory monitoring

Assessments

Data were collected daily, from randomization until day 28, in the patient proforma. For patients who were discharged before day 7, structured telephone calls were made to the patient or the family on days 7, 14, and 28 by an interviewer who was unaware of the assigned trial group to assess the vital status and return to routine activities. All samples were processed by PCR for genes N and E of SARS-CoV-2. Demographic, clinical, laboratory, and radiology data from patients' medical records were collected by the research team. The data were evaluated by a trained team of physicians. The date of disease onset was defined as the day when the symptom was noticed. Data on symptoms, vital signs, and laboratory values on biomarkers of disease progression, biomarkers [C-reactive protein (CRP), D-dimer, interleukin 6 (IL-6), ferritin, and lactate dehydrogenase (LDH)], and treatment measures during the hospital stay were collected. Patient assessments included physical examination, respiratory status (respiratory rate, type of oxygen supplementation, and blood oxygen saturation), adverse events, and concomitant medications. Blood-based investigations were done on days 1 and 5 post-randomization/hospitalization as per the routine analysis regime followed in the hospital settings. These investigations included measurement of blood cell counts, serum creatinine, glucose, total bilirubin, liver transaminases, and inflammatory biomarkers. Perceived stress was assessed using the Perceived Stress Scale 10 (PSS-10) (22). Site investigators assessed clinical status daily from days 1 to 14 or hospital discharge on a 7-point ordinal scale. The clinical status and mortality outcomes on the 28th day were assessed telephonically. In case of over a day change in the scores observed for the clinical status, worse scores of the hospitalized patients were documented. Final assessments on clinical status were done on day 28 personally for hospitalized patients or through telephonic interviews for already discharged patients.

Intervention

We built a yoga protocol adjusted to isolated patients and staff, including delivery through tele-(videos) and in-person intervention. The recorded videos were used for the asynchronous delivery of tele-intervention. Instructional short videos were prepared in different languages constituting the intervention. While these videos were self-explanatory, yoga was delivered as supervised sessions with modules presented as recorded videos supervised by trained yoga therapists along with the distribution of practical training materials including both audio and video inputs. On day 1, the hands-on intervention was carried out in the COVID-19 wards through teams of certified yoga therapists in personal protective suites, within 4 h of randomization. The intervention was further continued in the hospital settings using tele-mode until discharge day using tele-(videos) along with facilitation through the physical presence of an instructor. The intervention was delivered daily two times for a duration of 10 min. For those who were discharged before 14 days post-randomization, tele-yoga sessions were continued from their home settings. Typical morning sessions were of 15-min duration and included flexibility exercises [hands in and out breathing (2 min), hands stretch breathing (2 min), and shoulder rotation (2 min) as part of their regular warm up]. These exercises were followed by quick relaxation and subsequent 8 min of pranayama (breathing exercises), consisting of abdominal breathing (3 min), alternate nostril breathing or Nadishuddhi pranayama (3 min), and Bhramari pranayama (2 min). These practices have been reported to have effects on the strengthening of the respiratory muscles, and respiratory function, including the development of awareness of expansion and contraction of the airways and continuous and rhythmic breathing, which has been reported to aid in thorough oxygenation of the lungs and reduce inflammation. The practice sessions ended with guided relaxation of 2 min with a resolve. Evening sessions were 10 min and focused on the aforementioned breathing exercises and concluded with guided meditation.

Clinical guidelines were followed up for treating patients via tele-yoga and hands-on techniques in cooperation with the medical heads of departments. The instructor or therapist monitored and ensured that the practices were done as per the module protocol and corrected the patients along with the doubt clarifications.

Standard of care

The standard of care was based on the recommendations of the Indian Council of Medical Research, which was updated as per the evolving evidence generated in drug trials and international consensus guidelines (23, 24). Overall, it included antibiotic agents, antiviral agents, corticosteroids, vasopressor support, and anticoagulants at the discretion of the clinicians.

Randomization

Randomization was done in permuted blocks of four in sequences created by the unblinded research staff in Microsoft Excel version 19.0 who provided masked allotment to the yoga trainers. Owing to the nature of the intervention, blinding was not possible, but outcome measures were blinded for the randomization groups. Eligible patients were randomly assigned in a 1:1 ratio to receive either standard of care or adjunct yoga. Allocation assignment was concealed from investigators and patients.

Statistical analysis

Sample size calculation

The sample size of 230 patients with a 1:1 randomization of adjunct tele-yoga to the standard of care provides ∼80% power to detect a 15% difference between treatment groups in time cumulative hospital discharge (i.e., with or without limiting abilities) rates of 80% in the adjunct tele-yoga group and 75% in the standard of care group, on day 14, using a two-sided 5% alpha. Analysis was performed with SPSS version 23 [IBM Corp., (N.Y., USA)].

The trial was analyzed by comparing patients randomized to adjunct tele-yoga vs. those randomized to standard of care, with the placebo group serving as the referent. The primary outcome was analyzed with a multivariable proportional odds model adjusted with age, sex, and comorbidities. Further adjustments with baseline (pre-randomization) COVID Outcomes Scale category and duration of acute respiratory symptoms are reported as *post-hoc* analysis. The results are presented with corresponding 95% confidence intervals. As mentioned earlier, for patients who were discharged prior to 7 days after randomization, primary outcome ascertainment was completed by telephone calls. Patients who could not be reached by telephone for the primary outcome assessment on days 7, 14, or 28 had the COVID Outcomes Scale score carried forward from the last outcome follow-up call if such a call was successfully completed or had a category 6 score (not hospitalized and unable to perform normal activities) imputed if no prior follow-up calls were successfully completed (8). For patients who remained hospitalized 14 days after randomization, primary outcome ascertainment was completed by a review of the medical records. Given the deviation from normality for the study variables, analysis of covariance was done using the rank transformation to study the influence of adjunct tele-yoga intervention on biomarker levels. A p-value of <0.05 was considered to indicate significant differences.

The heterogeneity of treatment effect by prespecified baseline characteristics was evaluated by adding an interaction term between randomized group assignment and the baseline characteristic of interest in the primary model. Baseline characteristics evaluated in the heterogeneity of treatment effect analyses included baseline COVID Outcomes Scale category, and duration of symptoms prior to randomization, age, sex, and race/ethnicity.

All-cause mortality was estimated using the Kaplan–Meier product limit method. The adjunct tele-yoga group was compared with the standard of care group using the log-rank test, and the mean estimates and 95% CIs were provided.

We also used the paramed command in SPSS to perform mediation analysis by fitting a linear regression model to the outcomes with yoga treatment, and the mediators included were the covariates. We applied the causal mediation method, to investigate whether biomarkers could be a causal pathway between intervention and the outcome. Regression models were fitted to the mediators with treatments included as covariates.

Post-hoc analyses

We also conducted sensitivity analyses of the primary endpoint adjusting for the day 1 clinical score and duration of symptoms. In addition, given the imbalance in the proportion of breathlessness at the baseline, we further analyzed the primary outcome with breathlessness prevalence as a covariate in the ordinal regression model. We also performed a *post-hoc* analysis that was stratified by CRP and LDH levels. We also calculated and compared the proportions of patients with a one-point or greater improvement, no change, or worsening of clinical status on days 7, 14, and 28.

Results

During the 60 days enrollment period (31 May and 22 July 2021), 326 patients were screened, 66 (20.24%) patients were excluded for being hospitalized for more than 48 h at the time of screening, and 24 (7.36%) had tested negative for RT-PCR on day 0 (baseline) for COVID-19. Furthermore, 11 eligible patients refused to participate (2.76%) (see Figure 1). Hence, out of 326 eligible patients, 225 could be randomized, 113 were randomized to the adjunct tele-yoga, and 112 were randomized to the standard of care group. The last outcome assessment was on 31 July 2021. Demographics and baseline disease characteristics of participants in both groups are presented in Table 1. Overall, the median age of the participants was 43 years (IQR, 35–53 years), 54.67% were male subjects, 37.78% had diabetes, 20.89% had hypertension, and 6.67% had coronary artery disease. There was an equal distribution of age, gender, and days before the onset of symptoms, comorbidities, and inflammatory markers between the study arms (Table 1; Supplementary Table S2). Overall, at baseline, 70.22% of patients presented with perceived or objective fever, 72.44% presented with cough, 12.44% presented with a sore throat, 25.33% presented with headache, and 50.72% presented with breathlessness. Other than the prevalence of breathlessness ($P = 0.006$), there were no remarkable differences between groups with respect to the distribution of covariates. The median duration of symptoms prior to randomization was 3 days (IQR, 2–4 days) in both groups. There were no differences in either vital signs or full blood count between

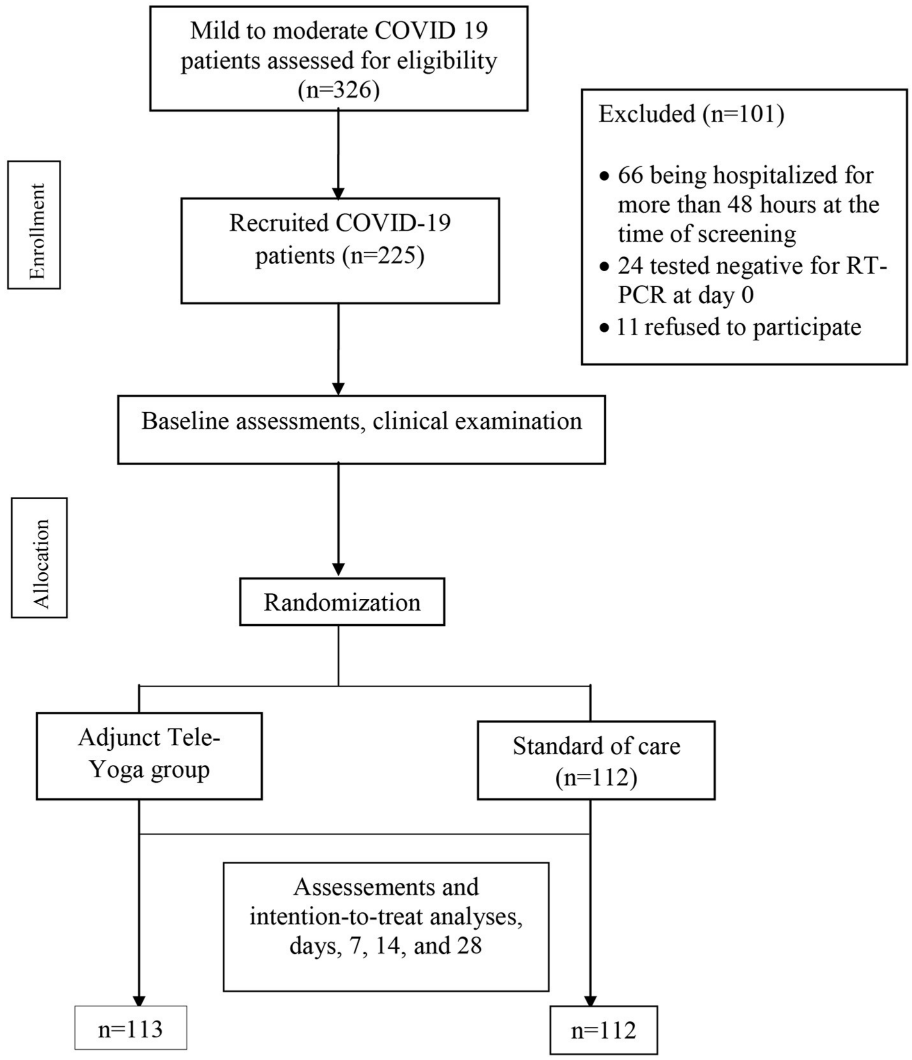


FIGURE 1
Trial profile.

the groups (Supplementary Table S2). Of the 113 patients in the adjunct yoga group, 29 (76%) were discharged before 7 days post-randomization and thus continued with tele-yoga sessions until the 14th day.

Primary outcome

For the analysis of outcomes, 113 and 112 patients were included for the adjunct tele-yoga and the standard of care groups, respectively; the analysis was by the originally assigned groups. The primary outcome (status on the 7-point ordinal scale on day 14) was assessed in all patients who were still hospitalized on day 14 or who were telephonically interviewed after being discharged from the hospital. The distribution of patients' scores on the seven-level ordinal scale at 14 days is shown in Figure 2. Patients randomized to the adjunct tele-yoga group had significantly higher odds of a better clinical status distribution on the 7-point ordinal scale compared with those randomized to standard care (odds ratio, 1.83, 95% CI = 1.11–3.03) (Figure 2). The model was adjusted for age, sex, and comorbidities. Sensitivity analyses of the primary endpoint adjusting for day 1 clinical status score and symptom duration using the intention-to-treat population produced no significant difference (Supplementary Table S3). Given the imbalance in the baseline distribution, we additionally adjusted the model for the prevalence of breathlessness, which did not lead to any significant reduction in effect size (Supplementary Table S3) (odds ratio, 1.84, 95% CI = 1.09–3.12). The results for the primary outcome were not different across the prespecified subgroups (Supplementary Table S4).

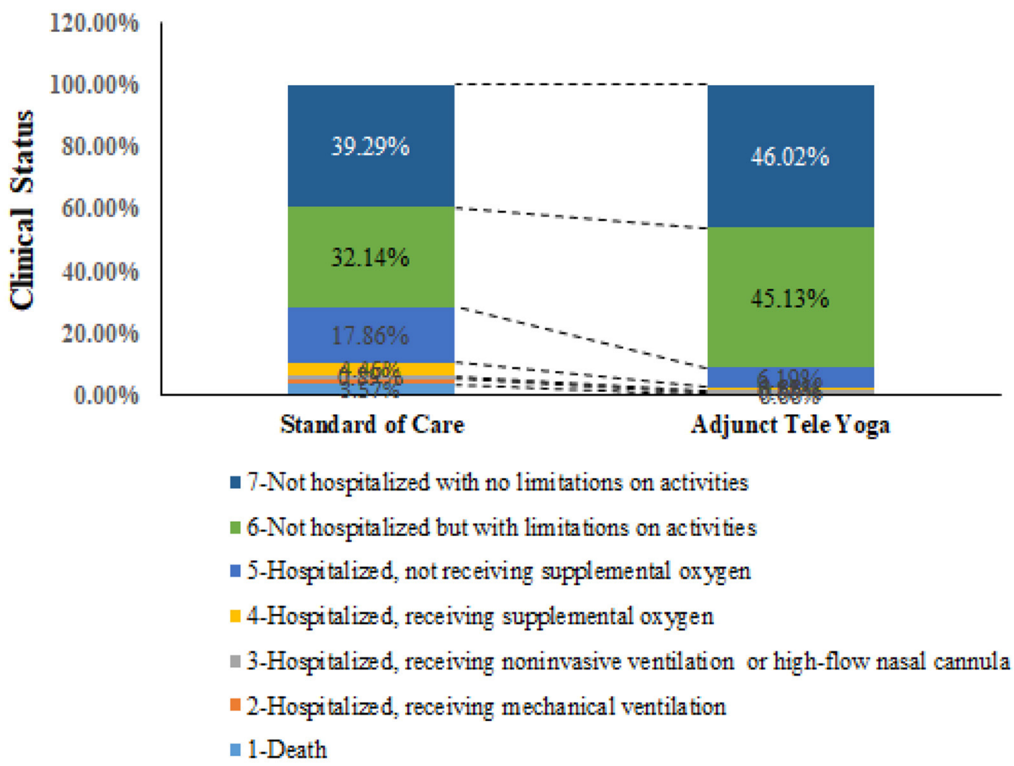
Secondary outcomes

There were significant differences between the adjunct tele-yoga and standard care groups in terms of improvement in

TABLE 1 Baseline patient characteristics.

Variable	Overall (n = 225)	Tele—yoga (n = 113)	Control (n = 112)	P-value
Age, median IQR	43 (35–53)	42 (35–53.5)	43 (36–52)	0.657
Sex				
Female	102 (45.33)	51 (45.13)	51 (45.54)	1.00
Male	123 (54.67)	62 (54.87)	61 (54.46)	
Coexisting conditions				
Hypertension, n (%)	47 (20.89)	21 (18.58)	26 (23.21)	0.416
Diabetes, n (%)	85 (37.78)	42 (37.17)	43 (38.39)	0.891
Coronary artery disease, n (%)	15 (6.67)	5 (4.43)	10 (8.93)	0.193
Hypothyroidism, n (%)	25 (11.11)	14 (12.39)	11 (9.82)	0.672
COPD, n (%)	3 (1.33)	3 (2.65)	0 (0)	0.222
Asthma, n (%)	2 (0.89)	0	2 (1.80)	0.244
Symptoms				
Fever/chills, n (%)	158 (70.22)	73 (64.61)	85 (75.89)	0.080
Cough, n (%)	163 (72.44)	82 (72.57)	81 (72.32)	1.000
Sore throat, n (%)	28 (12.44)	16 (14.16)	12 (10.71)	0.545
Nausea/vomiting, n (%)	13 (5.78)	7 (6.19)	6 (5.36)	1.000
General weakness, n (%)	92 (40.89)	48 (42.48)	44 (39.28)	0.685
Breathlessness, n (%)	105 (50.72)	44 (41.90)	61 (59.80)	0.006**
Headache, n (%)	57 (25.33)	34 (30.09)	23 (20.54)	0.125
Diarrhea , n (%)	11 (5.31)	4 (3.81)	7 (6.86)	NS
Previous medication use—no. (%)				
Glucocorticoid	7 (3.03)	5 (4.35)	2 (1.67)	NS
ACE inhibitor	12 (5.19)	7 (6.19)	5 (4.46)	NS
Angiotensin II–receptor antagonist	8 (3.46)	3 (2.61)	5 (4.35)	NS
Baseline ordinal COVID outcome score—no. (%)				
3. Hospitalized, not receiving supplemental oxygen	92 (40.89)	54 (47.79)	38 (33.93)	0.60
4. Hospitalized, receiving supplemental oxygen without positive pressure or high flow; requiring low-flow supplemental oxygen	125 (55.56)	57 (50.44)	68 (60.71)	
5. Hospitalized, receiving non-invasive ventilation or high-flow nasal cannula	8 (3.56)	2 (1.77)	6 (5.36)	
Ct value	28.00 (22.5–32.00)	27.00 (22.50–30.00)	28.0 (22.50–33.00)	0.125
Inflammatory markers				
C-reactive protein, mg/l	24.82 (8.09–63.67)	28.16 (8.43–65.46)	26.71 (8.47–67.40)	0.854
Ferritin, ng/ml	196 (81.85–421)	179 (82.30–404.50)	203 (77.40–441)	0.616
D-dimer, ng/ml	167 (94.00–242.00)	170 (94–245)	179 (95–250)	0.953
LDH, U/l	302 (241–392)	296 (226.50–355)	319 (248–436.94)	0.057
IL-6, mg/dl	37.65 (11.27–80.02)	31.89 (11.93–79.99)	39.76 (10.21–76.15)	0.808
Haemogram				
Hemoglobin (g/dl)	13.50 (12.20–14.60)	13.6 (12.10–14.70)	13.2 (12.20–14.45)	0.406
ALC ($\times 10^9$/L)	1.27 (0.87–1.92)	1.21 (0.84–1.86)	1.34 (0.88–1.95)	0.472
AMC ($\times 10^9$/L)	0.46 (0.29–0.74)	0.45 (0.28–0.72)	0.50 (0.32–0.77)	0.343
ANC ($\times 10^9$/L)	4.23 (2.85–6.71)	4.17 (2.91–6.64)	4.39 (2.73–6.83)	0.606
PSS	19 (15–24)	20 (16–25)	19 (13.25–23)	0.023*

For continuous variables, median and interquartile range (IQR) have been presented due to the non-normality of the data. Correspondingly, Mann–Whitney tests were used to assess whether differences between the study groups were statistically significant. For categorical variables, chi-square/Fisher's exact tests were used to check whether there was any association between the groups. Ct, cyclic threshold value; ALC, absolute lymphocyte count; AMC, absolute monocyte count; ANC, absolute neutrophil count; PSS, Perceived Stress Scale. $^*P < 0.05$; $^{**}P < 0.001$; NS, Not significant.



Primary outcome: Distribution n (%)	Total Subjects (n=225)	Standard of care (n=112)	Tele--yoga (n=113)
7: Not hospitalized with no limitations on activities	96 (42.67)	44 (39.29)	52 (46.02)
6: Not hospitalized but with limitations on activities	87 (38.67)	36 (32.14)	51 (45.13)
5: Hospitalized, not receiving supplemental oxygen	27 (12.00)	20 (17.86)	7(6.19)
4: Hospitalized, receiving supplemental oxygen	6 (2.67)	5 (4.46)	1 (0.88)
3: Hospitalized, receiving noninvasive ventilation or high-flow nasal cannula	2 (0.89)	1 (0.89)	1 (0.88)
2: Hospitalized, receiving mechanical ventilation	3 (1.33)	2 (1.79)	1 (0.88)
1: Death	4 (1.78)	4 (3.57)	0 (0.00)
Proportional Odds Ratio (OR, 95%CI)	1.83 (1.11-3.03), P=0.019		

FIGURE 2
Clinical status on the coronavirus disease (COVID) outcomes scale 14 days. The primary outcome was assessed in all patients who were still in the hospital on day 14 exactly and in outpatients (by means of telephonic interview) as close to day 14 as possible. OR—odds ratio was derived from the multivariable proportional odds model adjusted for baseline age, sex, and comorbidities (diabetes, hypertension, and hypothyroid). P-value <0.05 was considered significant.

clinical status on the 7th day (partially adjusted for age odds ratio, 3.61; 95% CI, 2.11–6.05; $P < 0.001$), but the follow-up outcome on 28th day was not significant (adjusted odds ratio, 1.70% CI = 1.03–3.44) (Supplementary Table S5). On day 5, there were significant reductions in CRP ($p = 0.001$) and LDH levels ($P = 0.029$) in the adjunct yoga group compared to the standard of care alone (Figure 3; Supplementary Table S6). There were no significant differences between the treatment groups in the duration of hospitalization, viral load (cyclic threshold values), and other markers of inflammation such as ferritin and D-dimer (Figure 3). The Kaplan–Meier estimates of all-cause mortality on day 28 were 1.80 vs. 5.40% for the standard of care [log-rank P-value = 0.144; adjusted hazard ratio (HR), 0.26; 95% CI, 0.05–1.30] (Supplementary Figure S1).

Exploratory outcomes

Since we could establish significant reductions in CRP and LDH on day 5 from post-randomization in the adjunct yoga

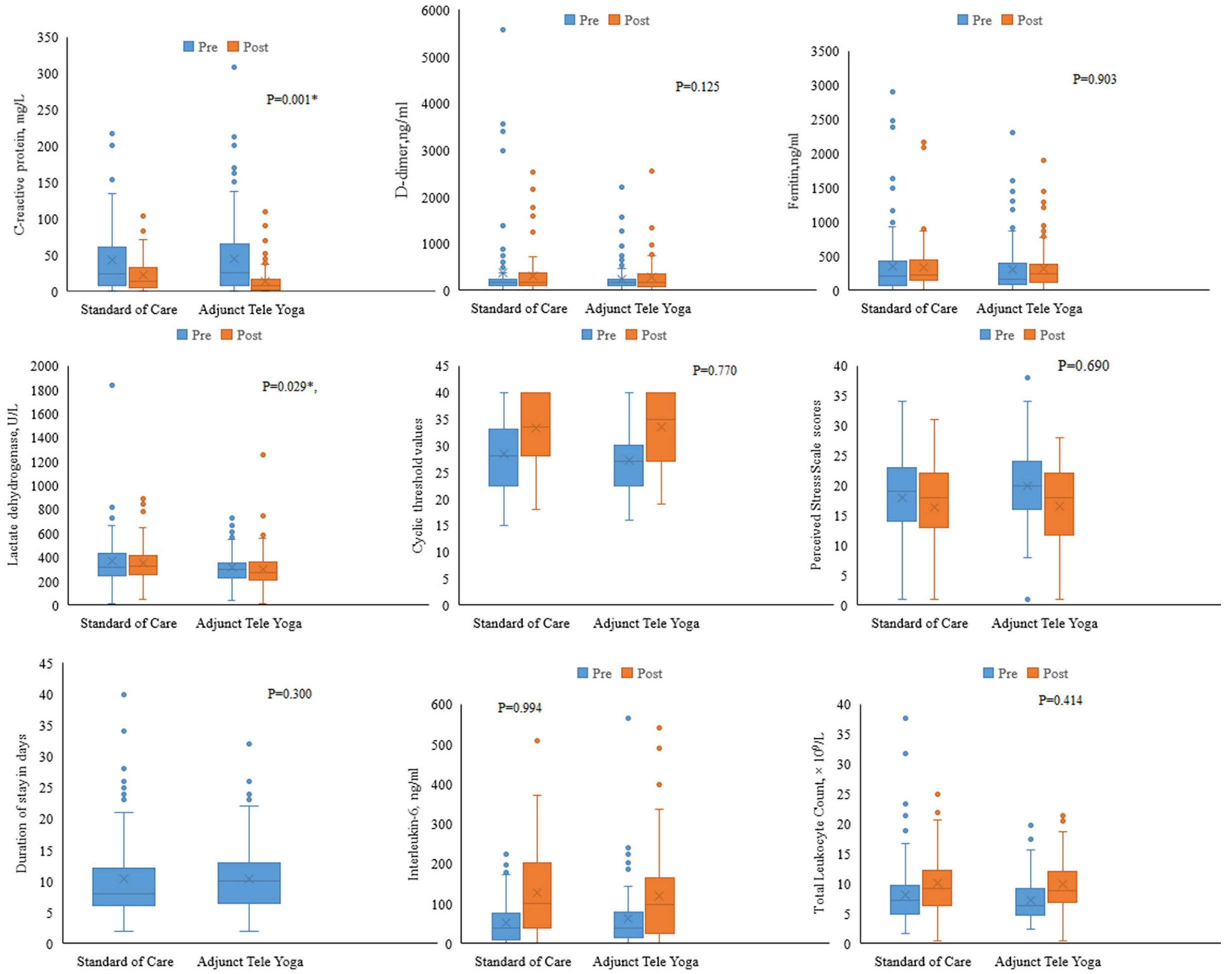


FIGURE 3
Biomarker levels on day 5 post-randomization. Changes in the biomarkers on day 5 were analyzed with respect to the baseline values. Analysis of covariance was done using the rank transformation to study the influence of adjunct tele-yoga intervention on biomarker levels. *Indicates *P*-value <0.05.

group compared to the standard of care group alone, we further tested for their mediating effects on the intervention (Table 2). The analyses indicated CRP as a potential mechanistic mediator of adjunct yoga on the improved clinical status on the 14th day post-intervention. There were also differences between proportions of subjects with at least 1 unit change in outcomes on day 7 from baseline between adjunct tele-yoga as compared to the standard of care groups. However, the distributions were not different for days 14 and 28 (Supplementary Figure S2).

Adverse effects

None of the eight deaths through day 28 [five (1%) in the standard of care, and three (2%) in the adjunct tele-yoga group] occurred in the patients with COVID-19 could be attributed to the tele-yoga intervention (Supplementary Table S7). In the tele-yoga group, the extension of hospitalization was 10.62%, whereas in the standard of care alone it was (21) 18.75%. Single cases of sinus tachycardia and pulmonary embolism were observed in the yoga group as compared to no cases in the standard of care.

Discussion

This study is a pioneer clinical trial that investigated the short-term acute interventional benefits of adjunct tele-yoga practice for the clinical management of hospitalized patients with COVID-19. We could establish a ∼1.9-fold improvement in the clinical status on the 14th day, in hospitalized patients with mild and moderate COVID-19 (odds ratio = 1.83, 95% CI = 1.11–3.03) as compared to those with the only standard of care. The odds of improvement with yoga intervention were higher on the 7th day (odds ratio = 3.61, 95% CI = 2.13–6.10). However, the effectiveness of the intervention was not found to be sustained at the 28th-day follow-up (odds ratio 1.70, 95% CI = 0.97–2.99, $P = 0.07$). Since patients had several coexisting diseases and were subjected to a diverse medication regimen, the complementary effects of tele-yoga could have been influenced by the heterogeneity of the sample and its treatment. However, when analyzed in the *post-hoc* subgroup

TABLE 2 Indirect, direct, and total effects of the mediation models on COVID-19 outcomes at 14-day post-randomization.

	Effect size	Proportion mediated
Direct effect of the adjunct tele-yoga vs. standard of care adjunct yoga	0.41 (0.03–0.78)	–
Total effect of the model	0.54 (0.17–0.91)	–
Indirect (mediating) effects		
LDH	−0.01 (−0.10 to 0.04)	Not significant
CRP	0.06 (0.05–0.16)*	11.11%

LDH, lactate dehydrogenase; CRP, C-reactive protein. $^{*}P < 0.05$.
Direct effect measures the direct influence of the intervention on the primary outcome that is not mediated by other variables in the model. An indirect or mediated effect expresses the portion of the intervention effect that is mediated through a specific mediator. The total effect is the sum of the direct and indirect effects of the BFY and mediators on the study outcomes.

analysis, adjunct yoga was found to be effective across all the strata of covariates. Concerning the influence of the intervention on mortality-related outcomes, no benefit could be observed for the adjunct yoga intervention with respect to mortality (hazards ratio = 0.26; 95% CI, 0.05–1.30). However, we could establish support for the primary endpoints with the observed secondary improvement in crucial biomarkers in the tele-yoga group compared to the standard of care on 5th-day post-randomization, CRP ($P = 0.001$) and LDH ($P = 0.029$). Both CRP and LDH have been reported as prognostic markers of deterioration in patients with COVID-19 including mild/non-severe cases as well (25, 26). We could also establish a mediation effect of CRP modulation underlying the effectiveness of tele-yoga intervention (∼11% proportion mediation on the observed improved outcome of clinical status on day 14). This inflammation-reducing effect of yoga well-aligns with the physiological modulation of vagal tone, one of the widely reported effects of yoga and meditation (12, 13). The anti-inflammatory potential of yoga could serve as a step forward in the fight against other serious forms of infectious diseases with a dominant inflammatory component, as proposed for malaria, HIV/AIDS, and SARS, among others. However, there was no significant modulating influence of the adjunct yoga intervention observed on other prognostic markers of COVID-19, in particular D-dimer and ferritin levels, which could be explained by their not so deregulated status at the baseline (D-dimer, median = 167 ng/ml (IQR, 94.00–242.00), and Ferritin levels, median = 196 ng/ml (IQR, 81.85–421).

We could not observe a significant effect of adjunct tele-yoga on the Perceived Stress Scale in patients with COVID-19 ($P = 0.69$). We speculate that the failure to obtain the desired effect on stress and several other variables could be due to the primarily virtual mode of the delivery of the intervention and the short duration of the intervention. However, the beneficial clinical outcomes observed in the study hold special significance in the present era with reemerging and recurring viral infections (27, 28). Overall, the findings of this study support the exploratory notions of several researchers and clinicians that certain meditation, yoga asana (postures), and pranayama (breathing) practices may be effective adjunctive means of treating SARS-CoV-2 infection (12). The findings also pave the foundation for the clinical implementation of tele-yoga-based adjunct interventions in hospital settings for the management of infectious diseases. A previous study on yoga had also reported it to be effective as an adjunct to anti-tuberculosis treatment (ATT) in patients with pulmonary tuberculosis by reducing the symptom scores, sputum conversion on microscopy, and improvement in the lung capacity and radiographic pictures (29).

This clinical exploration is one of the earliest to be reported among several other concomitant attempts to establish the efficacy of additional systems of medicine, against the combat of COVID-19, as evidenced by 67 such registered trials in the Clinical Trial Registry of India (CTRI) (30). Hence, given the lack of available findings from clinical trials on COVID-19 and yoga-based interventions, the findings of this trial could not be presented with comparisons.

The study has several strengths. One of the strengths of the study is the inclusion of WHO criteria for assessing the benefit on clinical status for patients hospitalized with mild and moderate COVID-19. This is the first report wherein yoga-based intervention was provided in a tele-mode to patients with COVID-19. This was done to prevent healthcare employees from being infected. Importantly, the trial included inflammatory markers as study outcomes, wherein an anti-inflammatory mediating influence of yoga intervention could be established to improve the outcomes of hospitalized patients with mild-to-moderate COVID-19. A key feature of the trial was the early implementation of treatment within 7 days of symptom onset (median duration of 3 days) which has been considered important for the treatment protocol, in particular antivirals such as remdesivir.

The trial was limited to hospitalized patients with COVID-19 which restricts the generalizability of the findings to other populations involving home-based care. The intervention duration was limited to 14 days, and assessments were limited to 28 days follow-up; however, the continued intervention could have led to sustained positive effects with respect to late complications of COVID-19. Reporting long-term outcomes of trial participants should have been considered. Given the nature of the intervention, the study used an open-label design, which could have led to biases in patient care and reporting of data. Due to logistic challenges, the laboratory-based parameters could not be collected on the prespecified 14th day time point. There was also an imbalance in the baseline distribution of the covariate, breathlessness, indicating differences in the severity status of the subjects between groups. However, we confirmed the robustness of the primary outcome with a *post-hoc* analysis adjusting for the baseline distribution of the covariate in the ordinal regression model.

Overall, we could observe clinically relevant effects among hospitalized patients with mild-to-moderate COVID-19, contesting the use of tele-yoga as a complementary treatment for patients with this disease. However, the positive signal found in this small-scale trial warrants the conduction of larger trials using tele-yoga for the treatment of COVID-19.

Data availability statement

Datasets are available on request to the corresponding author.

Ethics statement

The study protocol was approved by the Institutional Ethics Committees of the Narayana Health City and Swami Vivekananda Yoga Anusandhana Samsthana, Bengaluru, India. The patients provided their written informed consent to participate in this study.

Author contributions

VM, RNag, and NM take responsibility for the integrity of the data and the accuracy of the data analysis and drafting of the manuscript. RNag, NM, and VM contributed to concept and design. SP, SS, AG, MR, RNay, and VM contributed in acquisition, analysis, or interpretation of data. NM, RNag, MK, and HN did critical revision of the manuscript for important intellectual content. VM contributed in statistical analysis. VM, NM, and RNag obtained funding and contributed in administrative, technical, or material support. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1054207/full#supplementary-material

References

1. Dong E, Du H, Gardner L. An interactive web-based dashboard to track COVID-19 in real time [published correction appears in Lancet Infect Dis. 2020 Sep;20:e215]. *Lancet Infect Dis*. (2020) 20:533–4. doi: 10.1016/S1473-3099(20)30120-1

2. Phelan AL, Katz R, Gostin LO. The novel coronavirus originating in Wuhan, China: challenges for global health governance. *JAMA*. (2020) 323:709–10. doi: 10.1001/jama.2020.1097

3. World Health Organization. *COVID-19 Public Health Emergency of International Concern (PHEIC) Global Research and Innovation Forum*. (2020). Available online at: https://www.who.int/publications/m/item/covid-19-public-health-emergency-of-international-concern-(pheic)-global-research-and-innovation-forum (accessed November 10, 2022).

4. Sanders JM, Monogue ML, Jodlowski TZ, Cutrell JB. Pharmacologic treatments for coronavirus disease 2019 (COVID-19): a review. *JAMA*. (2020) 323:1824–36. doi: 10.1001/jama.2020.6019

5. Fan E, Beitler JR, Brochard L, Calfee CS, Ferguson ND, Slutsky AS, et al. COVID-19-associated acute respiratory distress syndrome: is a different approach to management warranted? *Lancet Respir Med*. (2020) 8:816–21. doi: 10.1016/S2213-2600(20)30304-0

6. Cusinato J, Cau Y, Calvani AM, Mori M. Repurposing drugs for the management of COVID-19. *Expert Opin Ther Pat*. (2021) 31:295–307. doi: 10.1080/13543776.2021.1861248

7. Spinner CD, Gottlieb RL, Criner GJ, López JRA, Cattelan AM, Viladomiu AS, et al. Effect of remdesivir vs standard care on clinical status at 11 days in patients with moderate COVID-19: a randomized clinical trial. *JAMA*. (2020) 324:1048–57. doi: 10.1001/jama.2020.16349

8. Self WH, Semler MW, Leither LM, Casey JD, Angus DC, Brower RG, et al. Effect of hydroxychloroquine on clinical status at 14 days in hospitalized patients with COVID-19: a randomized clinical trial. *JAMA*. (2020) 324:2165–76. doi: 10.1001/jama.2020.22240

9. López-Medina E, López P, Hurtado IC, Dávalos DM, Ramirez O, Martínez E, et al. Effect of ivermectin on time to resolution of symptoms among adults with mild COVID-19: a randomized clinical Trial. *JAMA*. (2021) 325:1426–35. doi: 10.1001/jama.2021.3071

10. Siemieniuk, R. A., Bartoszko, J. J., Ge, L., Zeraatkar, D., Izcovich, A., Kum, E., et al. Drug treatments for covid-19: living systematic review and network meta-analysis [published correction appears in BMJ. (2021) 373:n967]. *BMJ*. (2020) 370:m2980. doi: 10.1136/bmj.m2980

11. Murthy S, Gomersall CD, Fowler RA. Care for critically ill patients with COVID-19. *JAMA*. (2020) 323:1499–500. doi: 10.1001/jama.2020.3633

12. Bushell W, Castle R, Williams MA, Brouwer KC, Tanzi RE, Chopra D, et al. Meditation and yoga practices as potential adjunctive treatment of SARS-CoV-2 infection and COVID-19: a brief overview of key subjects. *J Altern Complement Med*. (2020) 26:547–56. doi: 10.1089/acm.2020.0177

13. Bower JE, Irwin MR. Mind-body therapies and control of inflammatory biology: a descriptive review. *Brain Behav Immun*. (2016) 51:1–11. doi: 10.1016/j.bbi.2015.06.012

14. Barrett B, Hayney MS, Muller D, Rakel D, Brown R, Zgierska AE, et al. Meditation or exercise for preventing acute respiratory infection (MEPARI-2): a randomized controlled trial. *PLoS ONE*. (2018) 13:e0197778. doi: 10.1371/journal.pone.0197778

15. Obasi CN, Brown R, Ewers T, Barlow S, Gassman M, Zgierska A, et al. Advantage of meditation over exercise in reducing cold and flu illness is related to improved function and quality of life. *Influenza Other Respir Viruses*. (2013) 7:938–44. doi: 10.1111/irv.12053

16. Jasti N, Bhargav H, George S, Varambally S, Gangadhar BN. Tele-yoga for stress management: need of the hour during the COVID-19 pandemic and beyond? *Asian J Psychiatr*. (2020) 54:102334. doi: 10.1016/j.ajp.2020.102334

17. Food and Drug Administration. *COVID-19: Developing Drugs and Biological Products for Treatment or Prevention*. (2020). Available online at: https://www.fda.gov/regulatory-information/search-fda-guidance-documents/covid-19-developing-drugs-and-biological-products-treatment-or-prevention (accessed August 23, 2021).

18. Ministry of Health and Family Welfare. Government of India. *Guidance Document on Appropriate Management of Suspect/Confirmed Cases of COVID-19*. Available online at: https://www.mohfw.gov.in/pdf/FinalGuidanceonMangaementofCovidcasesversion2.pdf (accessed December 1, 2020).

19. Cavalcanti AB, Zampieri FG, Rosa RG, Azevedo LC, Veiga VC, Avezum A, et al. Hydroxychloroquine with or without azithromycin in mild-to-moderate COVID-19. *N Engl J Med*. (2020) 383:e119. doi: 10.1056/NEJMx200021

20. World Health Organization. *WHO R&D Blueprint: Novel Coronavirus: COVID-19 Therapeutic Trial Synopsis*. Available online at: https://www.who.int/blueprint/priority-diseases/key-action/COVID-19_Treatment_Trial_Design_Master_Protocol_synopsis_Final_18022020.pdf (accessed June 28, 2020).

21. EuroQol Group. EuroQol: a new facility for the measurement of health-related quality of life. *Health Policy*. (1990) 16:199–208. doi: 10.1016/0168-8510(90)90421-9

22. Cohen S, Kamarck T, Mermelstein R. A global measure of perceived stress. *J Health Soc Behav*. (1983) 24:385–96. doi: 10.2307/2136404

23. Government of India. Ministry of Health & Family Welfare. *Clinical Management Protocol: COVID-19*. Available online at: https://www.mohfw.gov.in/pdf/ClinicalManagementProtocolforCOVID19.pdf (accessed December 1, 2020).

24. Malhotra V, Basu S, Sharma N, Kumar S, Garg S, Dushyant K, et al. Outcomes among 10,314 hospitalized COVID-19 patients at a tertiary care government hospital in Delhi, India. *J Med Virol*. (2021) 93:4553–8. doi: 10.1002/jmv.26956

25. Wang G, Wu C, Zhang Q, Wu F, Yu B, Lv J, et al. C-reactive protein level may predict the risk of COVID-19 aggravation. *Open Forum Infect Dis*. (2020) 7:ofaa153. doi: 10.1093/ofid/ofaa153

26. Shi J, Li Y, Zhou X, Zhang Q, Ye X, Wu Z, et al. Lactate dehydrogenase and susceptibility to deterioration of mild COVID-19 patients: a multicenter nested case-control study. *BMC Med*. (2020) 18:168. doi: 10.1186/s12916-020-01633-7

27. Abrahão JS, de Arruda LB. Special issue "emerging viruses: surveillance, prevention, evolution, and control". *Viruses*. (2020) 12:306. doi: 10.3390/v12030306

28. Karim SSA, Karim QA. Omicron SARS-CoV-2 variant: a new chapter in the COVID-19 pandemic. *Lancet*. (2021) 398:2126–8. doi: 10.1016/S0140-6736(21)02758-6

29. Visweswaraiah NK, Telles S. Randomized trial of yoga as a complementary therapy for pulmonary tuberculosis. *Respirology*. (2004) 9:96–101. doi: 10.1111/j.1440-1843.2003.00528.x

30. Umesh C, Ramakrishna KK, Jasti N, Bhargav H, Varambally S. Role of ayurveda and yoga-based lifestyle in the COVID-19 pandemic - a narrative review. *J Ayurveda Integr Med*. (2022) 13:100493. doi: 10.1016/j.jaim.2021.07.009

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Predictive importance of the visceral adiposity index and atherogenic index of plasma of all-cause and cardiovascular disease mortality in middle-aged and elderly Lithuanian population

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Background: Two indices: visceral adiposity index (VAI) and atherogenic index of plasma (AIP) during several recent years were implemented into epidemiological studies for predicting of cardiovascular diseases (CVD) and mortality risk. Our study aimed to evaluate the association of VAI and AIP with the risk of all-cause and CVD mortality among the Lithuanian urban population aged 45–72 years.

Methods: In the baseline survey (2006–2008), 7,115 men and women 45–72 years of age were examined within the framework of the international study Health, Alcohol and Psychosocial Factors in Eastern Europe (HAPIEE). Six thousand six hundred and seventy-one participants (3,663 women and 3,008 men) were available for statistical analysis (after excluding 429 respondents with the missed information on study variables) and for them, VAI and AIP were calculated. The questionnaire evaluated lifestyle behaviors, including smoking and physical activity. All participants in the baseline survey were followed up for all-cause and CVD mortality events until December 31st, 2020. Multivariable Cox regression models were applied for statistical data analysis.

Results: After accounting for several potential confounders, higher levels of VAI (compared 5th quintile to 1st quintile) were associated with significantly higher CVD mortality in men [Hazards ratio (HR) = 1.38] and all-cause mortality in women (HR = 1.54) after 10-year follow-up. CVD mortality significantly increased in men with 0 the highest AIP quintile compared with that for the lowest quintile (HR = 1.40). In women, all-cause mortality was significantly higher for the 4th quintile of AIP as compared with the 1st quintile (HR = 1.36).

Conclusions: High-risk VAI levels were statistically significantly associated with all-cause mortality risk in men and women groups. The higher AIP level (5th quintile vs. 1st quintile—in men and 4th quintile vs. 1st quintile—in women) was significantly associated with increased mortality from CVD in the men group and increased all-cause mortality in the women group.

KEYWORDS

visceral adiposity index, atherogenic index of plasma, cardiovascular diseases, mortality, gender

1. Background

Cardiovascular diseases (CVD) are the leading cause of death in most countries of Europe and other regions of the World (1, 2). The mortality from diseases of the circulatory system in a population aged 0–64 years in Lithuania during the period 2001–2016 has been decreasing from 131 to 103 cases per 100,000 population (1). Both increasing and decreasing trends of CVD morbidity and mortality indicators in the population are closely related to changes in the prevalence of biological and lifestyle risk factors such as arterial hypertension, smoking, hyperlipidaemia, physical inactivity, overweight and obesity, and other factors (3–6). Obesity is well-known and highly prevalent in most regions of Europe risk factor for CVD (7). In Lithuania, the prevalence of obesity during the period from 1999 to 2009 increased by 4.2% in men aged over 20 years (from 26.1 to 27.2%) and by 1.9% in women (from 26.1 to 26.3%). In 2030, the obesity prevalence in Lithuania maybe 35.7% in men and 36.0% in women (7). Body mass index (BMI) is the most widely used measure of obesity both in epidemiological studies of chronic non-communicable diseases and in clinical practice. However, BMI similar to waist circumference (WC), and another simple anthropometric measurement, cannot measure visceral and subcutaneous fat levels. It is demonstrated that visceral adipose and subcutaneous adipose tissues are related to the risk of CVD (8). The level of visceral adipose tissue and subcutaneous abdominal fat could be very precisely evaluated using magnetic resonance imaging (MRI) or computed tomography (CT), but these methods are very expensive to be applied in epidemiological studies of CVD or even in the practice of family doctors (9). Amato et al. a decade ago identified the visceral adiposity index (VAI) (10) which is calculated using a mathematical model and evaluates the level of visceral adipose tissue. The model uses both anthropometric (BMI and WC) and lipid parameters [triglyceride and high-density lipoprotein (HDL) cholesterol concentrations]. This index is also gender-specific: calculated separately for men and women using in the model different coefficients.

The atherogenic index of plasma (AIP) is another index quite recently been implemented in some epidemiologic studies of CVD (11–13). AIP is a logarithmic conversion of triglycerides into HDL cholesterol ratio, which as results of some epidemiological studies show is a stronger predictor of CVD risk as compared to individual lipid risk factors [total cholesterol, triglycerides, HDL cholesterol, and low-density lipoprotein (LDL) cholesterol] (14–16).

The association between individual lipid risk factors, overweight, and obesity same as some individual anthropometric measurements with risk of CVD incidence and mortality in the Lithuanian population was quite intensively studied, analyzed, and presented (17–19). But to the best of our knowledge, no study assessing the association between VAI and AIP with risk of all-cause and CVD mortality not only in the Lithuanian population but also in populations in other Baltic Sea countries: Latvia and Estonia. Therefore, our cohort study aimed to evaluate the association of VAI and AIP with the risk of all-cause and CVD mortality among the Lithuanian urban population aged 45–72 years.

Abbreviations: AIP, Atherogenic index of plasma; BMI, Body mass index; BP, Blood pressure; CAD, Coronary artery disease; CHD, Coronary heart disease; CI, Confidence interval; CT, Computed tomography; CVD, Cardiovascular disease; ECG, Electrocardiogram; HDL, High-density lipoprotein; HR, Hazards ratio; ICD-10, International classification of diseases, 10th Edition; LDL, Low-density lipoprotein; MC, Minnesota codes; MI, Myocardial infarction; MRI, Magnetic resonance imaging; SD, Standard deviation; VAI, Visceral adiposity index; VAT, Visceral adipose tissue; WC, waist circumference.

2. Materials and methods

2.1. Study sample

This prospective cohort study was performed as part of the international project Health, Alcohol and Psychosocial Factors in Eastern Europe (HAPIEE) (20). The baseline survey was carried out (during 2006–2008) on Kaunas city (Lithuania) men and women aged 45–72 years. The study sample of 10,980 individuals, stratified by gender and age group, was randomly selected from the National population register. Seven thousand one hundred and fifteen individuals responded to the invitation to participate in the baseline survey (the response rate was 65%). All participants in the baseline survey follow-up for all-cause and CVD mortality events until December 31st, 2020. A total of 6,671 participants (3,663 women and 3,008 men) were available for statistical analysis after excluding 429 respondents with the missed information on study variables. Exclusion criteria: respondents for whom the nurses could not take a blood sample; respondents who refused to give blood for tests, and respondents who did not fill in the questionnaires correctly. The study was approved by the Kaunas Regional Biomedical Research Ethics Committee, Lithuania (11 January 2005; No. 05/09) and by the Ethics Committee at University College London, UK. Written informed consent was obtained from all study participants.

2.2. Variables determined using a standard questionnaire

Sociodemographic factors (age and education), lifestyle factors (smoking habits and physical activity), angina pectoris, and the history of CVD [previous coronary heart disease (CHD) and stroke] were determined at the baseline survey using a standard questionnaire. The reliability and validity of the questionnaire were checked during a pilot study.

The education of the participants was categorized into 2 groups: (1) secondary, vocational, or lower education; (2) college and university education.

Smoking habits were categorized as never smoking, former smoking, and current regular smoking (regular smoking at least 1 cigarette per day).

The physical activity of the participants in their leisure time was assessed using 5 questions in the standard questionnaire. Physical activity was calculated by summarizing time spent per week during leisure time separately in autumn-winter and spring-summer seasons for activities such as walking, gardening, maintenance of the house, and other physical activities. The participants were divided into three equal groups (tertiles) according to their mean length of time spent per week on physical activities. The first tertile

TABLE 1 Visceral adiposity index (VAI) and atherogenic index of plasma (AIP) levels.

	Men		Women	
	Min–max	Mean (SD)	Min–max	Mean (SD)
VAI quintiles				
1st quintile	0.16 to 0.69	0.51 (0.12)	0.27 to 0.85	0.65 (0.14)
2nd quintile	0.69 to 1.03	0.85 (0.10)	0.85 to 1.22	1.03 (0.11)
3rd quintile	1.03 to 1.44	1.22 (0.12)	1.22 to 1.71	1.44 (0.14)
4th quintile	1.44 to 2.21	1.78 (0.23)	1.71 to 2.57	2.08 (0.24)
5th quintile	2.21 to 19.3	3.68 (1.94)	2.57 to 24.0	4.13 (2.03)
AIP quintiles				
1st quintile	−0.87 to −0.27	−0.40 (0.11)	−0.76 to −0.30	−0.42 (0.10)
2nd quintile	−0.27 to −0.10	−0.18 (0.05)	−0.30 to −0.15	−0.23 (0.04)
3rd quintile	−0.10 to 0.04	−0.03 (0.04)	−0.15 to 0.01	−0.08 (0.04)
4th quintile	0.04 to 0.22	0.13 (0.05)	0.01 to 0.16	0.07 (0.05)
5th quintile	0.22 to 1.15	0.40 (0.16)	0.16 to 1.10	0.33 (0.15)

SD, standard deviation.

maximal cut-off was 10 h per week. This cut-off was used for determining of insufficient physical activity of study participants.

To assess the history of previous myocardial infarction of the participants, 2 questions from the standard questionnaire were asked: "Has a doctor ever told you that you have had a myocardial infarction?" and "Has a doctor ever told you that you have had a stroke?". Angina pectoris was evaluated by G. Rose's questionnaire (21).

2.3. Anthropometric measurements

Height, weight, and WC were measured directly by trained nurses. Weight was measured, with participants minimally clothed without shoes, using medical scales. Weight values were recorded to the nearest 100 g. The height of participants (without shoes) was measured with an accuracy of one centimeter, using a stadiometer. WC was measured at the midpoint between the lower rib and the iliac crest over light clothing, using a tape meter. Measurements of the WC were recorded to the nearest 0.5 cm. BMI (kg/m^2) was calculated as weight (kg) divided by the square of the height (m^2).

2.4. Other clinical and laboratory measurements

Blood pressure (BP) was measured three times with an oscillometric device (Omron M5-1) after at least 5 min of rest in a seated position, and mean values of systolic BP and diastolic BP were taken.

A resting electrocardiogram (ECG) was recorded in the 12 standard leads, with calibration of 10 mm per 1 mV and a paper speed of 25 mm per s. ECG records were read by 2 independent experienced coders (trained cardiologists) using the 1982 edition of the Minnesota Code (MC) (22).

Blood samples were drawn for the measurement of total cholesterol, HDL cholesterol, LDL cholesterol, and triglyceride levels the morning after study participants fasted overnight. All these biochemical determinations were performed in the same laboratory (the WHO Regional Lipid Reference Center, Institute of Clinical and Experimental Medicine, Prague (Czech Republic) using standard laboratory methods. The concentration of glucose in capillary blood was determined by a Glucotrend glucometer (23).

VAI score was calculated according to the definition of Amato et al. (10) using the following sex-specific equations where triglycerides and HDL-cholesterol levels are expressed in mmol/L:

Males: $VAI = [WC\ (cm)/(39.68 + 1.88 \times BMI\ (kg/m^2))] \times (triglycerides/1.03) \times (1.31/HDL\ cholesterol)$

Females: $VAI = [WC\ (cm)/(36.58 + 1.89 \times BMI\ (kg/m^2))])] \times (triglycerides/0.81) \times (1.52/HDL\ cholesterol)$

The AIP was calculated using the formula proposed by Frohlich and Dobiasova (11) ($\log_{10}$ (triglycerides (mmol/L)/HDL cholesterol (mmol/L))).

2.5. Definitions

Arterial hypertension was defined as systolic BP ≥ 140 mmHg and/or diastolic BP ≥ 90 mmHg, or usage of anti-hypertensive medication during last 2 weeks (24).

Increased level of total serum cholesterol was determined as total cholesterol concentration ≥5.0 mmol/L and increased fasting glucose level as glucose concentration in capillary blood ≥6.1 mmol/L (25, 26).

Insufficient physical activity was determined in the case when the mean time spent per week by study participants

TABLE 2 Baseline characteristics by survival status of men of the Kaunas HAPIEE study (2006–2008).

Variables*	Living status		
	Alive (n = 2,126)	All causes of death (n = 882)	Dead from CVD (n = 414)
Age, years, mean (SD)	56.0 (7.46)	62.3 (7.55)[a]	63.1 (7.20)[a]
Systolic blood pressure, mmHg, mean (SD)	142.9 (20.0)	150.9 (23.4)[a]	153.7 (24.4)[a]
Diastolic blood pressure, mmHg, mean (SD)	92.3 (12.5)	94.8 (13.6)[a]	92.3 (12.5)[a]
Arterial hypertension, %	74.6	83.7[a]	86.3[a]
Total cholesterol, mmol/L, mean (SD)	5.81 (1.08)	5.71 (1.15)[a]	5.73 (1.13)
HDL cholesterol, mmol/L, mean (SD)	1.41 (0.37)	1.39 (0.39)	1.34 (0.38)[a]
Triglyceride, mmol/L, mean (SD)	1.48 (0.89)	1.55 (0.98)	1.69 (0.18)[a]
Fasting blood glucose, mmol/L, mean (SD)	5.72 (1.07)	6.01 (1.66)[a]	6.25 (2.00)[a]
Body mass index, kg/m^2, mean (SD)	28.3 (4.30)	29.0 (5.19)[a]	29.9 (5.39)[a]
WC, cm, mean (SD)	94.3 (11.8)	97.9 (13.7)[a]	100.3 (13.8)[a]
VAI, mean (SD)	1.59 (1.37)	1.75 (1.71)[a]	2.00 (2.12)[a]
AIP, mean (SD)	−0.02 (0.29)	0.001 (0.30)	0.047 (0.32)[a]
Diabetes mellitus, %	5.3	14.4[a]	18.7[a]
CVD, %	12.6	33.9[a]	43.3[a]
Physical active in leisure time, %	67.5	61.3[a]	59.5[a]
Smoking habits, %			
Smokers, %	34.0	36.5	33.3
Never smokers + former smokers, %	66.0	63.5	66.7
Education, %			
Secondary + vocational	42.7	58.8[a]	58.3[a]
College + university	57.3	41.2[a]	41.7[a]

*All variables are age-adjusted.
[a]$p < 0.05$ compared to the alive group.
CVD, cardiovascular diseases; HAPIEE, Health, Alcohol and Psychosocial factors In Eastern Europe; HDL, high-density lipoprotein; WC, waist circumference; AI, visceral adiposity index; AIP, atherogenic index of plasma.

during leisure time for physical activities was lower than 10 h.

The participants were ranked from the lowest to the highest values of VAI and AIP and divided into five equal groups (quintiles) according to the levels of these variables (Table 1).

Coronary heart disease (CHD) at baseline was determined by: (1) a documented history of myocardial infarction (MI) and/or ischemic changes on ECG coded by MC 1–1 or 1–2 (22); (2) angina pectoris as defined by G. Rose's questionnaire (without MI and/or MC 1–1 or 1–2) (21); (3) ECG findings coded by MC 1–3, 4–1, 4–2, 4–3, 5–1, 5–2, 5–3, 6–1, 6–2, 7–1, or 8–3 (without MI and/or MC 1–1, 1–2 and without angina pectoris). The previous stroke was determined according to a documented history of stroke.

CVD included CHD and/or stroke which were determined at the baseline survey.

2.6. Mortality outcome

We used data from the Kaunas mortality register based on death certificates with follow-up through December 31, 2020. Cause of death was categorized using the International Classification of Diseases, 10th Edition (ICD-10). All causes of death included ICD-10 codes A00-Z99. CVD-specific mortality was categorized using codes I00-I99.

2.7. Statistical analysis

All statistical analysis was performed using IBM SPSS Statistics (Version 27.0) (IBM Corp. Released 2020. IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY, USA). We performed an analysis of study data separately for men and women. All descriptive characteristics [proportions, means, and standard

TABLE 3 Baseline characteristics by survival status of women of the Kaunas HAPIEE study (2006–2008).

Variables*	Living status		
	Alive (n = 3,101)	All causes of death (n = 562)	Dead from CVD (n = 268)
Age, years, mean (SD)	56.4 (7.53)	63.4 (7.48)[a]	66.5 (5.43)[a]
Systolic blood pressure, mmHg, mean (SD)	133.3 (19.9)	143.4 (24.3)[a]	148.9 (23.9)[a]
Diastolic blood pressure, mmHg, mean (SD)	87.3 (11.4)	90.9 (12.8)[a]	92.5 (12.9)[a]
Arterial hypertension, %	65.5	79.7[a]	88.3[a]
Total cholesterol, mmol/L, mean (SD)	6.06 (1.12)	5.96 (1.14)	6.03 (1.19)
HDL cholesterol, mmol/L, mean (SD)	1.60 (0.37)	1.50 (0.36)[a]	1.47 (0.34)[a]
Triglyceride, mmol/L, mean (SD)	1.39 (0.75)	1.53 (0.81)[a]	1.60 (0.94)[a]
Fasting blood glucose, mmol/L, mean (SD)	5.73 (0.99)	6.16 (1.77)[a]	6.34 (2.03)[a]
Body mass index, kg/m^2, mean (SD)	29.4 (5.56)	31.4 (6.43)[a]	31.9 (6.82)[a]
WC, cm, mean (SD)	87.9 (13.4)	93.9 (15.1)[a]	95.1 (15.6)[a]
VAI, mean (SD)	1.74 (1.49)	2.08 (1.78)[a]	2.25 (2.18)[a]
AIP, mean (SD)	−0.098 (0.27)	−0.026 (0.26)[a]	−0.006 (0.27)[a]
Diabetes mellitus, %	6.1	17.5[a]	24.1[a]
CVD, %	17.7	33.6[a]	43.6[a]
Physical active in leisure time, %	81.7	74.0[a]	68.4[a]
Smoking habits, %			
Smokers	14.0	9.2[a]	5.3[a]
Never smokers + former smokers	86.0	90.8[a]	94.7[a]
Education, %			
Secondary + vocational	35.2	51.8[a]	59.9[a]
College + university	64.8	48.2[a]	40.1[a]

*All variables are age-adjusted.

[a]$p < 0.05$ compared to the alive group.

CVD, cardiovascular diseases; HAPIEE, Health, Alcohol and Psychosocial factors In Eastern Europe; HDL, high-density lipoprotein; WC, waist circumference; VAI, visceral adiposity index; AIP, atherogenic index of plasm.

deviations (SD)] were calculated and presented across the groups by vital status at the end of follow-up in two ways (alive and died from all causes; alive, died from CVD and died from other causes). Differences between groups were detected by independent sample t-test and ANOVA analysis with Bonferroni corrections for continuous variables. A Chi-squared test and Z-test with Bonferroni corrections were used for determining differences in categorical variables. P-values < 0.05 were considered statistically significant.

We fit Cox proportional hazards regression models to estimate the hazard ratio (HR) and 95% confidence interval (CI) for quintiles of VAI and AIP with all-cause and CVD mortality. The participants who previously had CVD (CHD or/and stroke) were removed from the analysis of CVD mortality risk. Standardized multivariable Cox regression models were used to evaluate the effect size of VAI and AIP with three steps. Model 1 includes a single VAI and AIP quintile with 1st quintile as the reference group. In Model 2 age as, a continuous variable, is added. Model 3 was adjusted for all the variables in Model 2 plus education, physical activity, smoking status, and biological factors (arterial hypertension, total cholesterol, and fasting glucose) (all categorical). Risk of all-cause and CVD mortality was also assessed using the same 3 Cox regression models when VAI and AIP values in the model changed per 1 quintile.

3. Results

The mean duration and SD of the follow-up of the participants were 12.6 ± 2.79 years. During the follow-up, there were 1,444 all-cause deaths (882 men and 562 women) and 682 deaths from CVD [414 men and 268 women (232 and 150 deaths, respectively, among participants without CVD at baseline survey)] registered.

The characteristics of the respondents at the baseline survey, according to their survival status are presented in Tables 2, 3. Men and women who died from all-cause deaths and CVD deaths during

TABLE 4 Risk of all-cause and cardiovascular mortality for visceral adiposity index (VAI) levels status according to gender over 10 years [follow-up for endpoints mean period (SD) 12.6 (2.75) years].

VAI level/cox models	All-cause deaths			CVD deaths*		
	HR	95% CI	*p*	HR	95% CI	*p*
Men	(*n* = 882)			(*n* = 232)		
Model 1						
1st quintile	1			1		
2nd quintile	0.87	0.70–1.08	0.201	1.04	0.74–1.47	0.803
3rd quintile	1.07	0.86–1.32	0.552	**1.47**	1.07–2.01	0.018
4th quintile	1.03	0.83–1.27	0.780	1.16	0.83–1.61	0.398
5th quintile	**1.26**	1.03–1.55	0.024	**1.78**	1.31–2.42	<0.001
Per quintile	**1.07**	1.02–1.12	0.006	**1.14**	1.06–1.22	<0.001
Model 2						
1st quintile	1			1		
2nd quintile	0.85	0.68–1.06	0.141	1.02	0.73–1.44	0.903
3rd quintile	0.99	0.81–1.23	0.990	1.37	0.995–1.88	0.054
4th quintile	1.01	0.82–1.25	0.935	1.13	0.81–1.58	0.473
5th quintile	**1.31**	1.07–1.60	0.010	**1.85**	1.36–2.52	<0.001
Per quintile	**1.08**	1.03–1.13	0.002	**1.15**	1.07–1.24	<0.001
Model 3						
1st quintile	1			1		
2nd quintile	0.91	0.73–1.14	0.411	1.05	0.75–1.48	0.788
3rd quintile	0.99	0.81–1.23	0.982	1.28	0.93–1.76	0.134
4th quintile	1.01	0.82–1.25	0.923	0.94	0.67–1.32	0.721
5th quintile	1.21	0.98–1.49	0.080	**1.38**	1.00–1.90	0.047
Per quintile	**1.05**	1.00–1.10	0.046	1.06	0.99–1.14	0.116
Women	(*n* = 562)			(*n* = 150)		
Model 1						
1st quintile	1			1		
2nd quintile	**1.74**	1.28–2.36	<0.001	**1.93**	1.22–3.06	0.005
3rd quintile	**1.75**	1.29–2.37	<0.001	**1.99**	1.26–3.15	0.003
4th quintile	**2.13**	1.59–2.87	<0.001	**2.26**	1.44–3.54	<0.001
5th quintile	**2.33**	1.74–3.12	<0.001	**2.75**	1.78–4.25	<0.001
Per quintile	**1.19**	1.12–1.26	<0.001	**1.22**	1.12–1.33	<0.001
Model 2						
1st quintile	1			1		
2nd quintile	**1.49**	1.09–2.02	0.011	1.55	0.98–2.45	0.060
3rd quintile	**1.41**	1.03–1.91	0.030	1.50	0.95–2.36	0.084
4th quintile	**1.60**	1.19–2.15	0.002	1.55	0.99–2.43	0.056
5th quintile	**1.72**	1.28–2.31	<0.001	**1.87**	1.21–2.89	0.005
Per quintile	**1.11**	1.05–1.18	0.001	**1.12**	1.02–1.22	0.014
Model 3						
1st quintile	1			1		
2nd quintile	**1.48**	1.08–2.01	0.014	1.51	0.95–2.40	0.081

(Continued)

TABLE 4 (Continued)

VAI level/cox models	All-cause deaths			CVD deaths*		
	HR	95% CI	*p*	HR	95% CI	*p*
3rd quintile	1.35	0.99–1.84	0.057	1.28	0.81–2.04	0.291
4th quintile	**1.51**	1.11–2.04	0.008	1.30	0.83–2.06	0.256
5th quintile	**1.54**	1.13–2.08	0.006	1.50	0.96–2.36	0.078
Per quintile	**1.08**	1.01–1.15	0.020	1.06	0.962–1.16	0.254

*Among participants without CVD at baseline survey.
HR, hazard ratios; CI, confidence interval; CVD, cardiovascular diseases.
Model 1 unadjusted data. Model 2 adjusted for age. Model 3 adjusted for age, education, physical activity and smoking status, and biological factors (arterial hypertension, total cholesterol, and fasting glucose). For details see "Methods" and "Statistical analysis".
Bold values means statistically significant difference of HR values compared with 1st quintile HR.

the follow-up period were significantly older and less educated at the baseline survey than those alive at the end of the follow-up. During the initial study, the age-adjusted means of some biological factors, such as systolic and diastolic BP, triglycerides, the fasting glucose level had been higher, and HDL cholesterol level had been lower in men and women who died from all-cause deaths and CVD deaths during the follow-up period compared to those who were alive. Moreover, it was determined that the respondents who died from all-cause deaths and CVD deaths during the follow-up period had been more often diagnosed with diabetes mellitus, CVD, and arterial hypertension than those who were alive at the end of the follow-up. Men and women who died from all-cause deaths and CVD deaths during the follow-up period were lower physically active in their leisure time and their mean BMI and WC levels had been higher than those alive at the end of the follow-up. It's important, that mean levels of VAI, and AIP had been higher in men and women who died from all-cause deaths and CVD deaths during the follow-up period compared to those who were alive.

In Table 4, we present the multiple cox regression assessments of VAI in the prediction of risk of all-cause and cardiovascular mortality according to gender over 10 years. Based on the crude model (Model 1) assessments, the men with higher VAI levels (5th quintile) had a 1.26-fold increased risk of all-cause mortality and 1.78-fold increased mortality from CVD risk compared with men with lower VAI levels (1st quintile). An increase per quintile in the VAI significantly increased the risk of all-cause mortality (by 7%) and the risk of mortality from CVD (by 14%) in the men group. After additional adjustment for age (Model 2) the same risk of all-cause mortality and mortality from CVD remained statistically significant in the men group. However, after adjustment for age, education, physical activity, smoking status, and biological factors (Model 3) a significant relationship was determined for all-cause mortality risk per quintile of VAI (by 5%), and for risk of mortality from CVD (by 38%) than compared the men with higher VAI level (5th quintile) to men with lower VAI level (1st quintile).

In the women group, an increase per quintile in the VAI significantly increased the risk of all-cause mortality (by 19%) and the risk of mortality from CVD (by 22%) (Model 1). Also, by increasing the quintile of VAI (2nd, 3rd, 4th, 5th quintile) the risk of all-cause mortality risk and CVD mortality risk increased compared with the lowest VAI quintile (1st quintile). However, after adjustment for age, education, physical activity, smoking status, and biological factors (Model 3) a significant relationship was determined only for all-cause mortality risk per quintile of VAI (by 8%) in the women group. Such a significant relationship was not determined for the risk of mortality from CVD in the women group.

In Table 5, we present the multiple Cox regression assessments of AIP in the prediction of risk of all-cause and CVD mortality according to gender over 10 years. Based on the crude model (Model 1) an increase per quintile in the AIP significantly increased the risk of all-cause mortality (by 5%) and the risk of mortality from CVD (by 13%) in the men group. After additional adjustment for age (Model 2) the same risk of all-cause mortality and mortality from CVD remained statistically significant in the men group. However, after adjustment for age, education, physical activity, smoking status, and biological factors (Model 3) the men with higher AIP levels (5th quintile) had a 1.40-fold increased risk of mortality from CVD risk compared with men with lower AIP level (1st quintile).

In the women group, an increase per quintile in the AIP significantly increased the risk of all-cause mortality (by 16%) and the risk of mortality from CVD (by 17%) (Model 1). Also, by increasing the quintile of AIP (2nd, 3rd, 4th, 5th quintile) the risk of all-cause mortality risk and CVD mortality risk increased compared with the lowest AIP quintile (1st quintile). However, after adjustment for age, education, physical activity, smoking status, and biological factors (Model 3) a significant association was not determined between AIP levels and all-cause mortality risk and the risk of mortality from CVD in the women group.

4. Discussion

In this study, we presented an independent association of two indices—VAI and AIP with risk of all-cause and CVD mortality in the middle-aged and elderly Lithuanian urban population.

We found that in Cox regression analyses, compared to the 1st VAI quintile, the 5th quintile was an independent positive predictor of all-cause and CVD mortality risk in males and females. This significant association remained after adjusting for several lifestyles and biological confounding factors for CVD mortality in men (HR = 1.38) and all-cause mortality in women (HR = 1.54). These data are consistent with previous studies in which researchers also found a positive association between increasing levels of VAI and risk of all-cause and CVD mortality (27, 28). Other researchers

TABLE 5 Risk of all-cause and cardiovascular mortality for the atherogenic index of plasma (AIP) levels status according to gender over 10 years [follow-up for endpoints mean period (SD) 12.6 (2.75) years].

AIP level/cox models	All-cause deaths			CVD deaths*		
	HR	95% CI	*p*	HR	95% CI	*p*
Men	(*n* = 882)			(*n* = 232)		
Model 1						
1st quintile	1			1		
2nd quintile	0.85	0.68–1.05	0.127	0.94	0.67–1.31	0.703
3rd quintile	0.98	0.79–1.21	0.830	1.36	0.99–1.85	0.055
4th quintile	0.96	0.78–1.19	0.709	1.00	0.72–1.40	0.995
5th quintile	1.19	0.97–1.46	0.092	**1.72**	1.27–2.32	<0.001
Per quintile	**1.05**	1.00–1.10	0.039	**1.13**	1.06–1.21	<0.001
Model 2						
1st quintile	1			1		
2nd quintile	0.82	0.66–1.01	0.064	0.90	0.64–1.26	0.539
3rd quintile	0.94	0.77–1.16	0.581	1.30	0.96–1.78	0.094
4th quintile	0.95	0.77–1.17	0.629	0.99	0.71–1.38	0.950
5th quintile	**1.24**	1.02–1.52	0.035	**1.81**	1.34–2.44	<0.001
Per quintile	**1.06**	1.01–1.12	0.011	**1.15**	1.07–1.24	<0.001
Model 3						
1st quintile	1			1		
2nd quintile	0.88	0.71–1.09	0.248	0.95	0.68–1.34	0.782
3rd quintile	0.95	0.77–1.18	0.655	1.25	0.91–1.71	0.171
4th quintile	0.96	0.78–1.19	0.698	0.85	0.61–1.20	0.354
5th quintile	1.16	0.95–1.43	0.152	**1.40**	1.03–1.91	0.033
Per quintile	1.04	0.99–1.09	0.102	1.07	0.99–1.15	0.079
Women	(*n* = 562)			(*n* = 150)		
Model 1						
1st quintile	1			1		
2nd quintile	**1.46**	1.09–1.97	0.012	**1.55**	1.00–2.39	0.047
3rd quintile	**1.54**	1.15–2.07	0.004	**1.63**	1.06–2.51	0.025
4th quintile	**1.88**	1.42–2.50	<0.001	**1.85**	1.22–2.82	0.004
5th quintile	**1.92**	1.45–2.55	<0.001	**2.08**	1.38–3.14	<0.001
Per quintile	**1.16**	1.09–1.23	<0.001	**1.17**	1.07–1.27	<0.001
Model 2						
1st quintile	1			1		
2nd quintile	1.23	0.92–1.66	0.168	1.23	0.80–1.89	0.355
3rd quintile	1.31	0.98–1.76	0.070	1.33	0.87–2.05	0.189
4th quintile	**1.41**	1.06–1.87	0.019	1.27	0.83–1.93	0.273
5th quintile	**1.46**	1.10–1.93	0.009	1.47	0.97–2.21	0.069
Per quintile	**1.09**	1.02–1.15	0.007	1.08	0.99–1.18	0.094
Model 3						
1st quintile	1			1		
2nd quintile	1.25	0.92–1.68	0.150	1.19	0.77–1.84	0.433

(Continued)

TABLE 5 (Continued)

AIP level/cox models	All-cause deaths		p	CVD deaths*		p
	HR	95% CI		HR	95% CI	
3rd quintile	1.29	0.96–1.73	0.096	1.19	0.77–1.84	0.425
4th quintile	**1.36**	1.01–1.81	0.040	1.08	0.71–1.67	0.714
5th quintile	1.31	0.98–1.76	0.068	1.20	0.78–1.83	0.412
Per quintile	1.06	0.99–1.12	0.081	1.02	0.93–1.12	0.662

*Among participants without CVD at baseline survey.
HR, hazard ratios; CI, confidence interval; CVD, cardiovascular diseases.
Model 1 unadjusted data. **Model 2** adjusted for age. **Model 3** adjusted for age, education, physical activity and smoking status, and biological factors (arterial hypertension, total cholesterol, and fasting glucose). For details see "Methods" and "Statistical analysis".
Bold values means statistically significant difference of HR values compared with 1st quintile HR.

demonstrated results that higher VAI was related to the risk of the incidence of CVD and cancer (29, 30).

VAI indirectly indicates visceral adipose tissue (VAT) deposits and functions in the human body (10). This index could be used in epidemiological studies and even clinical practice instead of expensive diagnostic methods such as CT, MRI, or sonographic assessment (31, 32). The anthropometric measurements such as WC, waist-to-hip ratio or abdominal sagittal diameter also could be used for the evaluation of regional intraabdominal fat deposition, but those measurements are characterized by low accuracy (33). WC also could not differentiate VAT from subcutaneous adipose tissue in the abdomen which has a lower CVD risk level (29, 34). A similar indicator recently proposed for the evaluation of VAT is anthropometrically predicted VAT (34, 35). This indicator is also VAI sex-specific and the equations for calculation of the indicator include anthropometric measures (BMI, WC, and thigh circumference) and age. VAI is the more specific and precise index for evaluation of VAT as compared to anthropometrically predicted VAT because models for calculation of such includes not only anthropometric data (BMI and WC) but also lipid levels (HDL cholesterol and triglycerides) (10). Several studies demonstrated that VAI was a better predictor of the incidence and mortality risk as compared to BMI and WC in the prognostic models alone (28, 36). Whereas, some studies presented research data indicating that the impact of VAI was not significantly different for predicting CVD risk in women and type 2 diabetes in the non-diabetic population as compared with simply measured anthropometric biomarkers (30, 37). In this study, we did not compare the impact of VAI and such anthropometric measurements as BMI, WC, waist-to-hip ratio, or waist-to-height ratio on the CVD mortality risk. Data from our previous study showed that among participants from three surveys the anthropometric measurements (BMI, WC, waist-to-hip ratio, and waist-to-height ratio) changing per 1 SD in multivariable-adjusted Cox's regression model significantly increased CVD mortality risk in men (HR varied from 1.40 to 1.49) but not in women (18).

The AIP is a logarithmically converted ratio of triglycerides to HDL cholesterol (11). The results of our study showed that values of AIP were higher among males as compared to females. Such gender differences in AIP values were demonstrated in most similar studies (38, 39). The results of ten observational studies performed in China, Turkey, and South Korea demonstrated that higher AIP values may be independently associated with the odds of coronary artery disease (CAD) (40). The AIP could be also considered an independent predictor of CVD incidence and mortality risk (38, 41). Results from a large-scale nationwide population cohort study carried on in the Republic of Korea showed that AIP HRs for CVD risk were higher as compared to HRs of triglycerides and HDL cholesterol when those variables were applied in the regression model alone (42). Whereas, a study performed among 1,131 male patients with angiographically diagnosed CAD and without CAD found that the AIP predictive value for diagnosing CAD was not significantly different as compared with traditional blood lipids (43). Our results have shown a positive association between increasing values of AIP and risk of CVD mortality after adjustment to many confounders in men but not women responders. In women responders, the risk of all-cause mortality was significantly higher by 36% when the 4th quintile of AIP was compared with the 1st quintile. The association between AIP and CVD incidence and mortality is mainly explained by the correlation of the index with lipoprotein particle size: it is inversely related to LDL cholesterol particle diameter (44). Results of some studies showed that small dense LDL cholesterol particles were related to higher risk of CVD (45, 46). However, the methods for determining small dense LDL cholesterol particles are quite complicated and the cost-effectiveness of such methods is low, therefore those methods are not recommended for use in clinical practice and large-scale epidemiological studies of CVD (47).

VAI and API calculations are cheap methods and could be used not only in epidemiological studies but especially in clinical practice for cardiologists or endocrinologists instead of expensive diagnostic methods.

4.1. Strength and limitations of the study

The main strength of our study was: a large sample size, adjustment using many confounding variables, and a cohort study design. Our study also has some limitations. Despite many variables used in the adjustment procedure, it is still possible that some not measured confounding variables could interfere with a part of the associations between AIP or VAI and CVD or all-cause mortality risk. The findings of this study cannot be generalized to the Lithuanian countrywide population because our study was carried out only in an urban one-city a middle-aged and elderly population. Therefore, further epidemiological investigations are needed to be performed in different regions of the country. Finally, we used the baseline AIP and VAI levels for the assessment of the association of those indices with the risk of all-cause and CVD mortality. Any changes during the follow-up both of AIP, VAI, and confounding variables are missing. Despite the mentioned limitations, our study provided additional insight into the association between higher levels of these indices and the risk of mortality.

5. Conclusion

High-risk VAI levels were statistically significantly associated with all-cause mortality risk in men and women groups. The higher AIP level (5th quintile vs. 1st quintile—in men and 4th quintile vs. 1st quintile—in women) was significantly associated with increased mortality from CVD risk in the men group (HR = 1.40) and increased all-cause mortality risk in the women group (HR = 1.36). Thus, the calculation of VAI and AIP levels is simple and universally available, which makes study results easily applicable to clinical practice.

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 study was approved by the Kaunas Regional Biomedical Research Ethics Committee, Lithuania (January 11, 2005; No. 05/09) and by the Ethics Committee at University College London, UK. The patients/participants provided their written informed consent to participate in this study.

Author contributions

AT and DL conceived the idea, collected, analyzed the data, and co-wrote the manuscript. RR, DS, and DK-B contributed to writing the manuscript and the interpretation of data. MB contributed to the study concept and design and as well as supervised the research group. All authors contributed to the article and approved the final version of it.

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Conflict of interest

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

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References

1. *European Health Information Gateway*. Available online at: https://gateway.euro.who.int/HighchartsExport.axd (accessed June 20, 2022).

2. Benjamin EJ, Blaha MJ, Chiuve SE, Cushman M, Das SR, Deo R, et al. Heart disease and stroke statistics-2017 update: a report from the American Heart Association. *Circulation.* (2017) 135:e146–603. doi: 10.1161/CIR.0000000000000491

3. Roth GA, Mensah GA, Johnson CO, Addolorato G, Ammirati E, Baddour LM, et al. Global burden of cardiovascular diseases and risk factors, 1990-2019: update from the GBD 2019 study. *J Am Coll Cardiol.* (2020) 76:2982–3021. doi: 10.1016/j.jacc.2020.11.010

4. Lear SA, Hu W, Rangarajan S, Gasevic D, Leong D, Iqbal R, et al. The effect of physical activity on mortality and cardiovascular disease in 130 000 people from 17 high-income, middle-income, and low-income countries: the PURE study. *Lancet.* (2017) 390:2643–54. doi: 10.1016/S0140-6736(17)31634-3

5. Lahey R, Khan SS. Trends in obesity and risk of cardiovascular disease. *Curr Epidemiol Rep.* (2018) 5:243–51. doi: 10.1007/s40471-018-0160-1

6. Mertens E, Sagastume D, Peñalvo JL. Quantification of disparities in the distribution of lifestyle and metabolic risk factors, prevalence of non-communicable diseases and related mortality: the Belgian Health Interview Surveys 1997-2018. *BMJ Open.* (2021) 11:e053260. doi: 10.1136/bmjopen-2021-053260

7. Krzysztoszek J, Laudańska-Krzemińska I, Bronikowski M. Assessment of epidemiological obesity among adults in EU countries. *Ann Agric Environ Med.* (2019) 26:341–9. doi: 10.26444/aaem/97226

8. Arderiu G, Lambert C, Ballesta C, Moscatiello F, Vilahur G, Badimon L. Cardiovascular risk factors and differential transcriptomic profile of the subcutaneous and visceral adipose tissue and their resident stem cells. *Cells.* (2020) 9:2235. doi: 10.3390/cells9102235

9. Ladeiras-Lopes R, Sampaio F, Bettencourt N, Fontes-Carvalho R, Ferreira N, Leite-Moreira A, et al. The ratio between visceral and subcutaneous abdominal fat assessed by computed tomography is an independent predictor of mortality and cardiac events. *Rev Esp Cardiol.* (2017) 70:331–7. doi: 10.1016/j.rec.2016.09.010

10. Amato MC, Giordano C, Galia M, Criscimanna A, Vitabile S, Midiri M, et al. Study group visceral adiposity index: a reliable indicator of visceral fat function associated with cardiometabolic risk. *Diabetes Care.* (2010) 33:920–2. doi: 10.2337/dc09-1825

11. Frohlich J, Dobiášová M. Fractional esterification rate of cholesterol and ratio of triglycerides to HDL-cholesterol are powerful predictors of positive findings on coronary angiography. *Clin Chem.* (2003) 49:1873–80. doi: 10.1373/clinchem.2003.022558

12. Fernández-Macías JC, Ochoa-Martínez AC, Varela-Silva JA, Pérez-Maldonado IN. Atherogenic index of plasma: novel predictive biomarker for cardiovascular illnesses. *Arch Med Res.* (2019) 50:285–94. doi: 10.1016/j.arcmed.2019.08.009

13. Hamzeh B, Pasdar Y, Mirzaei N, Faramani RS, Najafi F, Shakiba E, et al. Visceral adiposity index and atherogenic index of plasma as useful predictors of risk of cardiovascular diseases: evidence from a cohort study in Iran. *Lipids Health Dis.* (2021) 20:82. doi: 10.1186/s12944-021-01505-w

14. Edwards MK, Blaha MJ, Loprinzi PD. Atherogenic index of plasma and triglyceride/high-density lipoprotein cholesterol ratio predict mortality risk better than individual cholesterol risk factors, among an older adult population. *Mayo Clin Proc.* (2017) 92:680–1. doi: 10.1016/j.mayocp.2016.12.018

15. Guo Q, Zhou S, Feng X, Yang J, Qiao J, Zhao Y, et al. The sensibility of the new blood lipid indicator–atherogenic index of plasma (AIP) in menopausal women with coronary artery disease. *Lipids Health Dis.* (2020) 19:27. doi: 10.1186/s12944-020-01208-8

16. Çelik E, Çora AR, Karadem KB. The effect of untraditional lipid parameters in the development of coronary artery disease: atherogenic index of plasma, atherogenic coefficient and lipoprotein combined index. *J Saudi Heart Assoc.* (2021) 33:244–50. doi: 10.37616/2212-5043.1266

17. Tamosiunas A, Klumbiene J, Petkeviciene J, Radisauskas R, Vikhireva O, Luksiene D, et al. Trends in major risk factors and mortality from main non-communicable diseases in Lithuania, 1985-2013. *BMC Public Health.* (2016) 16:717. doi: 10.1186/s12889-016-3387-0

18. Luksiene D, Tamosiunas A, Virviciute D, Bernotiene G, Peasey A. Anthropometric trends and the risk of cardiovascular disease mortality in a Lithuanian urban population aged 45-64 years. *Scand J Public Health.* (2015) 43:882–9. doi: 10.1177/1403494815597582

19. Luksiene D, Tamosiunas A, Baceviciene M, Radisauskas R, Malinauskiene V, Peasey A, et al. Trends in prevalence of dyslipidaemias and the risk of mortality in Lithuanian urban population aged 45-64 in relation to the presence of the dyslipidaemias and the other cardiovascular risk factors. *PLoS ONE.* (2014) 9:e100158. doi: 10.1371/journal.pone.0100158

20. Peasey A, Bobak M, Kubinova R, Malyutina S, Pajak A, Tamosiunas A, et al. Determinants of cardiovascular disease and other non-communicable diseases in Central and Eastern Europe: rationale and design of the HAPIEE study. *BMC Public Health.* (2006) 6:255. doi: 10.1186/1471-2458-6-255

21. Rose GA, Blackburn H, Gillum RF, Prineas RJ. *Cardiovascular Survey Methods*. Geneva: Cardiovascular Disease Unit, WHO (1982).

22. Prineas RJ, Crow RS, Blackburn H. *The Minnesota Code: Manual of Electrocardiographic Fndings*. London: John Wright (1982).

23. Norkus A, Ostrauskas R, Sulcaite R, Baranauskienet E, Baliutaviciene D. Classification and diagnosis of diabetes mellitus (methodology recommendations). *Lith Endocrinol.* (2000) 3:234–41.

24. Mancia G, De Backer G, Dominiczak A, Cifkova R, Fagard R, Germano G, et al. 2007 Guidelines for the management of arterial hypertension. *Eur Heart J.* (2007) 28:1462–536. doi: 10.1093/eurheartj/ehm236

25. Visseren FLJ, Mach F, Smulders YM, Carballo D, Koskinas KC, Bäck M, et al. 2021 ESC Guidelines on cardiovascular disease prevention in clinical practice. *Eur Heart J.* (2021) 42:3227–337. doi: 10.1093/eurheartj/ehab484

26. WHO Consultation. *Definition, Diagnosis and Classification of Diabetes Mellitus and its Complications. Part 1: Diagnosis and Classification of Diabetes Mellitus*. Geneva: World Health Organization (1999). Report No. 99.2. Available online at: http://whqlibdoc.who.int/hq/1999/WHO_NCD_NCS_~99.2.pdf (accessed June 20, 2022).

27. Brown JC, Harhay MO, Harhay MN. Visceral adipose tissue dysfunction and mortality among a population-based sample of males and females. *Diabetes Metab.* (2016) 42:382–5. doi: 10.1016/j.diabet.2016.05.001

28. Kouli GM, Panagiotakos DB, Kyrou I, Georgousopoulou EN, Chrysohoou C, Tsigos C, et al. Visceral adiposity index and 10-year cardiovascular disease incidence: The ATTICA study. *Nutr Metab Cardiovasc Dis.* (2017) 27:881–9. doi: 10.1016/j.numecd.2017.06.015

29. Britton KA, Massaro JM, Murabito JM, Kreger BE, Hoffmann U, Fox CS. Body fat distribution, incident cardiovascular disease, cancer, and all-cause mortality. *J Am Coll Cardiol.* (2013) 62:921–5. doi: 10.1016/j.jacc.2013.06.027

30. Mohammadreza B, Farzad H, Davoud K, Fereidoun Prof AF. Prognostic significance of the complex "Visceral Adiposity Index" vs. simple anthropometric measures: Tehran lipid and glucose study. *Cardiovasc Diabetol.* (2012) 11:20. doi: 10.1186/1475-2840-11-20

31. Ryckman EM, Summers RM, Liu J, Munoz del Rio A, Pickhardt PJ. Visceral fat quantification in asymptomatic adults using abdominal CT: is it predictive of future cardiac events? *Abdom Imaging.* (2015) 40:222–6. doi: 10.1007/s00261-014-0192-z

32. Vlachos IS, Hatziioannou A, Perelas A, Perrea DN. Sonographic assessment of regional adiposity. *AJR Am J Roentgenol.* (2007) 189:1545–53. doi: 10.2214/AJR.07.2366

33. Bonora E, Micciolo R, Ghiatas AA, Lancaster JL, Alyassin A, Muggeo M, et al. Is it possible to derive a reliable estimate of human visceral and subcutaneous abdominal adipose tissue from simple anthropometric measurements? *Metabolism.* (1995) 44:1617–25. doi: 10.1016/0026-0495(95)90084-5

34. Brown JC, Harhay MO, Harhay MN. Anthropometrically-predicted visceral adipose tissue and mortality among men and women in the third national health and nutrition examination survey (NHANES III). *Am J Hum Biol.* (2017) 29:10.1002/ajhb.22898. doi: 10.1002/ajhb.22898

35. Samouda H, Dutour A, Chaumoitre K, Panuel M, Dutour O, Dadoun F. VAT=TAAT-SAAT: innovative anthropometric model to predict visceral adipose tissue without resort to CT-Scan or DXA. *Obesity.* (2013) 21:E41–50. doi: 10.1002/oby.20033

36. Dereziński T, Zozulińska-Ziółkiewicz D, Uruska A, Dabrowski M. Visceral adiposity index as a useful tool for the assessment of cardiometabolic disease risk in women aged 65 to 74. *Diabetes Metab Res Rev.* (2018) 34:e3052. doi: 10.1002/dmrr.3052

37. Janghorbani M, Amini M. The visceral adiposity index in comparison with easily measurable anthropometric markers did not improve prediction of diabetes. *Can J Diabetes.* (2016) 40:393–8. doi: 10.1016/j.jcjd.2016.02.008

38. Sadeghi M, Heshmat-Ghahdarijani K, Talaei M, Safaei A, Sarrafzadegan N, Roohafza H. The predictive value of atherogenic index of plasma in the prediction of cardiovascular events; a fifteen-year cohort study. *Adv Med Sci.* (2021) 66:418–23. doi: 10.1016/j.advms.2021.09.003

39. Cai G, Liu W, Lv S, Wang X, Guo Y, Yan Z, et al. Gender-specific associations between atherogenic index of plasma and the presence and severity of acute coronary syndrome in very young adults: a hospital-based observational study. *Lipids Health Dis.* (2019) 18:99. doi: 10.1186/s12944-019-1043-2

40. Wu J, Zhou Q, Wei Z, Wei J, Cui M. Atherogenic index of plasma and coronary artery disease in the adult population: a meta-analysis. *Front Cardiovasc Med.* (2021) 8:817441. doi: 10.3389/fcvm.2021.817441

41. Mangalesh S, Yadav P, Dudani S, Mahesh NK. Atherogenic index of plasma predicts coronary artery disease severity and major adverse cardiac events in absence of conventional risk factors. *Coron Artery Dis.* (2022) 33:523–30. doi: 10.1097/MCA.0000000000001166

42. Kim SH, Cho YK, Kim YJ, Jung CH, Lee WJ, Park JY, et al. Association of the atherogenic index of plasma with cardiovascular risk beyond the traditional risk factors: a nationwide population-based cohort study. *Cardiovasc Diabetol.* (2022) 21:81. doi: 10.1186/s12933-022-01522-8

43. Hong L, Han Y, Deng C, Chen A. Correlation between atherogenic index of plasma and coronary artery disease in males of different ages: a retrospective study. *BMC Cardiovasc Disord.* (2022) 22:440. doi: 10.1186/s12872-022-02877-2

44. Dobiásová M, Frohlich J, Sedová M, Cheung MC, Brown BG. Cholesterol esterification and atherogenic index of plasma correlate with lipoprotein size and findings on coronary angiography. *J Lipid Res.* (2011) 52:566–71. doi: 10.1194/jlr.P011668

45. Kokubo Y, Watanabe M, Higashiyama A, Honda-Kohmo K. Small-dense low-density lipoprotein cholesterol: a subclinical marker for the primary prevention of coronary heart disease. *J Atheroscler Thromb.* (2020) 27:641–3. doi: 10.5551/jat.ED134

46. Qiao YN, Zou YL, Guo SD. Low-density lipoprotein particles in atherosclerosis. *Front Physiol.* (2022) 13:931931. doi: 10.3389/fphys.2022.931931

47. Kanonidou C. Small dense low-density lipoprotein: analytical review. *Clin Chim Acta.* (2021) 520:172–8. doi: 10.1016/j.cca.2021.06.012

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Impact of environmental interventions based on social programs on physical activity levels: A systematic review

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Background: The design of social programs at the environmental level such as in schools, parks, bicycle paths, or workspaces generates changes in the behavior of individuals and modifies lifestyles by increasing physical activity (PA) levels.

Objective: To determine the effectiveness of environmental interventions based on social programs by changing the population's level of PA.

Methodology: Natural experiment studies that involved environmental interve ntion programs at a social level were included. The primary outcome was PA levels with consideration of both objective and subjective measurements. An electronic search was carried out in Medline/Pubmed, SCIENCE DIRECT, WEB OF SCIENCE, and CINAHL databases up to January 2022 with two reviewers screening titles and abstracts and selecting studies for full-text reading. Two reviewers also acquired relevant data and evaluated study quality using the ROBINS I tool. A qualitative analysis was performed.

Results: Three thousand eight hundred and sixty-five articles were found in the 4 consulted databases. After eliminating duplication (200), two reviewers screened 3,665 titles and abstracts and excluded 3,566 that did not meet the inclusion criteria, leaving 99 articles to be read in full text. The 99 full texts were reviewed of which 24 papers met the eligibility criteria. All were natural experiments published between 2011 and 2020 and all evaluated environmental social programs revealing that social programs at the environmental level promoted PA in various populations at the community level worldwide.

Conclusion: The 24 reviewed studies suggest innovative proposals for social programs that seek to increase PA and promote healthy lifestyles related to public activity policies developed in the countries in which they were generated. Environmental social programs can positively impact PA levels among children and adults.

Systematic review registration: https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=229718, identifier: CRD42021229718.

KEYWORDS

physical activity, environmental, build environment, natural experiment, programs

Introduction

A variety of factors worldwide have altered patterns of physical activity (PA), with an increase in the level of sedentary lifestyles especially in middle and low-income countries (1). Low level of PA is one of the key factors related to the development of chronic diseases. In addition, morbimortality due to chronic diseases secondary to physical inactivity has been found to be related to the worldwide prevalence of type 2 diabetes, coronary artery disease, and cancer among others, with relative risk (RR) of physical inactivity of 1.16 (95% CI 1.04–1.30)for all causes worldwide (2).

The world's economic and health behavior changes, such as an increase in working hours especially for mothers, unhealthy food consumption, a reduction in leisure and recreation time, the reduced metabolic expenditure given the influence of the obesogenic space because of less PA and the imbalance between intake and consumption lead to the presence of childhood and adult obesity (3). In this sense, the evidence shows that the economic market has a substantial influence on the commercial aspect of food in advertising for children, television time, and high investments in fast food restaurants. In contrast to the above investments there is a low investment in environmental modifications that may have a greater effect on the time spent in PA which may have a favorable effect on the imbalance between intake and demand and decrease obesity (4, 5).

Health policies, especially the guidelines generated by the World Health Organization (WHO) are aimed to increase PA in populations, with a minimum of 150 min and nutritional improvement with a balanced diet, to reduce the presence of chronic non-communicable diseases (6, 7). Moreover, PA interventions or strategies at the individual, community, environmental, and social levels may favorably alter poor health behaviors and have a positive impact on levels of PA improving the population's general health and chronic non-communicable diseases (8, 9).

The WHO describes environmental strategies regarding social programs as global actions, community approaches and public policy developed to allow the implementation of social determinants of health within community spaces as schools, parks, bicycle routes, bicycle lanes, companies, or cities (10–13). Examples of such programs have been implemented worldwide as methods to promote PA (1, 14, 15). In the United Kingdom and other countries, national guidelines have been developed for environmental modification and the creation of social programs to encourage greater PA and reduce sedentary lifestyles (16, 17). The conceptual background of environmental social programs has been described in international documents such as the National Institute for Health and Care Excellence (NICE) in which the role of PA is highlighted stating "Local strategies, policies and plans to encourage and enable people to be more physically active" (18). The socio-ecological models of PA explain how to facilitate and implement PA at different levels of the individual including behavioral, social, and physical environmental constructs (19, 20). For example, schools with in-school or out-of-school programs for children are likely to promote more PA and less sedentary lifestyles. In addition, the implementation of active walking or cycling routes, modification of cities with the inclusion of active programs, and the reduction of spaces that induce obesity to reduce the level of sedentary lifestyles in men, women, and children throughout the life cycle have been reported (15, 21–25).

Worldwide, environmental modification programs from the social perspective have gained relevance for the implementation of policy-based programs in countries whose impact has been evaluated through natural experiments. Natural experiments have been described as observational studies in which an event or a situation that allows for the random or seemingly random assignment of study subjects to different groups is used to answer a particular question (24). Thus, natural experiments can observe large populations in a real-world environment to examine the effects of global actions or community approaches. The medical research council has recommended the use of natural experimental approaches to evaluate population health interventions. Thus, natural experiments are extremely important since the exposure to an event or intervention of interest has not been manipulated by a researcher making the natural experiment not only an observational study, but an experimental study especially when a clinical trial may be impractical or unethical (26).

The effect of social programs at the environmental level can be assessed by natural experiments and appear to generate favorable change in the behaviors and lifestyles of individuals in work, school, and university settings. The use of transportation methods to facilitate healthy lifestyle habits has also been suggested as a strategy to improve PA, however, the results are inconclusive (15, 27–30). Therefore, this systematic review aims to examine the effectiveness of environmental interventions based on programs at a social level on levels of PA in studies that have employed natural experiments.

Methodology

This study is a systematic review conducted according to the guidelines of Cochrane methodology (31) and PRISMA guidelines (32). The protocol is registered in the international database of systematic reviews PROSPERO under the number CRD42021229718.

Selection criteria

Type of study

The type of study is natural experiments that involve environmental interventions at the social level which includes local strategies, plans, programs, or policies to promote PA with the understanding that a natural experiment is a research study in which the exposure to an event or intervention of interest has not been manipulated by a researcher (26).

Type of participants or population of interest

The type of participants and population of interest includes the general population such as students in schools and universities, individuals in the workplace, the population of individuals in cities and neighborhoods, and older adults in institutions. Studies that have targeted specific populations with diseases or conditions

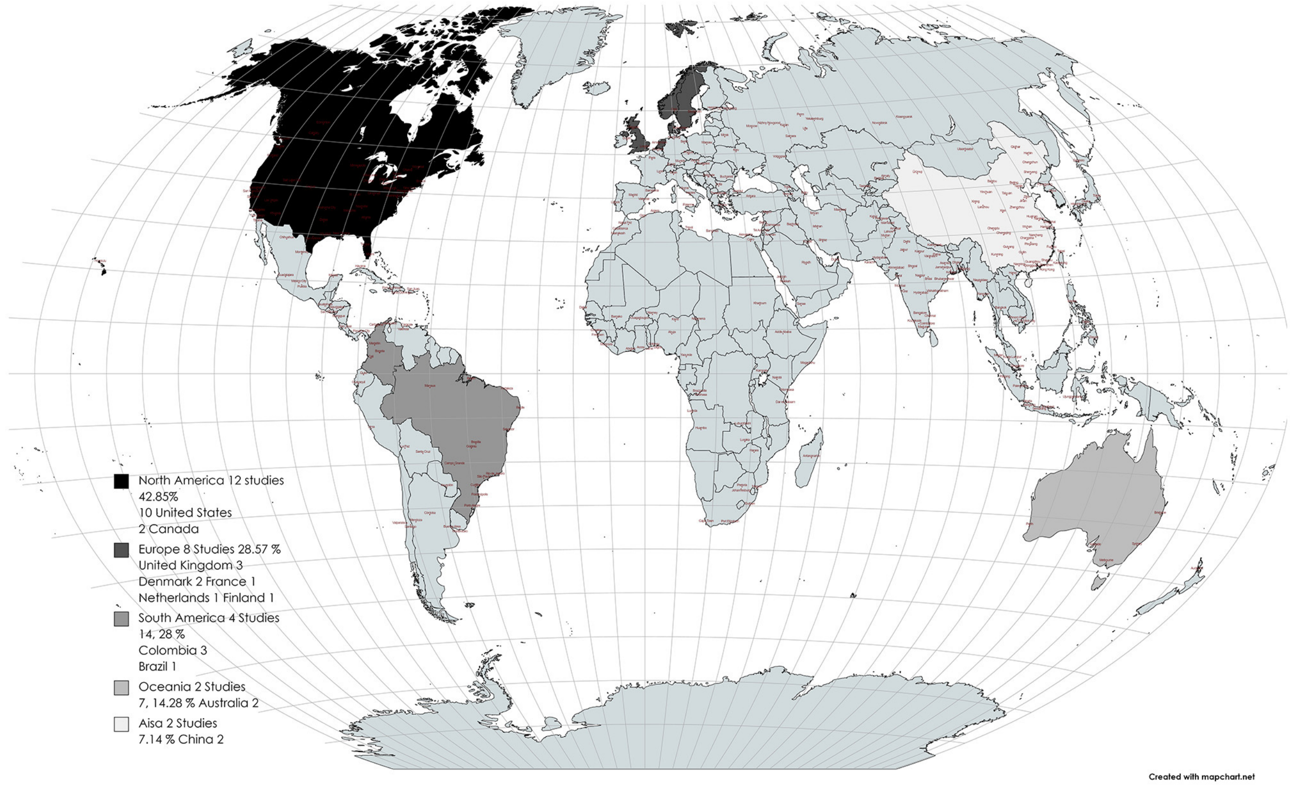

FIGURE 1
Study distribution around the world.

such as neuromuscular disease (sclerosis, cerebrovascular disease, and dystrophies), musculoskeletal diseases (lupus, arthritis, and osteoarthritis), or cardiovascular diseases (infarction, arrhythmia, valve diseases, etc.) as well as studies on athletes were excluded.

Type of interventions

Studies that evaluated programs focused on the promotion of PA from an environmental perspective at the social level such as programs involving parks, bicycle commuting, bicycle lanes, school curriculum modifications, or city programs to promote PA such as muevete and recreovia Bogota, Biking Barcelona, Biking Boulevards Australia, Agita São Paulo, role of public policy in active schools in Ontario, and others.

Type of outcomes

The primary outcome is PA defined as variation or levels reached and measured objectively or subjectively. Objective measurements included PA measured by pedometers, accelerometers, heart rate monitors, and direct and indirect calorimetry. Subjective measurements included self-reports or questionnaires such as the IPAQ, CHAMPS, or the PA Recall, among others. Both the objective and subjective measurements could be expressed continuously [such as total energy expenditure (Kcal/Kg/week, kcal/week), metabolic consumption in METS, oxygen consumption or differences in CO_2/Vo_2, heart rate, heart variability, total minutes of physical activity or the number of steps, among others] or categorically (such as of light, moderate, or vigorous PA). Participation in the programs, percentage or amount of PA performed, measures of fitness level if they were reported in metabolic expenditure or oxygen consumption, and measurement scales of individual or group physical activity were also examined.

Search strategy

A search for studies was performed through January 2022 using the following electronic databases: Medline/Pubmed, Web of Science, Science Direct, and CINAHL, using Mesh, Decs, and Emtree terms. Appendix 1 provides the search strategies employed in the study. Additionally, a search of crossed references was done manually as well as a search of gray literature in specialist journals, university repositories or general websites related to the topic.

Study selection

Study selection involved two reviewers (EH, EC) who screened the articles by title and abstract according to the inclusion criteria. The selected studies were then blinded, read in full text format by both reviewers and the results and conclusions compared. In the case of disagreements, a third reviewer acted as a peer evaluator to settle disagreements for the definitive selection of studies. To optimize the work at this stage, the Rayyan© software was used (33).

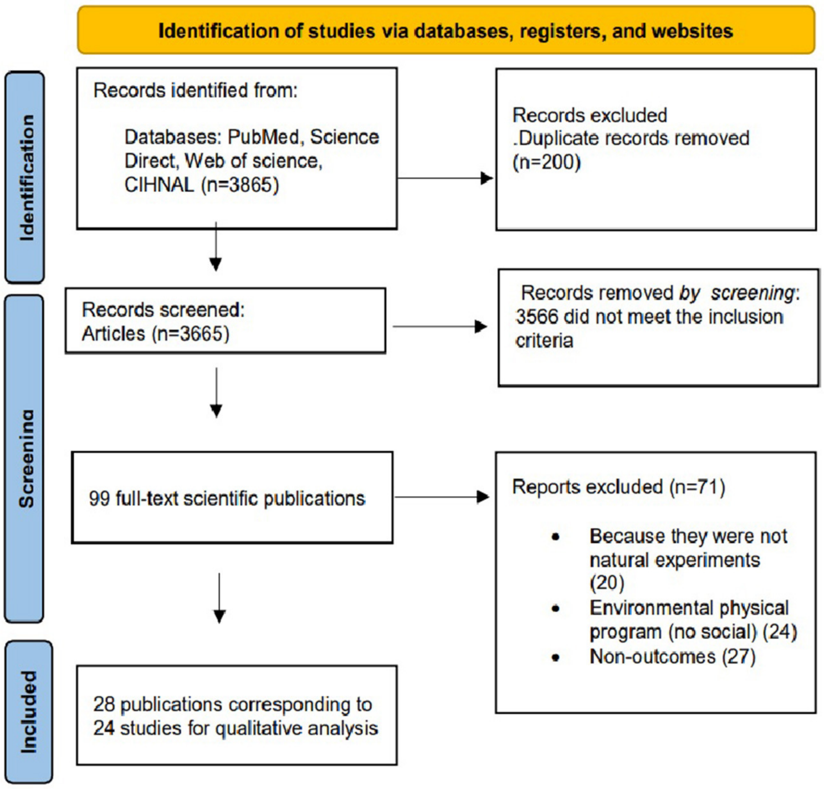

FIGURE 2
Flowchart of the selection process.

Data extraction and risk of bias evaluation

Data extraction was accomplished using a spreadsheet in which the characteristics of the studies were recorded, such as title, authors, year and place of publication, program undertaken and its characteristics, start and end date, the scope of the program's intervention, outcomes and considered measurements, and reported results.

The risk of bias was assessed using the recommendations and evaluation criteria of the ROBINS I tool for non-randomized intervention studies (34). Which made it possible to evaluate specific risks of bias at three points in the study: (1) pre-intervention where the bias of confounding and participant selection were considered, (2) during the intervention where measurement bias was assessed, and (3) post-intervention where the bias of the interventions performed and outcome measurements as well as attrition bias were considered.

Data analysis

The data analysis was undertaken qualitatively through figures and tables showing the information obtained in the data extraction process which provided an organized and visual presentation of the intervention programs, methodological findings, and results of each study.

Results

Three thousand eight hundred and sixty-five articles were found in the 4 databases. After eliminating duplicates (200), two reviewers screened 3,665 titles and abstracts and excluded 3,566 articles because they did not meet the inclusion criteria. Thus, 99 full texts were reviewed in depth to determine that 28 studies fulfilled the eligibility criteria. The reasons for exclusion were: 20 articles were not natural experiments, 27 did not have outcomes of interest, and 24 were natural experiments but focused on physical environmental structural modification. It is important to note that of these 28 full-text readings, 4 had double reporting in different articles, resulting in a total of 24 reports. Of these 24, 7 studies examined both physical environmental modifications and social programs. The 24 papers used in this study as well as those with double reports are shown in Figure 1.

Characteristics of the selected studies

The 28 study reports (35–62). That were selected were natural experiments published between 2011 and 2020, with the evaluation of environmental social programs from different parts of the world (Figure 2). Regarding the scope, 10 were implemented at school programs, 6 were related to active transportation, 4 were in active cities, 2 were in parks, and 2 were in workspaces (Table 1).

TABLE 1 Characteristics of the studies included and areas of emphasis.

References	Country/Continent	Infrastructural focus	Intervention program	Description of the group
Dill et al. (36)	United States/North America	Active transport	Bicycle paths were planned and built and compared to the control.	Six studies focus on the implementation of active transportation or commutation, whether understood as walking spaces, bicycle programs, or transportation interchange between bus and walking. Four of these studies focus on bicycle programs in the community environment to encourage the use of this form of transportation, focusing on commuting to work. And two of the subway system in which the use of non-escalators vs. escalators at station exits is encouraged with a cognitive program to encourage the use of escalators and the other on a new subway line measures the use of commutation transportation related to transportation to the subway line and distance to stations with the objective of encouraging physical activity.
Panter et al. (37)	United Kingdom/Europe	Active transport commute	A new transportation system was built in Cambridge between 2007 and 2011 19 kilometers of busway and bike/walking lanes and the commuter program was implemented.	
Goodman et al. (40)	United Kingdom/Europe	Active transport bicycling	18 cities with bicycle programs were included for use of bicycles for commuting to work, school, bus and subway stations.	
Allais et al. (46)	France/Europe	Active transport Activity promotion	worked with three stations of the French subway to encourage the use of stairs, three experimental and control stations to see the change in the pattern of use of stairs.	
Sun et al. (51)	China/Asia	Active transport	A new metro line with 24 stations in a population that had no metro line and the change of habits in the type of transport was determined.	
Heinen et al. (60)	Australia/Oceania	Active transport	Based on the habitat cohort in which a program is designed in which we seek to look at changes in the pattern of transport with cycling and its effect on physical activity	
Simões et al. (41)	Brazil /South America	Active community cities	Academy program of city of Pernambuco Brazil with 184 cities that participated in the activity in three groups.	4 studies carried out in urban environments at the community level, all different from each other but with the same perspective, which is the community work to promote physical activity, within the framework of the activity policy.
Nicosia and Datar (50)	United States/North America	Active community cities	Projected exercise and nutrition environment of military housing, measured days of physical activity with activity minutes and follow-up.	
Mölenberg et al. (52)	Holland/Europe	Active community cities	18 new spaces in economically depressed sectors, in which spaces for the promotion of physical activity were created in Rotterdam.	
Sharma et al. (54)	United States/North America	Active community cities	Multicomponent healthy eating and physical activity program for pregnant women, the program promotes breastfeeding, nutrition and physical activity, community-based 6-week program	

(Continued)

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TABLE 1 (Continued)

References	Country/Continent	Infrastructural focus	Intervention program	Description of the group
Gesell et al. (38)	United States/North America	After School Program	After-school activity program with the department parks with its modified areas and spaces for physical activity at the community level.	10 studies focused on educational environments, 9 in schools and 1 at the university level, all based on environmental social activities either inside or outside the educational environment but with the objective of promoting physical activity. Of the 10 school-based, 6 are associated with the curriculum and 4 are after school associated with summer programs or park activities. The program at the university level is focused on determining whether the distance between university dormitories to gyms and dining halls influences the level of physical activity of students.
Esdaile et al. (42)	Australia/Oceania	Intra-school School Program	Parent-led physical activity and nutrition program known as PEACH, which consists of a 90-min activity program for school children.	
Hunt et al. (44)	United States/North America	After-school program	First and second grade students were included in a 7-week summer learning and activity program.	
Lee et al. (45)	United States/North America	School infrastructure	Transfer of a group of students at a school outside a neighborhood to one with the school in the neighborhood and to see the change in behavior from sedentary to active and to the transport.	
Tarp et al. (48)	Denmark/Europe	Interschool school program	Effect of the multimodal CHAMPS (Childhood Health, Activity, and Motor Performance School study DK) program in an intervention group relative to the control group in response to presenting risk factors in 10 schools in Denmark.	
D'Agostino et al. (49)	United States/North America	After School Program	A 10-month after-school program called FIT2PLAY, generated for ethnic minorities in a Miami county.	
Kapinos et al. (53)	United States/North America	College program	To determine how proximity of dormitories to the gymnasium or dining areas or food courts influences freshmen college students' weight gain or sedentary behavior and obesogenic environment	
Madsen (55)	United States/North America	After school program	California fitness program evaluates the physical condition of children in grades 5–7th and 9th through the Fitness Gram.	
Stone et al. (58)	Canada /North America	In-school school program	The study takes place in Ontario's statewide policy of a minimum of 20 min per day of moderate and vigorous physical activity in school structure and schedules, 16 districts are involved	
Azevedo et al. (59)	United Kingdom/Europe	In-school school program	Dance mat program for students in grades 9–11 at the school level to see the effect on physical activity level, 16 mats and a driving unit were delivered to the schools to be used for 12 weeks.	

(Continued)

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TABLE 1 (Continued)

References	Country/Continent	Infrastructural focus	Intervention program	Description of the group
Torres et al. (35)	Colombia/Sur América	Parks and surrounding recreovia	Effect of physical activity in free time on participants in 9 parks in the capital district of Bogotá	Two programs focused on parks aimed at promoting physical activity with the development of physical activity classes in the free time in the participants in recreational areas, one uses the frozen roads to create trails for walking, measures the use of these and the activity physical activity developed in contrast the other works with the development of physical activity classes in the city and how this allows to modify the life habits of the populations
McGavock et al. (62)	Canada /North America	Parks and surrounding	Impact of a frozen pathway on the users' visits to estimate activity patterns Physical activity associated with the pathway in the winter in Canada.	
Zhu et al. (47)	China/Asia	Work environment	PA and sedentary behavior among the employees of a company in response to job modification, it is a two-arm experiment, one of intervention with modification of the job, adaptation of the chairs and desks.	2 experiments, one from the Asian region and the other from Europe, both focus on physical activity at work, with adaptation of the spaces and the inclusion of adjustable desks and furniture that allow the practice of activity, or the switching of the type of transportation of the company to homes with adaptation of lanes and roads for the use of bicycles and walking.
Aittasalo et al. (57)	Finland/Europe	Work environment active transport	Two-arm natural experiment with two groups of companies in a two-phase socioecological model to determine the use of the bicycle or walking as a means of active transport.	

Designs of the natural experiments found

Several approaches were used in the natural experiments as shown in Table 2. From pre- and post-cohorts with a control group or prospective cohorts (36, 38, 43, 52, 53, 60), controlled before and after studies (40, 46–48, 57, 59, 62) before and after studies with and without a control group (49–51, 54, 55), as well as quasi-experimental (37, 56), cross-sectional pre- and post-intervention studies with or without a control group (35, 39, 41, 42, 58, 61) providing repeated measures and retrospective studies (44, 45). The 24 studies indicated that they were working on PA policies worldwide or nationally, but 25% did not specify the specific PA policy Using natural experiments to evaluate population health interventions: new Medical Research Council guidance (36, 44, 47, 51, 59, 62), 37.5% described the PA policy, but did not evaluate its development (35, 37, 40–42, 55, 57, 58, 60) and the remaining studies were framed within national public policies on PA or active transportation clearly showing the evaluation of implementation at the level of parks, cities, schools or active transportation (Table 2).

Measurements of physical activity in the studies

All included studies reported the outcome of PA with valid and reliable measurements as shown in Table 2. At the non-instrumental level, the IPAQ PA questionnaire was used in 2 studies, the SOPARC leisure or activity measurement system in parks in another 2 studies, and the RPARQ PA level measurement survey in recreation in one study (35–37, 40, 41). Fifteen studies provided levels of PA as light, moderate or vigorous (35–38, 40, 41, 47, 48, 50, 52, 54, 57–59, 62), and the hours/minutes of activity were reported in 19 studies (43, 50–52, 54, 57, 58, 62).

Objective measurement data of PA was measured with the following instruments including an accelerometer in 7 studies (35, 36, 40, 44, 48, 58, 59) a pedometer in 1 (62); and global or geographic location such as GPS, and ACTIVE-PAL-3C in 4 studies (36, 40, 47, 50). Finally, 8 studies reported other physiologic measures including anthropometrics, vascular resistance, METS, and blood chemistry such as lipid profile, cholesterol, triglycerides, and glycemia (38, 42–44, 48, 49, 55, 59).

Effectiveness of the programs

The percentage of PA performed at the end of the intervention was examined in 10 studies (36, 38, 40, 41, 47, 48, 52, 58, 59, 61) as shown in Table 3. The level of PA in the majority of the populations was found to be light PA (LPA). For example, the reports in two of the largest studies, one conducted in Pernambuco Brazil on active cities (41) and another one recreo *via* in Colombia (61), found that 25.8 and 57.8% of the population performed LPA, respectively. In addition, the greatest effects of environmental interventions at the social level were in schools and workplaces. In schools, the percentage increase of PA was 2.3–6 points after a period of 12–16 weeks of the program (38). Regarding workplaces, the increase from moderate to vigorous activity was 19.3% in 1 week (47).

TABLE 2 Main methodological characteristics of the studies.

References	Population	Groups	Physical activity measurements	Type of natural experiment	Public policy
Torres et al. (35)	1,533 participants over 18 years of age in the recreation track and 9 parks	3 groups of parks with new recreation track, old recreation track and without recreation track	IPAQ Accelerometers MVPA Activity level	Cross-sectional Pre-post comparison with control group	Recreovía program in Bogotá, Colombia, Muevete Bogota
Dill et al. (36)	8 bicycle lanes and 11 control streets, 353 adults	Pre- and post-intervention with two groups in bicycle lanes	IPAQ Accelerometers MVPA level of activity Location with GPS	Cohort pre-post with control group	Part of the policy but does not express it,
Prinss et al. (37)	8,783 participants 175 trips 40,000 users	1 km green corridor compared to control group	SOPARC Physical activity level MPA—MVPA	Quasi-experimental nested in a cohort	Be active, be healthy: a plan for getting the nation moving London: Department of Health; 2009.
Gesell et al. (38)	400–800 users in the 4 parks	Two intervention parks and two control parks	Level of physical activity MPA—MVPA Metabolic expenditure in METS	Prospective cohort	Strategic Plan for NIH Obesity Research. Shaping America's Youth. White House Task Force on Childhood Obesity.
Barradas et al. (39)	1,533 participants over 18 years of age in the recreation track and 9 parks	3 groups of parks with new recreation track, old recreation track and without recreation track	IPAQ Accelerometers MVPA Activity level	Cross-sectional Pre-post comparison with control group	Recreovía program in Bogotá, Colombia, Muevete Bogota
Goodman et al. (40)	1,164 individuals, both genders	New transportation system in Cambridge 19 kilometers of busway and bike/walking lanes	RPAQ Accelerometers MVPA Activity level GPS location monitored	Controlled before and after	Cycling-England-cycling-city-and-towns-end-of-program
Simões et al. (41)	8,900 users in 84 cities in Pernambuco	Two intervention groups with modification and physical activity programs and control without modification	IPAQ leisure and transport Level of activity according to walking and participation	Cross-sectional Pre-post nested	Academia da Cidade (AC-R) program of the city of Recife (AC-R), a supervised classes
Esdaile et al. (42)	926 children 816 families	Two groups, one UTC and one TCT each to determine weight loss and activity.	Sociodemographic data Parental data according to economic level and poverty index.	Cross-sectional pre and post with control group	Queensland Health. The Health of Queenslanders 2016. Report of the Chief Health Officer Queensland. Brisbane: Queensland Government
Kapinos and Yakusheva (43)	237 Students assigned to dormitories	Pre- and post-intervention, groups were worked according to distance from the dormitories to gyms and restaurants	Questionnaire Height and weight data, sociodemographic aspects Exercise and diet data with direct questions of frequencies and number	Pre- and post-cohort with control group	U.S. Department of Health and Human Services. Healthy people 2010: With understanding and improving health and objectives for improving health, In: Services USDoHaH, Washington, DC

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TABLE 2 (Continued)

References	Population	Groups	Physical activity measurements	Type of natural experiment	Public policy
Hunt et al. (44)	31 children average 6 year old and parents	Pre- and post-intervention to a group with an after school program	Height and weight measures Cardiorespiratory fitness 20-meter running test and PACER Activity measurement with accelerometer Activity management forms for child self-reporting time spent on daily activities such as watching television, home work time, and computer and video games	Repeated measures	Part of the policy but does not express it,
Lee et al. (45)	165 surveys of students were processed	Two intervention groups with modification of a neighborhood school	Survey of forms of transport to and from school in children who were transferred and level of activity	Retrospective	The federal Safe Routes to School (SRTS) programs, pedestrian safety trainings at local schools, Walking School Bus (WSB) programs (a group of students walking to school together led by an adult supervisor), and walking-to-school day events
Allais et al. (46)	300 users of the transport system	3 groups, 2 intervention and 1 control group at metro stations	Filming of users with hidden cameras Measurement of stairway usage and frequency of usage	Controlled before-after	French National Nutrition and Health Program, 2011
Zhu et al. (47)	52 participants in the study and 36 in the post-test, 12 test control and 24 intervention	Two groups. The intervention was called stand up and move and a new adjustable workstation was provided compared to a control	ActivePAL3C to measure the activity, position and time MVPA level of activity	Two-arm non-randomized controlled trial	Part of the policy but does not express it,
Tarp et al. (48)	312 students from 10 public schools	2 groups from 14 schools in the municipality, 10 intervention and 4 control.	Blood, lipid and glucose profile measurements. Blood pressure and waist circumference measurements. Andersen's cardiovascular endurance test was performed to measure physical fitness with fast running. Activity measurements by self-recording and accelerometer level of physical activity from MPA- MVPA	Controlled before-after with control group	Aldersrelateret træning—Målrettet og forsvarlig træning af børn og unge. 2005, Copenhagen, Denmark: Team Danmark
D'Agostino et al. (49)	2,250 children aged 6–15 years	Program is 10 months of after-school activity	Sociodemographic data Measure of change in ethnic group segregation. BMI and fat folds according to CDC percentiles and systolic and diastolic blood pressure numbers. Aerobic capacity test with the 400-m run test	Before-after	CDC. Decrease in infant mortality and sudden infant death syndrome among Northwest American Indians CDC. A public health action plan to prevent heart disease and stroke

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TABLE 2 (Continued)

References	Population	Groups	Physical activity measurements	Type of natural experiment	Public policy
Nicosia and Datar (50)	749 children of military	Two groups, military transfer parents and non-transfer controls	Level of physical activity in minutes per week and perception of nutrition by intake Time and frequency of MPA-MVPA activity during the week Sites or scenarios available for the practice of activity with GIS system.	Before-after	U.S. Department of Defense. Overweight Children in the Military Health System. Washington,
Sun et al. (51)	Number of trips and change in the types of trips	An intervention group with a new subway line with 24 stations pre- and post-measurement	Questionnaire of the preferences and type of uses of transport, bus, bicycle, walking or car, how long and with what frequency	Before-after with control group	Part of the policy but does not express it,
Mölenberg et al. (52)	$n = 1,841$ ages 6 (2008–2012) and 10 (2012–2015). ($n = 1,607$) outside playground ($n = 1,545$). Sedentary behavior	Two intervention groups with 18 new spaces in economically depressed areas compared to a control	Distance from the houses and neighborhoods to sporting grounds. Use of spaces. Hours spent on activity in open environments during the week and at the weekend. Level of physical activity of the participants.	Prospective cohorts	World Health Organization, 2012. The Built Environment: Designing Communities to Promote Physical Activity in Children usa and Denmark
Kapinos et al. (53)	237 Students assigned to the dormitories	Pre- and post-intervention, the groups were worked according to distance from the dormitories to gyms and restaurants	Questionnaire, height and weight data, sociodemographic aspects, exercise and diet data with direct questions on frequencies and number of meals per day and nutritional level. Exercise and diet data with direct questions on frequency and number of meals per day and nutritional level, number of days and frequency of exercise and distance walked to use the areas.	Cohort pre and post with control group	U.S. Department of Health and Human Services. Healthy people 2010: With understanding and improving health and objectives for improving health, In: Services USDoHaH, Washington, DC
Sharma et al. (54)	329 women	Multi-component pre- and post-intervention program	Sociodemographic data. Data on environmental, psychological and behavioral aspects. Dietary behaviors related to frequency of consumption, type of food, physical activity in terms of intensity, duration and frequency. Physical activity in terms of intensity, duration and frequency; Psychosocial factors related to food security, attitudes and ways of eating.	Before-after	Early life-cycle approach in tackling obesity, while advocating for a holistic, systems-based per-spective in the formulation of policies and interventions

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TABLE 2 (Continued)

References	Population	Groups	Physical activity measurements	Type of natural experiment	Public policy
Madsen (55)	6,967,120 school district students	Pre- and post-California Fitness Program for children ages 5–7th and 9th	Physical fitness was assessed using the Fitness Gram. Body composition area, BMI and skinfolds or by electrical impedance.	Before-after	Policy Position Statement on Body Mass Index (BMI) Surveillance and Assessment in Schools. American Heart Association; 2008
Klakk et al. (56)	1,218 children	2 groups of 10 schools in the municipality, 6 intervention and 4 control.	Blood, lipid, and glucose profile measurements. Blood pressure and waist circumference measurements. Andersen's cardiovascular endurance test was performed to measure physical fitness with fast running. Activity measurements by self-recording and accelerometer for the level of physical activity from MPA-MVPA	Quasi-experimental.	Pryce R, Willeberg S, Falkentoft C, Meyhoff T: Aldersrelateret træning—Målrettet og forsvarlig træning af børn og unge. 2005, Copenhagen, Denmark: Team Danmark
Aittasalo et al. (57)	44 companies, 1,833 workers	11 companies. The presence of lanes or roads for cycling or walking and use by workers for active transport was determined compared to control	Questionnaires on the use of the bicycle or walking as a method of active transport Time of use in hours or minutes and number of times per week on the activity LPA/MPA/VPA level of physical activity	Randomized controlled trial	Ministry of Transport and Communications (Liikenne- ja viestintäministeriö). Program for Promoting Walking and Cycling (Kävelyn ja pyöräilyn edistämisohjelma). 2018
Stone et al. (58)	16 school districts, 1,027 children and parents	BEAT pre-and post-program, environmental project to encourage physical activity in school children in Ontario	Accelerometry School-day and school-time activity, measures of activity time in counts, frequency and intensity of MVPA	Cross-sectional before-after	Ontario Ministry of Education. Daily physical activity in schools: Guide for school boards
Azevedo et al. (59)	497 participants intervention $n =$ 280; control 217	Two groups of 7 schools, intervention 5,280; control 2	Accelerometry to determine moderate to vigorous activity times, calculation of activity type according to counts Sedentary or active style according to level Anthropometric measurements of height weight, BMI by calculation and densitometry Aerobic capacity with the 20-m multistage running test for VO_2 Cardiovascular response and self-efficacy of physical activity with the self-efficacy questionnaire for children and quality of life with the kids screen 27. Qualitative interview with teacher and student	Non-randomized controlled trial with qualitative study.	Part of the policy but does not express it

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TABLE 2 (Continued)

References	Population	Groups	Physical activity measurements	Type of natural experiment	Public policy
Heinen et al. (60)	4,279 users responded and were included in the study and 40% completed	The low-cost community bicycle habitat program in Australia, pre and post, with 2,000 community bicycles	Questionnaire psychological stages to cycling Change in transport activity pattern to cycling, use, frequency, use for recreation or use for commuting to work Calculated bicycle use time by self-reporting and determined bicycle use exposure by distance from work to home and other commuting sites	Cohorts	Brisbane City Council, 2016. *via*: https://www.brisbane.qld.gov.au/facilities-recreation/sports-leisure/cycling-brisbane
Sarmiento et al. (61)	4,925 park users	3 groups of parks with new playgrounds, old playgrounds and no playgrounds	SOPARC Types of areas and use Physical activity level MPA/MVPA	Cross-sectional Comparison pre/post with control group	Recreovía program in Bogotá, Colombia, Muevete Bogota
McGavock et al. (62)	176 users	Two intervention groups of two frozen waterways in winter	Number of counts of the use of the tracks in the groups by means of an infrared system Level of physical activity in users who attended the track with the use of pedometers on their waist MVPA and counts steps	Before-after with control group	Part of the policy but does not express it

Main methodological, LPA, light physical activity; MPA, moderate physical activity; MVPA, moderate-vigorous physical activity; VPA, vigorous physical activity; METS, metabolic equivalents; AC-R, Academia da Cidade; SOPARC, system to assess the practice of physical activity and recreation in parks and natural surroundings; IPAQ, physical activity questionnaire; RPARQ, recreation physical activity questionnaire; GPS, Global Positioning System; HEAL, Healthy Eating Active Living; PALMS, Physical activity location measurement system; ActivePAL3C, active https://journals.lww.com/epidem/Fulltext/2008/11001/Geospatial_Measurement_Analysis_Of_Physical.186.aspx Physical activity location measurement system; PACER, walk system measurement; BMI, body mass index; CDC, center disease control; VO_2, volume Oxygen consumption; NIH, National institute of health; UTC, Universal Eligibility Criterion; TCT, Targeted Eligibility Criterion; SRTS, the federal Safe Routes to School; WSB, Walking School Bus.

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TABLE 3 Effectiveness of the programs.

	Activity level				Sedentary time	Program impact
References	Counts/sample	Activity type	% Physical activity	Time physical activity (%)		
Torres et al. (35)	1,533 participants 80% reported participating in the program for more than 3 months, 29% attending weekly and 43% monthly, 64% participating in classes AND (71%) Weekly class attendance	97% reported walking on the recreovía, cardiovascular (84%), walking or bicycling as Public Transportation (73%) and (18%), respectively.	-	↑ Number of minutes reported for leisure walking by 30 min compared to controls which has a decrease of 90 min. Recreational users *via* were more active on accelerometers relative to New users of vigorous 16 min at week ± 40, and at the weekend (79 min of MVPA ± 49) and at weekend 20 min MVPA ratio 225 start 305 finish	-	Positive evidence of the program at the district level with increased physical activity and inclusion of new users in higher levels of physical activity, this program being one of the ways to materialize the public policy.
Dill et al. (36)	↓ 307–240 and from 183 to 123 In second follow-up	_	↓ MV from 39.5 to 39.6%	↓ Total time on bicycle from 104 to 66 min and walking from 107 to 89	_	The active transportation program modifies habits in the population but does not favor an increase in activity during transportation time given the limitations presented in the study.
Prinss et al. (37)	414 participants	↑ in bicycle use 23.2% and 22.8% in each group	-	↑ minutes cycled between groups 85.4 (71.8) and 87.2 (74.9)	-	The effect of the commute program is important for increasing activity times on transportation as a public policy to encourage activity.
Gesell et al. (38)	82 children included	-	↑ Light total physical activity in the out-of-school intervention group (LMV) by 3.0 percentage points ($P = 0.006$), and 6 percentage points over 12-week study period and decrease in control group ↑ MVPA by a mean of 2.8 percentage points in each measurement period ($P = 0.006$), with a total increase of 5.6% points over the 12 weeks. The mean difference observed between the two groups of children who had data at week 12 was 10.8 ($P = 0.001$) percentage points in LMV and 13 percentage points in MVPA ($P < 0.001$)	.	-	Establishing community recreation centers that incorporate structured physical activity opportunities is associated with significant increases in physical activity during after-school activity time for public school children and could be a promising low-cost approach to improving children's health trajectories cost.

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TABLE 3 (Continued)

	Activity level				Sedentary time	Program impact
References	Counts/sample	Activity type	% Physical activity	Time physical activity (%)		
Barradas et al. (39)	1,533 participants.	-	-	↑ Total levels minute of leisure-time PA 158.1 (SD = 230.2) men 187.7 (SD = 245.3) women 145.8 (SD = 222.6) Moderate levels of leisure-time PA 81.9 (SD = 154.5) men 104.4 (SD = 176.8) women 72.5 (SD = 143, 2) Vigorous levels of leisure time PA 76.2 (SD = 160.2) men 83.2 (SD = 160.9) women 73.2 (SD = 159.8)	-	Participants reported elevated levels of both HRQoL and Life Satisfaction LS. Participants who reported higher LS scores also reported higher levels of leisure-time PA. No differences were found in differences between HRQoL scores and leisure-time PA. The second objective of the study was to differentiate levels of HRQoL and LS among Recreovía participants. Participants in Recreovía showed better indices of psychological wellbeing, highlighting the potential of the program to improve physical health.
Goodman et al. (40)	-	↑ 5.81–6.78% prevalence of cycling to work in 2011. Relative effect of 1.09 (95% CI: 1.07, 1.11). ↓ Prevalence of driving to work [−3.01 (−3.13, −2.88)]. 14 out of 18 cities ↑ higher cycling prevalence in 2011	Increased prevalence of walking to work [+1.71 (95% CI 1.62, 1.81)] percentage points lesser extent, of public transport use [+0.32 (0.24, 0.41)] percentage points	-	-	City-level interventions have potential health and environmental benefits, cycling is accompanied by decreased car commuting to work and increased commutation with lifestyle modification. The results indicate that city and cycling city initiatives have so far promoted cycling for healthy commuting and health equity, while also providing environmental benefits.
Simões et al. (41)	10,000 participants	–	The proportion of individuals that reached the LPA guidelines was 25.8%	For those who never participated and began their participation and to reach the levels (OR = 1.61; 95% CI 1.18; 2.20, <6 months 1.83; 95% CI 1.17; 2.86, *p*-value = 0.0078) more than 6 months (OR = 5.06; 95% CI 3.34; 7.67, *p*-value b0.0001)	–	The community-based physical activity intervention had a positive impact on LTPA levels in the population, especially among women. Evaluation of complex programs such as AC-P is feasible, with the study design and flexibility to rapidly fund and implement the study.

(Continued)

TABLE 3 (Continued)

	Activity level				Sedentary time	Program impact
References	Counts/sample	Activity type	% Physical activity	Time physical activity (%)		
Esdaile et al. (42)	720 children the total number of sessions ↑for children enrolled in groups with UEC (Mdn = 7, IQR = 4.25–9, Mean Rank = 387) than for children enrolled in groups with TEC (Mdn = 7, IQR = 3–9, Mean Rank = 352), U = 43,178.5, p = 0, 049 two-tailed	–	–	-	–	Program results suggest that families with overweight children are more likely to enroll in a healthy lifestyle program without weight criteria, in which marketing is aimed at improving healthy lifestyle behaviors, than in a weight management program with specific eligibility criteria. The program is also likely to have eligibility criteria and recruitment materials focused on healthy weight.
Kapinos and Yakusheva (43)	488 students	Dorm 7 houses one of the campus gyms and dorm 2 is only 0.13 miles from dorm 7. Despite exercising more frequently, only females assigned to dorm 2 weighed significantly less in the spring.		Although male students reported exercising more frequently on average, both males and females reported exercising less frequently during the first year compared to the year prior to entering college. Females in dorms 2 and 7 exercised more frequently during the first year.		
Hunt et al. (44)	26 children	PACER for walking ↑ median, but the change was not statistically significant (baseline = 11 laps, outcome = 14 laps, Δ = 3.00 laps, p = 0.26). On program break weekends, children accumulated 17.0 min less MVPA (72.4 min, SD = 45.5). And 13.5 min less AFMV (75.9 min, SD = 45.0).	–	89.4 min of AFMV (SD = 38.6) in the program. On days when the program ran but children did not attend, they accumulated 11.3 min less AFMV (78.1 min, SD = 38.0). During the week of the program break, children accumulated 10.0 fewer min of MVPA (79.4 min, SD = 37.3). Program attendance with MVPA was 45 min compared to 24 min for children when they did not attend the program or program break	–	This finding suggests that attendance at a structured summer program may mitigate BMI gain and loss of CRF, the impact of a structured program on weight gain and fitness loss, as well as obesogenic behaviors. Children maintained fitness, BMI, zBMI, and BMI percentile from the beginning to the end of the SLP.by helping children adopt healthier behaviors.
Lee et al. (45)	Out of 165 subjects 68 changed to active transport	41% active transport by bicycle or walking, 58.8% no change	–	–	–	The study notes that the shift from sedentary to active mode is associated with perceived environmental changes, such as shorter travel distance, improved safety conditions on the way to school, and greater availability of programs to support walking to school. This study offers some initial insights into additional factors, beyond the obvious distance factor, associated with mode shift.

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TABLE 3 (Continued)

	Activity level				Sedentary time	Program impact
References	Counts/sample	Activity type	% Physical activity	Time physical activity (%)		
Allais et al. (46)	205 individuals (49, 69, and 87 for the easy, health and control groups, respectively).	_	-	↑ Use of stairs at the beginning of the intervention in both the health and easy groups, with stronger effects for the latter but not maintained over time.	_	No differences between the treatment and control groups in the number of times individuals reported playing sports in a week. The stair use Advertisement program did not create a habit of stair use. At best, the effects of the PDPs lasted 2 weeks after the end of the intervention. As mentioned at the end of the Introduction, one effect of programs that encourage investment activities is to encourage the use of stairs.
Zhu et al. (47)	_	-	↑ 24.9–17.5 LPA and ↓ 6.6 to 6.5 MPA	_	↓ 337–281 sitting and ↑ 111–165 sedentary time	Natural experiment with high ecological validity with an intergroup design and a strong comparison group. The intervention group showed less prolonged standing at the workstation. The effect appears to have been sustained for 18 months, with concomitant improvements in cardio-metabolic and productivity outcomes.
Tarp et al. (48)	495 children Structured participation in leisure-time physical activity [odds ratio: 0.79 (0.46–1.36)], differed significantly between intervention and control	_	% MVPA/day [unstandardized beta: −0.17 (– 0.67 to 0.33)], nor mean counts/minute [unstandardized beta: −25 (−58 to 8)].	As for the blood chemistry variables by increase over time, the differences expressed in untransformed scales were −0.03 (−0.12 to 0.06) mmol/l, −0.08 (−0.24 to 0.08) and −0.10 (−0.33 to 0.14) for triglycerides, TC: HDL-c and HOMA-IR, respectively	On non-transformed scales, differences between intervention and control schools were −0.3 (−2.1 to 1.5) mmHg, −0.2 (−1.6 to 1.2) centimeters and −9 (−39 to 20) meters for systolic blood pressure, waist circumference and cardiorespiratory fitness, respectively.	Despite the effectiveness of the intervention over 2 years, tripling curricular physical activity from kindergarten to grade 6. did not result in a significant reduction in the number of children in the classroom or the number of clustered or individual biological risk factors between intervention and control schools, when assessed after 6.5 years.

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TABLE 3 (Continued)

	Activity level				Sedentary time	Program impact
References	Counts/sample	Activity type	% Physical activity	Time physical activity (%)		
D'Agostino et al. (49)	2,250 children			Girls who had decreased segregation showed greater improvement in all outcomes cardiovascular activities compared to boys Both non-Hispanic Afro and Hispanics who had decreased segregation	Non-Hispanic Afro showed greater improvements in skinfold thickness, SBPP, and running time, while Hispanics showed greater improvements in BMIP and DBPP 187–126 sg in 400-m run in cardiovascular health 140–104 sg in 400-m run	Worldwide, parks are accessible to the public and should be considered a valuable global resource in the effort to prevent childhood obesity and promote health equity. Effective global public health policy must address health inequalities through targeted prevention strategies and resource-based health equity. The United States suggests that increasing population physical education in public schools is a cost-effective method to reduce the burden of hypertension and reduce the burden of cardiovascular disease attributed to hypertension.
Nicosia and Datar (50)	829 children.		By type of PA, the association of interest was significant only for vigorous PA, but never for moderate PA. For vigorous PA, the coefficient coefficient of the interaction statistically significant (coefficient 12, 5, po0.05), those living outside the facility (coefficient 18.6, po0.05), and only for those who moved (coefficient 12.1, po0.05).	Who had moved recently from those who had not, the association of interest was positive and significant among those who had moved less recently (coefficient 21.7, po0.05), but not among those who had moved more recently. The coefficient was higher among less recent movers who consistently live away from home (coefficient 35.9, po0.01)	–	This study suggests that greater access to PA opportunities in neighborhoods may be an important avenue for increasing PA among adolescents. The focus on children in military families could raise concerns of generalizability. However, the majority of the sample did not meet recommended levels of PA, similar to the general population. The results might not be generalizable to younger children who rely on their parents for PA or to adults with stronger habits. The natural experiment addressed assignment to location in terms of facility and individual-level fixed effects but did not address unobservable facility variables and individual-level fixed effects over time.

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TABLE 3 (Continued)

	Activity level				Sedentary time	Program impact
References	Counts/sample	Activity type	% Physical activity	Time physical activity (%)		
Sun et al. (51)	↓ 5,436–1,770 participants	↓ % of time journeys for work and not walking bicycle and bus between 2 and 28% in each, and increase in metro, car and metro from 28 to 33%	–	–	–	Natural experiments are becoming an increasingly popular tool to help transportation and health researchers generate better evidence when real experiments are not possible. The results the context of a developing city provide new evidence of the impact of the new subway on modal commute and active travel, new urban trains or urban rail system does not necessarily encourage increased active travel or reduced car use. Finally, knowledge of urban and transportation planning can help design and develop complex natural experiments on transportation and health.
Mölenberg et al.(52)	171 children participated in the use of 600 m of new spaces	.	Having 600 m of space dedicated for PA % no change in outdoor play in children 6–10 years compared to control	Children aged 10 years played 40 min more and in families with low maternal education level the children played 96 min more during the week	Reducing the distance to 100 meters did not present effects in sedentary behavior or increase in activity	The introduction of spaces dedicated to PA can increase outdoor play time and change in sedentary behaviors for children from more socioeconomically disadvantaged families. 10-year-olds with a nearby PA space played 0.5 h/week more outdoors compared to children without dedicated PA spaces around the house. In the case of children from families with a lower maternal educational level, outdoor play was 1.5 h/week higher. These estimates are larger than those found in the experimental (natural) setting, suggesting that both selection and causal mechanisms may explain the relationship between access to play facilities and physical activity.

(Continued)

TABLE 3 (Continued)

	Activity level				Sedentary time	Program impact
References	Counts/sample	Activity type	% Physical activity	Time physical activity (%)		
Kapinos et al. (53)	1,935 participants Differences in changes according to distance to gym in 5 h per week by proximity	No effect of Proximity to gym on BMI for females, those living within 0.39 miles of a campus gym more likely to exercise frequently (more than 5 h per week), females living 0.39 miles or farther away less likely to exercise frequently.		Proximity to a campus gym had no effect on exercise frequency for males. Males living more than 0.39 miles from the nearest campus gym had significantly lower BMI and those living closer were significantly less likely to exercise.		Exogenous changes in the physical activity environment may lead to changes in weight and related behaviors but we failed to provide clear and robust evidence for such a relationship. Understanding spatial effects is challenging, as simple linear distances may not capture the implicit cost of using nearby physical activity services.
Sharma et al. (54)	210 women	14% increase in the number of women who reported being able to walk at least 10 min 5+ days per week	-	Physical activity for a total of at least 30 min during the past 7 days 3+ days per week from 82 to 113 Walking at least 10 min in a row for the last 7 days from 97 to 125 15% increase in the number of women reporting themselves active for at least 30 min per day 3 or more days per week	–	Programs such as HEAL provide a framework for successfully initiating clinic-community linkages and demonstrate the initial feasibility and acceptability of their implementation. HEAL demonstrates the feasibility of implementing this framework at the clinic and community level, >95% fidelity in program implementation, and acceptability of program strategies. By integrating a primary prevention approach to childhood obesity into the healthcare system, HEAL aims to create a model for system-level approaches to childhood obesity prevention, beginning in pregnancy. The study demonstrated an increase in physical activity among HEAL participants before and after the intervention, each week the women participated in physical activity sessions.

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TABLE 3 (Continued)

	Activity level				Sedentary time	Program impact
References	Counts/sample	Activity type	% Physical activity	Time physical activity (%)		
Madsen (55)	6,967,120 students	–	–	Valid BMI data for 6,967,120 students, representing 72.7% of all 5th, 7th, and 9th graders for the years 2001–2008	–	Widespread use of BMI screening and reporting is encouraging, as it reflects the willingness of schools to devote resources to addressing the obesity problem. In addition, research could explore how this type of information could be used more widely with other stakeholders and in policy. In the meantime, schools are likely to reap greater benefits if resources are used o increase opportunities for physical activity and improve nutrition.
Klakk et al. (56)	1,218 (81%), 697 of 773 (90%) from intervention schools and 521 of 734 (71%) but with different measures control		The difference in changes between intervention and control for TC: HDL, WC and CRF was small and insignificant. CRF 896–967 mt int and 893–961 mt cont	Six physical education classes per week significantly changed children's composite CVD risk score in favor of children attending intervention schools.		Mandatory physical education intervention with six lessons per week in public schools may reduce cardiovascular risk factors in children. The effect size observed in this healthy pediatric cohort, with the largest effect in the subgroup with the poorest composite risk score, which encompasses children in need of prevention, underscores the potential for school-based intervention programs.
Aittasalo et al. (57)	↑ 646–1,013 cycling and 309 to 346 walking	↑ Commute to bicycle 36% and walking 11%	–	↑ Commute time from walking and cycling for transport	–	The present study uses a socio-ecological framework in promoting commutation in a way, which has not been used in previous studies. Environmental improvements were part of the city's traffic plans and social and behavioral strategies. In addition, the intervention included several types of workplaces and the feasibility of the protocol related to the social and behavioral strategies had been previously tested.

(Continued)

TABLE 3 (Continued)

	Activity level				Sedentary time	Program impact
References	Counts/sample	Activity type	% Physical activity	Time physical activity (%)		
Stone et al. (58)	856 participants 16.6% participated in daily activity on 2 days, 17.9% on 3 days, and 16.1% on 4 days		19.3% of participants ($n = 165$) accumulated at least 1 sustained session (≥5 min) of MVPA during the school week. The proportion varied among the 16 participating schools (0–45%). Most children (74.5%) accumulated 1 session, while 18.2 and 3.7% accumulated 2 and 3 sessions, respectively; only 6 children (3.6% of the sample) accumulated 4 sessions	The overall intensity of their activity was activity was higher and they accumulated significantly more minutes of moderate to vigorous activity throughout the school days (MVPAWD) and during the school day period (MVPASD) TPAWD 422. 429 (124,245) to 460,778 (135,477) MWD 437. 5 (140.9) A 463.9 (166.4) MVPAWD 30.2 (13.8)A 34.1 (16.1) MVPASD 15.1 (7.3) 18.0 (8.8)	DPA frequency was positively associated with total physical activity 423,386 (126,369), mean counts and cumulative weekday MVPA minutes ($r = 0.10–0.13$, $p < 0.01$). 29.6 (13.5) DAYS	The objective of this paper was to assess whether the Ontario Ministry of Education's daily physical activity policy (DPA) is being effectively implemented in elementary schools. The results show that most schools do not meet the required frequency (5 days) or intensity (maintaining vigorous activity for at least 20 min) of the DPA policy. However, our work demonstrates that frequency and intensity of DPA is positively related to student health behaviors/outcomes. Although our design prevents us from determining cause and effect, a positive relationship between DPA and physical activity/health in children clearly exists. Longitudinal studies are needed to establish whether benefits in students when the policy is effectively implemented.
Azevedo et al. (59)	497 participants (intervention $n = 280$; control $n = 217$).	There was no statistical difference between intervention and control participants between follow-up adjusted means for self-efficacy for physical activity or aerobic fitness.	Percentage of light physical activity (mean difference = −2.3%, 95% CI = −4.5 to 0.2, $p = 003$ MVPA (min.d-1) Basal 52.2 ± 16.4 post 58.2 ± 16.0 diff −5.6 (−13.6 to 2.3)	Light physical activity (min.d-1) basal 205.6 ± 36.0 post 234.3 ± 36.4 diff = −28.7, (95% CI = −46.5 to −10.8, $p = 0.02$), MV (min.d-1) Basal 52.2 ± 16.4 post 58.2 ± 16.0 diff −5.6 (−13.6 to 2.3). Total MV activity (counts min-1) basal 892.5 ± 187.2 post 993.0 ± 230.7 diff −100.5 (−193.3 to −7.6)	Sedentary time (min. d-1) BASAL 502.3 ± 66.5 (152) POST 512.7 ± 63.5 (32) percent sedentary time (mean difference = 3.3%, 95% CI = −0.7 to −5.9, $p = 0.01$)	Implementation of a dance mat exergaming scheme in public high schools was associated with an improvement weight, BMI, body fat percentage and some parameters of health-related quality of life, but not with aerobic capacity, self-efficacy for physical activity or school attendance.

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TABLE 3 (Continued)

	Activity level				Sedentary time	Program impact
References	Counts/sample	Activity type	% Physical activity	Time physical activity (%)		
Heinen et al. (60)	4,637 respondents	No statistically significant associations. between proximity to a bike share station and changes in time spent cycling		Reduction in total time spent cycling by 1.98 min per week. Average time spent 8.8% ($n =$ 362) increased their total cycling time by 35 min or more in 1 week, 81.5% ($n =$ 3,356) changed their total cycling time by <35 min. 9.7% ($n =$ 400) reduced total cycling time by 35 min.		Our results indicate that residential proximity to a bike share station was not significantly associated with a higher level of (intention to) use nor with a greater propensity to increase total time spent bicycling, perhaps due to the older cohort in our sample. Studies have indicated that older people are less likely to adjust their travel behavior compared to the younger age cohort.
Sarmiento et al. (61)	4,925 users Parks with existing recreational pathways $n =$ 994 % 29.9 Parks implementing future recreational pathways $n =$ 147% 29.8 Control parks $n =$ 338% 33	Women aerobic (7.7%), walking (7.0%) and basketball (6.6%). less frequent swinging (0.6%) and running (0.5%), parks with existing Recreovía, aerobic 21.2%). parks with future Recreovía, the main activity skating (5.9%). control parks activity carried out basketball (11.4%). Men soccer (14.3%), basketball (10.1%) and standing (8.5%). least common jogging/running and stretching (0.6%),	Mild Parks with existing recreational trails $n =$ 991% 57.8 Parks implementing future recreational trails = 106% 50.3 control parks $n =$ 144% 44.7 Vigorous: Parks with existing recreational trails $n =$ 287% 16.8 Parks implementing future recreational trails = 39% 18.5 control parks $n =$ 35% 10.9	women parks with existing Recreovía moderate to vigorous physical activity (MVPA), compared to women observed in parks without Recreovía 75 vs. 61%; p-value < 0.00 Males more likely to engage in MVPA in parks without Recreovía vs. parks with Recreovía 71 vs. 65%, (p-value $<$ 0.01) 1		Parks with Recreovía were more likely to be used by women and had a higher percentage of users compared to parks without the Recreovía program. The presence of the Recreovía program was also associated with higher levels of MVPA observed among women. Providing culturally appropriate PA and dance classes and dance classes in public parks on weekends could be a promising strategy to promote PA among women.
McGavock et al. (62)	↑ 405–1,813 and 2,449–4,516 in two follow-ups 4,195 steps in 39 min, 4,796 vs. 3,987 steps during the week	–	–	↑ MVPA in minutes (32 vs. 25 min) and accumulated 27 ± 18 min of MVPA	–	The creation of a trail on a frozen waterway resulted in a significant increase in visitors to a network of urban trails. The activity dose that users achieved while on the frozen waterway was within the range necessary for health benefits. Trail users reported significant health benefits associated with trail use. Frozen waterways are a novel population health intervention to support increased physical activity after the winter vacations.

Effectiveness of the programs, PA, physical activity; LPA, light physical activity; MPA, moderate physical activity; MVPA, moderate-vigorous physical activity; VPA, vigorous physical activity; METS, metabolic equivalents; MVPAWD, moderate-vigorous physical activity week day; MVPASD, moderate-vigorous physical activity school day; DPA, Diary physical activity; HRQoL, health related quality of life; TC, total cholesterol; HDL, high density Lipids; CRF, Cardiorespiratory function; CVD, Cardiovascular Disease; BMI, Body mass index; HEAL, Healthy Eating Active Living; PDPs, Point-of-decision prompts; PACER, walk system measurement.

In contrast, in two studies, one with an intervention of activity in the neighborhood in the cities (52) and the other examining bicycle commuting (36), no changes in the use of bicycle areas or boulevards were reported.

The increase of PA as an outcome was reported in 14 records corresponding to 11 studies (35, 37, 40, 43–45, 51, 54, 57, 59, 60). In these studies, aerobic activities such as running, jogging, or walking were implemented. Also, the use of bicycles as an activity, commuting as a means of transportation, or as a method to access public areas was found (35, 37) with bicycling being the most effective as a means of transportation reported in 7 studies (35, 37, 40, 45, 51, 57, 60). One of these studies (40) reported an increase in the prevalence of bicycle use from 5.81 to 6.78%, with an Odds Ratio (OR) of bicycle use of 1.09 (95%CI: 1.07–1.11), and a decrease in the use of the vehicle with an OR of 3.01 (95%CI: 3.13 to −2.88). Three studies found an increase in school activities and walking, and also intra- or extracurricular PA with two of the studies in schools (44, 59) and one in parks (35). The study examining PA in parks found an increase of 97% in walking on the playground, 84% in cardiovascular activities, and 18% in cycling as transportation.

Changes in the time of PA were also examined of which 15 of 22 studies) (35–37, 39, 41, 43, 44, 46, 48–50, 52–62) demonstrated that the changes generated an increase or modification in minutes spent in PA, whether it was daily, weekly, and total PA for the population. Eight studies in the school area (43, 44, 48, 49, 55, 56, 58, 59) reported an increase of 89.4 min of weekly PA in students with increases in LPA from 422 to 460 min, vigorous PA from 30 to 40 min per week, and total PA from 187 to 230 min per week. Similarly, the studies of PA in parks and cities (35, 41, 50, 52) found an increase in the minutes of participation in recreational pathways, parks, or modified city areas, with an accumulated total time of 27 min of moderate-vigorous PA (MVPA). An improvement in the number of women actively participating in provided programs was also reported, with an increase in walking time that was >30 min with a variation of 82 (54, 61). In children, an increase in PA of 40 min was observed, and in children over 10 years of age or in children from economically deprived families, the increase in PA time ranged from 96 to 113 min (50, 52). The study of Brazilian cities (41) demonstrated a dose-response relationship where a stronger association with adherence to leisure time PA guidelines was found the more exposed the population was to the program and whether the exposure was current compared to a past exposure. In this same sense, commuting as a form of transportation increased the time spent cycling or walking as shown in Table 3.

Finally, three studies reported a change from sedentary to active lifestyle (47, 52, 59) with an increase in PA time and a decrease in sedentary time highlighted by a diminution in sitting time from 337 to 281 min in participants who were examined in the workplace, school children, and city programs.

Risk of bias in the included studies

Natural experiments are very useful in public policy due to the fact that the population is assessed in their environment at the time that programs or policies are implemented (63, 64). At the same time, one weakness of natural experiments is the risk of bias. Table 4 illustrates the results of the risk of bias assessment of the studies included. As shown, the risk of bias differs among studies, but there is an implicit risk of bias in natural experiments in the pre-intervention, during intervention, and post-intervention periods.

Discussion and conclusions

This systematic review focused on environmental social strategies to increase PA. The results found multiple social programs worldwide were studied through natural experiments. Twenty-four experiments from 28 reports developed in different environments such as schools, workplaces, streets or cities, neighborhoods, and parks were reviewed and analyzed to determine the effectiveness of promoting PA in populations. Of the included studies, 12 were carried out in external environments such as parks, cities, neighborhoods, or crosswalks, and the other 12 were carried out indoors or outdoors such as in schools and companies. The experiments provided innovative proposals for social programs that seek to increase PA and promote healthy lifestyles related to public policies developed in the countries in which they were generated.

Worldwide, environmental modification programs from the social perspective have gained relevance for the implementation of policy-based programs in countries whose impact has been evaluated through natural experiments (26). Natural experiments have strengths and weaknesses inherent to their methodological design and the scope of their conclusions. These studies have a higher risk of bias given population selection and confounding in the management of variables. But it is important to note that, although they have these central problems, they allow the analysis of community or environmental interventions in large populations and groups. In our systematic review, natural experiments were of vital importance given the prospects of working on PA from a population standpoint and reducing chronic non-communicable diseases as established by the WHO (65).

The use of natural experiments and their impact on the modification of public health problems like our study have been presented in three key studies. One of the largest studies was reported by the WHO in a different area with three large projects. The first was from Austria about the regulation of trans fatty acids to prevent mortality from all cardiovascular causes and coronary heart disease (66). The second was from Russia on the effects of tobacco control policy to prevent cardiovascular disease (67) and finally, a study from Romania on the increase in tobacco taxes (68). These three experiments from the WHO European project of natural experiments raise the strengths of their use in implementing public policies but their methodological weaknesses as well.

Another important factor to consider is the manner in which environmental modification and active transportation is related to health equity (69). A previous review included 28 studies carried out in adult and child populations. In contrast to our study, they included prospective, longitudinal, cross-sectional, repeated measures studies, and a natural experiment. Although the types of studies were different, all programs were focused on promoting PA through walking, bicycling, park-based programs, neighborhood modification, and even environmental recreation activities. Another difference was the list of risk of bias evaluation in which the instrument of evaluation of public policies in health practices of the Canadian Association for observational studies

TABLE 4 Risk of bias in the studies included.

Author/ measurement	Pre-intervention		During intervention	Post-intervention		
	Confounding	Selection	Intervention measures	Interventions performed	Outcome measures	Reporting bias
Torres et al. (35)	X Lack of control of variables	X Selection by recreation *via*	√	√	X Measurements in subsamples not the whole population	√
Dill et al. (36)	X Lack of confusion management	X Selection of participation in boulevard	√	X Losses to follow-up	X Measures vary among participants as there are losses to follow-up	√
Panter et al. (37)	√ Protocol	X Selection of participation	√	√	√	√
Gesell et al. (38)	√	X Broad inclusion criteria	√	√	√	√
Barradas et al. (39)	X Lack of control of variables	X Selection by recreation *via*	√	√	X Measurements in subsamples not the whole population	√
Goodman et al. (40)	√ Protocol	X Selection of participation	√	√	√	√
Simões et al. (41)	X Lack of control of variables	X Selection by participation in the cities	√	√	√	√
Esdaile et al. (42)	X Lack of control of confounding variables	X Selection is by entry into the Peach program	√	√	X Measures focus on BMI	√
Kapinos and Yakusheva (43)	X Lack of control of variables	X Selection by allocation of bedrooms	√	√	X Bias due to self-reporting measures or no direct measurement of anthropometric changes	√
Hunt et al. (44)	√	X Broad inclusion criteria in after-school program	√	√	X Measurements are not population-wide	√
Lee et al. (45)	X Lack of control of confounding variables	X Selection is by entry into the Peach program	√	√	X Retrospective measures	√
Allais et al. (46)	X Lack of control of confounding variables	X Selection is by use of subway stairs	√	X Loss to follow up.	√	√
Zhu et al. (47)	X Lack of control of confounding variables	√	√	X Loss to follow-up	√	X Non-uniform measurements in the two groups
Tarp et al. (48)	X Confusion present no nutritional information in the analysis	X Selection bias, although it establishes entry criteria	√	X Loss to follow-up and data.	√	√
D'Agostino et al. (49)	X Lack of control of confounding variables	X Selection by participation in the program although there are broad criteria	√	√	√	√
Nicosia and Datar (50)	X Confusion present due to program entry at military bases	√	√	√	X Risk of bias measured by self-reporting	√

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TABLE 4 (Continued)

Author/ measurement	Pre-intervention		During intervention	Post-intervention		
	Confounding	Selection	Intervention measures	Interventions performed	Outcome measures	Reporting bias
Sun et al. (51)	X Confusion because it is handled according to distance to the meter √ √ √	X Selection bias due to unclear inclusion criteria	√	√	X Bias in measurement due to memory bias	√
Mölenberg et al. (52)	X Confusion because it is handled by participation in the new spaces of the city √	X Selection bias due to not having clear inclusion criteria	√	X Loss of sample of the subjects evaluated because they lived far from the selection area	X Not having GPS measurements that determines the distances of the children to the work areas, and memory bias in the parents could affect the measurement	√
Kapinos et al. (53)	X Lack of control of variables √ √ √	X Selection by allocation of bedrooms	√	√	X Bias by self-report measures or by not directly measuring anthropometric changes	√
Sharma et al. (54)	X Risk due to control of confounding variables	√	√	√	√	√
Madsen (55)	X Risk due to control of confounding variables X √ √ √	X Selection by allocation fitness program	√	√	X Risk in measurement only imc measure is reported as indirect measure of activity	√
Klakk et al. (56)	√	X Selection bias, although it establishes entry criteria √	√	X Loss to follow-up and data	√	√
Aittasalo et al. (57)	X Attempt is made to control variables but missing √	X Selection by use of transportation	√	X Loss of sample of subjects evaluated	X Bias by self-report measures and loss in accelerometry measures	X Attempt is made to control variables but missing √
Stone et al. (58)	√ Protocol	X Convenience selection bias	√	√	X Loss of measured variables due to incomplete data	√
Azevedo et al. (59)	X Lack of control of variables	X Differences in baseline between schools	√	X Loss to follow-up and data	X Loss of measured variables due to incomplete data	√
Heinen et al. (60)	X Confusion present due to participation in the program.	X Selection due to participation in the bicycle programs	√	X Loss to follow-up	X Bias due to self-reporting measures and loss in measures	√
Sarmiento et al. (61)	X Lack of control of variables	X Selection by recreo *via*	√	√	√	√
McGavock et al. (62)	X Lack of control of variables	X Selection by frozen channel use	√	√	X Bias by measures of register of channel use	√

was used, but although the list was different, the evaluation was similar, finding weaknesses in the studies methodology but with the advantage in the description of the effectiveness of the promotion of PA. The previous research measured the activity reported ranging from the use of types of transportation to specific measures of activity in metabolic expenditure in METS or level of PA from mild to moderate to vigorous. Within the impact reports, increases in the number of users, metabolic work, or the level of moderate or vigorous activity were found to have a greater impact in school and adult physical activity programs, followed by those of parks or playgrounds modifications and those of urban renewal with the implementation of programs in the scenarios similar to our review.

In this same line, but in systematic reviews in different levels of evidence related to public policies and environmental modifications is an integrative review of systematic reviews and meta-analysis of urban modification and promotion of PA in Latin America. The results were reported in 14 articles and included 8 systematic reviews with studies of different levels from cohorts, cross-sectional, experimental, cases, and controls among others (70). The studies were developed especially in Australia, the United States, and England. The findings showed that programs which were proposed in the environment such as the development of bike paths or recreational spaces, transportation, and commute to active transportation increased the PA. Within the programs found there was evidence of an improvement in the levels of activity within a range of 8–33 min of walking per day with an increase in activity similar to that found in our results. In addition, the study found that the development of outdoor spaces that created scenarios in the population for the practice of the activity and the use of active transportation such as bicycles, walking at school and work level improved PA. The results of the study also suggest that the level of activity could rise by maximizing the use of physical spaces by satellite geo-referencing in neighborhoods and cities to increase activity and shows the relevance of developing public policies related to PA.

In the area of environmental programs focused on active transportation, there were two reviews, one systematic and the other synthesis of evidence from systematic reviews. The first was based on interventions to increase cycling (71) and the second was on urban environmental interventions to increase PA (72). In the first report with 12 studies, 2 clinical trials and 10 pre- and post-intervention of individual, group, and environmental interventions with outcomes to promote active transportation found that the implementation of programs focused on the individual or environmental infrastructure increases the level of transportation trips from 7 to 12%, with an OR of 7.8 in participants who rode a bicycle more than 2 km. Also an increment of 27.5% during the use of cyclists who use active transportation in the last 5 months, similar to what was reported in our study with the increase in time and number of trips. Similarly, an increase of 47.5% in the number of cyclists was found in a program in New Zealand where a bridge was constructed and not only improved PA levels, but also increased health status (71). Secondly, eight systematic reviews all of which were focused on the impact of urban interventions on PA demonstrated an increase in activities such as walking, cycling, switching from bus transportation to walking, or the use of bike lanes for the control of chronic non-communicable diseases (70).

Related to the topic of environmental modification, a systematic review but in different levels of evidence ranging from controlled trials to cross-sectional studies in the school setting, focused on in-school programs as in our study. The review of the effects of classroom-based programs on PA outcomes and academic performance (73) included 39 studies that examined the effect of activity programs in school settings. As in this review, there were programs to increase activity in the classroom for children and adolescents and included active rest periods based on aerobic activity to achieve the movement of students in the class to extra-classroom programs focused on sports or with additional equipment and implements to increase the level of activity. It is also noteworthy that the time and activity were variable among the programs ranging from 4-min of daily vigorous-level classroom activities to 20 min of moderate PA twice a week. Also, programs focused on the curriculum, such as the Ontario Natural Experiment have been studied in which in mathematics, language, science, or social studies classes incorporated cognitive academic skills with PA goals. In this paper three studies, two experimental cluster studies and one quasi-experimental study, were meta-analyzed to determine the effect of the program on PA, finding 95% heterogeneity with a non-significant effect of 0.40 CI −0.15 to 0.95.

About the applicability of these results in our review is important to consider since most of the studies come from high-income countries, and little information exists on middle- and low-income countries, likely because the urban modifications in-built environments is determined by the use of the land, density, and urbanization. This is important because economic and educational aspects influence the type of environmental interventions implemented and the possibility of changing behaviors in the population. The evidence shows some favorable results related to the implementation but stronger evidence is needed to determine the changing in behaviors (72, 74).

In conclusion the 24 reviewed studies suggest innovative proposals for social programs that seek to increase PA and promote healthy lifestyles related to public activity policies developed in the countries in which they were generated. Environmental social programs can positively impact PA levels among children and adults. It is important to highlight that these documents presented and this research reflect the importance of implementing public policies aimed at promoting PA from an environmental perspective. Structural modifications and the creation of social programs from socioecological perspectives allow the establishment of other perspectives of approaching PA that not only focus on the individual but also how changes in the environment facilitate the implementation of plans, programs, and public policies for PA. It appears important that a central mission of a country is to implement policies to promote PA with a comprehensive vision centered on the populations within a country.

Strengths and limitations

This systematic review based on natural experiments has several advantages including (1) the examination of large populations in natural settings providing an understanding of the effect programs and modifications to existing program may promote PA and (2) examining the implementation and measurement of public policies and programs established in the studies. A risk of bias is implicit in natural experiments and may introduce bias in the selection, measurement, and reporting of results. Nonetheless, natural experiments are an important type of study for decision-making in public health and especially in assessment of PA in environmental interventions.

Data availability statement

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

Author contributions

Overall content as guarantor: EH. Study concept and design: EH and PS. Screening titles and abstracts: EH, PS, and EC. Search and extracted the evidence: EH and EC. Writing and revising the manuscript for important intellectual content and approved the final manuscript: EH, EC, LC, and PS. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1095146/full#supplementary-material

References

1. Stankov I, Garcia LMT, Mascolli MA, Montes F, Meisel JD, Gouveia N, et al. A systematic review of empirical and simulation studies evaluating the health impact of transportation interventions. *Environ Res.* (2020) 186:109519. doi: 10.1016/j.envres.2020.109519

2. Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT, et al. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet.* (2012) 380:219–29. doi: 10.1016/S0140-6736(12)61031-9

3. Grossman M. *Determinants of Health*. New York, NY: Columbia University Press (2017).

4. Brownson RC, Chriqui JF, Burgeson CR, Fisher MC, Ness RB. Translating epidemiology into policy to prevent childhood obesity: the case for promoting physical activity in school settings. *Ann Epidemiol.* (2010) 20:436–44. doi: 10.1016/j.annepidem.2010.03.001

5. Puhakka S, Pyky R, Lankila T, Kangas M, Rusanen J, Ikäheimo TM, et al. Physical activity, residential environment, and nature relatedness in young men—A population-based MOPO study. *Int J Environ Res Public Health.* (2018) 15:322. doi: 10.3390/ijerph15102322

6. Fallis A. Global recommendations on physical activity for health (WHO). *J Chem Inf Model.* (2013).

7. de la Haye K, Fluke M, Laney PC, Goran M, Galama T, Chou CP, et al. In-home obesity prevention in low-income infants through maternal and social transmission. *Contemp Clin Trials.* (2019) 77:61–9. doi: 10.1016/j.cct.2018.12.010

8. Pratt M, Charvel Orozco AS, Hernandez-Avila M, Reis RS, Sarmiento OL. Obesity prevention lessons from Latin America. *Prevent Med.* (2014) 69:S120–2. doi: 10.1016/j.ypmed.2014.09.021

9. Shi J, Kobayashi LC, Grundy A, Richardson H, SenGupta SK, Lohrisch CA, et al. Lifetime moderate-to-vigorous physical activity and ER/PR/HER-defined post-menopausal breast cancer risk. *Breast Cancer Res Treat.* (2017) 165:201–13. doi: 10.1007/s10549-017-4323-4

10. *BMJ Global Health*. Available online at: http://gh.bmj.com/ (accessed November 30, 2022).

11. Pfeiffer KA, Saunders RP, Brown WH, Dowda M, Addy CL, Pate RR. Study of health and activity in preschool environments (SHAPES): study protocol for a randomized trial evaluating a multi-component physical activity intervention in preschool children. *BMC Public Health.* (2013) 13:728. doi: 10.1186/1471-2458-13-728

12. Chen B, Waters CN, Compier T, Uijtdewilligen L, Petrunoff NA, Lim YW, et al. Understanding physical activity and sedentary behaviour among preschool-aged children in Singapore: a mixed-methods approach. *BMJ Open.* (2020) 10:e030606. doi: 10.1136/bmjopen-2019-030606

13. French SA, Sherwood NE, Mitchell NR, Fan Y. Park use is associated with less sedentary time among low-income parents and their preschool child: the NET-Works study. *Prev Med Reports.* (2017) 5:7–12. doi: 10.1016/j.pmedr.2016.11.003

14. Chow CK, Lock K, Teo K, Subramanian S, McKee M, Yusuf S. Environmental and societal influences acting on cardiovascular risk factors and disease at a population level: a review. *Int J Epidemiol.* (2009) 38:1580–94. doi: 10.1093/ije/dyn258

15. Mitra R, Cantello ID, Buliung RN, Faulkner GEJ. Children's activity-transportation lifestyles, physical activity levels and social-ecological correlates in Toronto, Canada. *J Transp Heal.* (2017) 6:289–98. doi: 10.1016/j.jth.2017.03.010

16. *Cycling and Walking Investment Strategy - GOV.UK*. Available online at: https://www.gov.uk/government/publications/cycling-and-walking-investment-strategy (accessed July 20, 2021).

17. Adams MA, Frank LD, Schipperijn J, Smith G, Chapman J, Christiansen LB, et al. International variation in neighborhood walkability, transit, and recreation environments using geographic information systems: the IPEN adult study. *Int J Health Geogr.* (2014) 13:43. doi: 10.1186/1476-072X-13-43

18. *Overview | Physical Activity and the Environment | Guidance | NICE*. Available online at: https://www.nice.org.uk/guidance/ng90 (accessed April 20, 2021).

19. Mehtälä MAK, Sääkslahti AK, Inkinen ME, Poskiparta MEH. A socio-ecological approach to physical activity interventions in childcare: a systematic review. *Int J Behav Nutr Phys Activity.* (2014) 11:22. doi: 10.1186/1479-5868-11-22

20. Maddison R, Vander HS, Jiang Y, Mhurchu CN, Exeter D, Dorey E, et al. The environment and physical activity: the influence of psychosocial, perceived and built environmental factors. *Int J Behav Nutr Phys Act.* (2009) 6:19. doi: 10.1186/1479-5868-6-19

21. Sugiyama T, Paquet C, Howard NJ, Coffee NT, Taylor AW, Adams RJ, et al. Public open spaces and walking for recreation: moderation by attributes of pedestrian environments. *Prev Med (Baltim).* (2014) 62:25–9. doi: 10.1016/j.ypmed.2014.01.030

22. Seefeldt V, Malina RM, Clark MA. Factors affecting levels of physical activity in adults. *Sport Med.* (2002) 32:143–68. doi: 10.2165/00007256-200232030-00001

23. Sisson SB, Salvatore AL, Hildebrand D, Poe T, Merchant C, Slawinski M, et al. Interventions to promote healthy environments in family child care homes in Oklahoma - Happy Healthy Homes: study protocol for a randomized controlled trial. *Trials.* (2019) 20:541. doi: 10.1186/s13063-019-3616-9

24. Bramante CT, Thornton RLJ, Bennett WL, Zhang A, Wilson RF, Bass EB, et al. Systematic review of natural experiments for childhood obesity prevention and control. *Am J Prev Med.* (2019) 56:147–58. doi: 10.1016/j.amepre.2018.08.023

25. Herías MV, Cruz JR, González-Cossío T, Nave F, Carlsson B, Hanson LA. The effect of caloric supplementation on selected milk protective factors in undernourished Guatemalan mothers. *Pediatr Res.* (1993) 34:217–21. doi: 10.1203/00006450-199308000-00024

26. Craig P, Cooper C, Gunnell D, Haw S, Lawson K, Macintyre S, et al. Using natural experiments to evaluate population health interventions: new Medical Research Council guidance. *J Epidemiol Community Heal.* (2012) 66:1182–6. doi: 10.1136/jech-2011-200375

27. Barrera EAV, Lima RA, Hardman CM, Soares FC, Martins CL, Bezerra J. Perfil sociodemográfico, ocupacional e prática de atividade física em trabalhadores de um programa comunitário de atividade física TT - Perfil sociodemográfico, ocupacional y actividad física entre los trabajadores del programa comunitario de actividad f. Rev andal med. *Deport.* (2019) 12:71–5. doi: 10.33155/j.ramd.2019.01.003

28. Van Dyck D, Cerin E, De Bourdeaudhuij I, Hinckson E, Reis RS, Davey R, et al. International study of objectively measured physical activity and sedentary time with body mass index and obesity: IPEN adult study. *Int J Obes.* (2015) 39:199–207. doi: 10.1038/ijo.2014.115

29. Cohen DA, Marsh T, Williamson S, Golinelli D, McKenzie TL. Impact and cost-effectiveness of family Fitness Zones: a natural experiment in urban public parks. *Health Place.* (2012) 18:39–45. doi: 10.1016/j.healthplace.2011.09.008

30. Brittin J, Frerichs L, Sirard JR, Wells NM, Myers BM, Garcia J, et al. Impacts of active school design on school-time sedentary behavior and physical activity: a pilot natural experiment. *PLoS ONE.* (2017) 12:e0189236. doi: 10.1371/journal.pone.0189236

31. Deeks JJ, Higgins JPT, Altman D. Chapter 9: analysing data and undertaking. *Cochrane Handb Syst Rev Interv Version 5.1.0* (2011).

32. Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred reporting items for systematic reviews and metaanalyses: the PRISMA statement. *PLoS Med.* (2009) 21:e1000097. doi: 10.1371/journal.pmed.1000097

33. Elmagarmid A, Fedorowicz Z, Hammady H, Ilyas I, Khabsa M, Ouzzani M. Rayyan: a systematic reviews web app for exploring and filtering searches for eligible studies for Cochrane Reviews. In: *Evidence-Informed Public Health: Opportunities and Challenges Abstracts of the 22nd Cochrane Colloquium.* Hyderabad (2014).

34. Bero L, Chartres N, Diong J, Fabbri A, Ghersi D, Lam J, et al. The risk of bias in observational studies of exposures (ROBINS-E) tool: concerns arising from application to observational studies of exposures. *Syst Rev.* (2018) 7:242. doi: 10.1186/s13643-018-0915-2

35. Torres A, Díaz MP, Hayat MJ, Lyn R, Pratt M, Salvo D, et al. Assessing the effect of physical activity classes in public spaces on leisure-time physical activity: "Al Ritmo de las Comunidades" A natural experiment in Bogota, Colombia. *Prev Med.* (2017) 103:S51–8. doi: 10.1016/j.ypmed.2016.11.005

36. Dill J, McNeil N, Broach J, Ma L. Bicycle boulevards and changes in physical activity and active transportation: findings from a natural experiment. *Prev Med.* (2014) 69:S74–8. doi: 10.1016/j.ypmed.2014.10.006

37. Prins RG, Panter J, Heinen E, Griffin SJ, Ogilvie DB. Causal pathways linking environmental change with health behaviour change: natural experimental study of new transport infrastructure and cycling to work. *Prev Med.* (2016) 87:175–82. doi: 10.1016/j.ypmed.2016.02.042

38. Gesell SB, Sommer EC, Lambert EW, Vides De Andrade AR, Whitaker L, Davis L, et al. Comparative effectiveness of after-school programs to increase physical activity. *J Obes.* (2013). 2013:576821. doi: 10.1155/2013/576821

39. Barradas SC, Finck Barboza C, Sarmiento OL. Differences between leisure-time physical activity, health-related quality of life and life satisfaction: Al Ritmo de las Comunidades, a natural experiment from Colombia. *Glob Health Promot.* (2019) 26:5–14. doi: 10.1177/1757975917703303

40. Goodman A, Panter J, Sharp SJ, Ogilvie D. Effectiveness and equity impacts of town-wide cycling initiatives in England: a longitudinal, controlled natural experimental study. *Soc Sci Med.* (2013) 97:228–37. doi: 10.1016/j.socscimed.2013.08.030

41. Simões EJ, Hallal PC, Siqueira FV, Schmaltz C, Menor D, Malta DC, et al. Effectiveness of a scaled up physical activity intervention in Brazil: a natural experiment. *Prev Med.* (2017) 103:S66–72. doi: 10.1016/j.ypmed.2016.09.032

42. Esdaile E, Hernandez E, Moores CJ, Vidgen HA. Enrolment of families with overweight children into a program aimed at reducing childhood obesity with and without a weight criterion: a natural experiment. *BMC Public Health.* (2019) 19:756. doi: 10.1186/s12889-019-6894-y

43. Kapinos KA, Yakusheva O. Environmental influences on young adult weight gain: evidence from a natural experiment. *J Adolesc Heal.* (2011) 48:52–8. doi: 10.1016/j.jadohealth.2010.05.021

44. Hunt ET, Whitfield ML, Brazendale K, Beets MW, Weaver RG. Examining the impact of a summer learning program on children's weight status and cardiorespiratory fitness: a natural experiment. *Eval Program Plann.* (2019) 74:84–90. doi: 10.1016/j.evalprogplan.2019.02.009

45. Lee C, Yoon J, Zhu X. From sedentary to active school commute: multi-level factors associated with travel mode shifts. *Prev Med.* (2017) 95:S28–36. doi: 10.1016/j.ypmed.2016.10.018

46. Allais O, Bazoche P, Teyssier S. Getting more people on the stairs: the impact of point-of-decision prompts. *Soc Sci Med.* (2017) 192:18–27. doi: 10.1016/j.socscimed.2017.09.006

47. Zhu W, Gutierrez M, Toledo MJ, Mullane S, Stella AP, Diemar R, et al. Long-term effects of sit-stand workstations on workplace sitting: a natural experiment. *J Sci Med Sport.* (2018) 21:811–6. doi: 10.1016/j.jsams.2017.12.005

48. Tarp J, Jespersen E, Møller NC, Klakk H, Wessner B, Wedderkopp N, et al. Long-term follow-up on biological risk factors, adiposity, and cardiorespiratory fitness development in a physical education intervention: a natural experiment (CHAMPS-study DK). *BMC Public Health.* (2018) 18:605. doi: 10.1186/s12889-018-5524-4

49. D'Agostino EM, Patel HH, Ahmed Z, Hansen E, Mathew MS, Nardi MI, et al. Natural experiment examining the longitudinal association between change in residential segregation and youth cardiovascular health across race/ethnicity and gender in the USA. *J Epidemiol Community Health.* (2018) 72:595–604. doi: 10.1136/jech-2018-210592

50. Nicosia N, Datar A. Neighborhood environments and physical activity: a longitudinal study of adolescents in a natural experiment. *Am J Prev Med.* (2018) 54:671–8. doi: 10.1016/j.amepre.2018.01.030

51. Sun G, Zhao J, Webster C, Lin H. New metro system and active travel: a natural experiment. *Environ Int.* (2020) 138:105605. doi: 10.1016/j.envint.2020.105605

52. Mölenberg FJM, Noordzij JM, Burdorf A, van Lenthe FJ. New physical activity spaces in deprived neighborhoods: does it change outdoor play and sedentary behavior? A natural experiment. *Health Place.* (2019) 58:102151. doi: 10.1016/j.healthplace.2019.102151

53. Kapinos KA, Yakusheva O, Eisenberg D. Obesogenic environmental influences on young adults: evidence from college dormitory assignments. *Econ Hum Biol.* (2014) 12:98–109. doi: 10.1016/j.ehb.2013.05.003

54. Sharma SV, Chuang R-J, Byrd-Williams C, Danho M, Upadhyaya M, Berens P, et al. Pilot evaluation of HEAL EAa natural experiment to promote obesity prevention behaviors among low-income pregnant women. *Prev Med Reports.* (2018) 10:254–62. doi: 10.1016/j.pmedr.2018.04.005

55. Madsen KA. School-based body mass index screening and parent notification: a statewide natural experiment. *Arch Pediatr Adolesc Med.* (2011) 165:987–92. doi: 10.1001/archpediatrics.2011.127

56. Klakk H, Andersen LB, Heidemann M, Møller NC, Wedderkopp N. Six physical education lessons a week can reduce cardiovascular risk in school children aged 6–13 years: a longitudinal study. *Scand J Public Health.* (2014) 42:128–36. doi: 10.1177/1403494813505726

57. Aittasalo M, Tiilikainen J, Tokola K, Suni J, Sievänen H, Vähä-Ypyä H, et al. Socio-ecological natural experiment with randomized controlled trial to promote active commuting to work: process evaluation, behavioral impacts, and changes in the use and quality of walking and cycling paths. *Int J Environ Res Public Health.* (2019) 16:661. doi: 10.3390/ijerph16091661

58. Stone MR, Faulkner GEJ, Zeglen-Hunt L, Bonne JC. The daily physical activity (DPA) policy in Ontario: is it working? An examination using accelerometry-measured physical activity data. *Can J Public Heal.* (2012) 103:170–4. doi: 10.1007/BF03403807

59. Azevedo LB, Burges Watson D, Haighton C, Adams J. The effect of dance mat exergaming systems on physical activity and health - Related outcomes in secondary schools: Results from a natural experiment. *BMC Public Health.* (2014) 14:951. doi: 10.1186/1471-2458-14-951

60. Heinen E, Kamruzzaman M, Turrell G. The public bicycle-sharing scheme in Brisbane, Australia: evaluating the influence of its introduction on changes in time spent cycling amongst a middle- and older-age population. *J Transp Heal.* (2018) 10:56–73. doi: 10.1016/j.jth.2018.07.003

61. Sarmiento OL, Rios AP, Paez DC, Quijano K, Fermino RC. The recreovía of bogotá, a community-based physical activity program to promote physical activity among women: baseline results of the natural experiment al ritmo de las comunidades. *Int J Environ Res Public Health.* (2017) 14:633. doi: 10.3390/ijerph14060633

62. McGavock J, Brunton N, Klaprat N, Swanson A, Pancoe D, Manley E, et al. Walking on water-A natural experiment of a population health intervention to promote physical activity after thewinter holidays. *Int J Environ Res Public Health.* (2019) 16:627. doi: 10.3390/ijerph16193627

63. Macmillan F, George ES, Feng X, Merom D, Bennie A, Cook A, et al. Do natural experiments of changes in neighborhood built environment impact physical activity and diet? A systematic review. *Int J Environ Res Public Health.* (2018) 15:217. doi: 10.3390/ijerph15020217

64. Crane M, Bohn-Goldbaum E, Grunseit A, Bauman A. Using natural experiments to improve public health evidence: a review of context and utility for obesity prevention. *Health Res Policy Syst.* (2020) 18:48. doi: 10.1186/s12961-020-00564-2

65. Kahn EB, Ramsey LT, Brownson RC, Heath GW, Howze EH, Powell KE, et al. The effectiveness of interventions to increase physical activity. A systematic review. *Am J Prev Med.* (2002) 22:73–107. doi: 10.1016/S0749-3797(02)00434-8

66. Grabovac I, Hochfellner L, Rieger M, Jewell J, Snell A, Weber A, et al. Impact of Austria's 2009 trans fatty acids regulation on all-cause, cardiovascular and coronary heart disease mortality. *Eur J Public Health.* (2018) 28(Suppl. 2):4–9. doi: 10.1093/eurpub/cky147

67. Gambaryan M, Reeves A, Deev A, Popovich M, Drapkina O, Snell A, et al. Effects of tobacco control policy on cardiovascular morbidity and mortality in Russia. *Eur J Public Health.* (2018) 28(Suppl. 2):14–6. doi: 10.1093/eurpub/cky148

68. Ciobanu M, Iosif I, Calomfirescu C, Brinduse L, Stuckler D, Reeves A, et al. Variation across Romania in the health impact of increasing tobacco taxation. *Eur J Public Health.* (2018) 28(Suppl. 2):10–3. doi: 10.1093/eurpub/cky180

69. Smith M, Hosking J, Woodward A, Witten K, MacMillan A, Field A, et al. Systematic literature review of built environment effects on physical activity and active transport - an update and new findings on health equity. *Int J Behav Nutr Phys Act.* (2017) 14:1–27. doi: 10.1186/s12966-017-0613-9

70. Gomez LF, Sarmiento R, Ordoñez MF, Pardo CF, de Sá TH, Mallarino CH, et al. Urban environment interventions linked to the promotion of physical activity: a mixed methods study applied to the urban context of Latin America. *Soc Sci Med.* (2015) 131:18–30. doi: 10.1016/j.socscimed.2015.02.042

71. Stewart G, Anokye NK, Pokhrel S. What interventions increase commuter cycling? A systematic review. *BMJ Open.* (2015) 5:945. doi: 10.1136/bmjopen-2015-007945

72. Cleland C, Reis RS, Ferreira Hino AA, Hunter R, Fermino RC, Koller de Paiva H, et al. Built environment correlates of physical activity and sedentary behaviour in older adults: A comparative review between high and low-middle income countries. *Health Place.* (2019) 57:277–304. doi: 10.1016/j.healthplace.2019.05.007

73. Watson A, Timperio A, Brown H, Best K, Hesketh KD. Effect of classroom-based physical activity interventions on academic and physical activity outcomes: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act.* (2017) 14:114. doi: 10.1186/s12966-017-0569-9

74. Thondoo M, Goel R, Tatah L, Naraynen N, Woodcock J, Nieuwenhuijsen M. The built environment and health in low- and middle-income countries: a review on quantitative health impact assessments. *Curr Environ Heal Reports.* (2021) 91:90–103. doi: 10.1007/s40572-021-00324-6

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Psychological well-being, mental distress, metabolic syndrome, and associated factors among people living in a refugee camp in Greece: a cross-sectional study

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Background: Forcibly displaced people face various challenges and are therefore at higher risk of being affected by mental and physiological distress. The present study aimed to determine levels of psychological well-being, PTSD symptom severity, metabolic syndrome, and associated factors among forcibly displaced people in Greece in response to WHO's call for evidence-based public health policies and programs for forcibly displaced people.

Methods: We conducted a cross-sectional study among n=150 (50% women) forcibly displaced people originating from Sub-Sahara Africa and Southwest Asia living in a Greek refugee camp. Self-report questionnaires were used to assess psychological well-being, symptoms of PTSD, depression, generalized anxiety disorder and insomnia, perceived stress, headache, and perceived fitness. Cardiovascular risk markers were assessed to determine metabolic syndrome, and cardiorespiratory fitness was measured with the Åstrand-Rhyming Test of Maximal Oxygen Uptake.

Results: The prevalence of mental distress and physiological disorders was overall elevated. Only 53.0% of participants rated their psychological well-being as high. Altogether, 35.3% scored above the clinical cut-off for PTSD, 33.3% for depression, 27.9% for generalized anxiety disorder, and 33.8% for insomnia. One in four (28.8%) participants met criteria for metabolic syndrome. While the prevalence of moderate or severe insomnia symptoms and metabolic syndrome differed little from the global population, the risk of being affected by mental distress was markedly increased. In multivariable analysis, higher perceived fitness was associated with higher psychological well-being (OR=1.35, p=0.003) and a decreased likelihood for metabolic syndrome (OR=0.80, p=0.031). Participants with elevated psychiatric symptoms were less likely to report high psychological well-being (OR=0.22, p=0.003) and had increased odds for higher PTSD severity

(OR=3.27, p=0.034). Increased stress perception was associated with higher PTSD symptoms (OR=1.13, p=0.002).

Conclusion: There is an elevated risk for mental distress compared to the global population and an overall high mental and physiological burden among people living in a Greek refugee camp. The findings underpin the call for urgent action. Policies should aim to reduce post-migration stressors and address mental health and non-communicable diseases by various programs. Sport and exercise interventions may be a favorable add-on, given that perceived fitness is associated with both mental and physiological health benefits.

KEYWORDS

prevalence, physical health, non-communicable disease, PTSD, stress, migrant, fitness

Introduction

Human-made conflicts and natural disasters have led to a doubling of forced displacement in the past 10 years, reaching an all-time high of 94.7 million affected people in 2021 (1). These figures will likely continue to grow due to armed conflicts, political oppression and environmental changes (2). Even though most people are internally displaced or find refuge in neighboring countries, forced migration to Europe has more than tripled in the past decade (3). Greece has been one of the main entry points for over 1.2 million forcibly displaced people since 2015, as one of the southernmost countries in Europe and due to its close sea border with Asia (1).

Forcibly displaced people are generally challenged with severe mental and physical strains before, during, and after their flight (4). While infectious diseases and injuries are often treated shortly after arrival, new complaints, such as non-communicable diseases, can arise (2). In addition, ongoing post-migration stressors such as uncertainty about migration status, legal barriers, harsh treatment by authorities, socioeconomic hardship, language barriers, discrimination, social exclusion, limited access to health services, and lack of access to healthy food hinder the recovery from pre-migration trauma and increase the risk of being affected by posttraumatic stress disorder (PTSD) (2, 5). While it has been reported that forcibly displaced people show high levels of resilience (6), the likelihood of being affected with mental and non-communicable diseases is markedly increased compared to the host population (7, 8). A recent meta-analysis (9) documented prevalence rates among forcibly displaced people of 31% for PTSD, 25% for depression, and 14% for generalized anxiety disorders. In addition, a series of physical health complaints have been recorded among forcibly displaced people that can be clustered in the metabolic syndrome and are associated with an increased risk for cardiovascular diseases and diabetes (7, 10). Overall, this double burden of mental and physical comorbidities negatively affects the psychological well-being of individuals and families and drastically reduces life expectancy compared to unaffected counterparts (11). Organized sport and exercise activities have shown promising effects in addressing mental and physical complaints (12). At the same time, these complaints are often accompanied by low fitness levels, whereas low fitness levels may contribute to these physical complaints and, at the same time, also be a cause of mental distress and physiological disorders (13).

Prevalence of mental disorders vary widely across studies with forcibly displaced people, ranging from 2 to 88% for PTSD, 5 to 81% for depression, and 1 to 90% for generalized anxiety disorder (14). While heterogeneity in prevalence can be caused to some extent by methodological differences, the discrepancy could also be attributable to sociodemographic and post-migration differences (15). Therefore, it is important to obtain population and context specific data. A recent call has been made by the World Health Organization (8) for more detailed data to accurately monitor and address the health status of forcibly displaced people. This monitoring should also encompass the conjunction of mental and physical determinants (16). Understanding the specific health needs of forcibly displaced people and their circumstances can provide valuable indicators for targeted programs. Timely addressing individual mental and physical challenges could prevent short- and long-term adverse consequences for forcibly displaced people and the host countries. Since the marked increase of forced migration to Europe in 2015, however, only three studies (17–19) have examined the mental health of forcibly resettled adults in Greece. As these studies focused predominantly on one mental condition, a more comprehensive approach that incorporates mental and physical health parameters is needed.

The present study aims to determine levels of mental distress, physiological disorders, and associated factors among people living in a refugee camp in Greece. Specifically, the study explored the prevalence of mental distress and physiological disorders compared to the global population and examined the association of specific socio-demographic characteristics and clinical parameters with

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Abbreviations: 95% CI, 95% Confidence interval; BMI, Body mass index; BP: Blood pressure; DSM-5, Diagnostic and Statistical Manual of Mental Disorders (5th edition); GAD-7, Generalized Anxiety Disorder scale (7-item version); Hb, Hemoglobin; HbA1c, Glycated hemoglobin; HDL-C, High-density lipoprotein cholesterol; ICD-10, International Classification of Diseases (10th version); IES-R, Impact of Event Scale-Revised; ISI: Insomnia Severity Index; ISRCTN, trial registry Primary clinical trial registry recognized by the WHO and ICMJE; M: Mean, OR: Odds ratio; PHQ-9, Patient Health Questionnaire (9-item version); PSS-10, Perceived Stress Scale (10-item version); PTSD, Post-traumatic stress disorder; SD, Standard deviation; SPSS, Statistical Package for the Social Sciences; VAS, Visual analog scale; VO2max (ml/kg/min), Maximal oxygen uptake; WHO, World Health Organization; WHO-5, 5-item World Health Organization Well-Being Index.

psychological well-being, PTSD symptom severity, and metabolic syndrome to identify risk groups and obtain indications for possible interventions.

Methods

Design and setting

This analysis is part of a larger randomized controlled trial that examines the effects of a sport and exercise intervention on mental health, cardiovascular risk markers, and physical fitness among people living in a refugee camp in Greece (ISRCTN16291983). The sample and the procedures of the present study were based on the sampling and the procedures described in the registration of the project (20). In this paper, we present cross-sectional data from the baseline data assessment. Ethical approval was obtained by the Research Ethics Committee of the University of Thessaly, ref. approval no. 39 and the ethical review board of Northwest and Central Switzerland, ref. approval no. AO_2020–00036.

The study was implemented in a refugee camp in central Greece. The camp was founded in 2016 and can host around 1700 people. At present, the camp operates under the management of an officer appointed by the Ministry of Migration and Asylum and serves as a temporary accommodation center where people wait for their asylum applications to be processed. People live in the camp in containers, which we will refer to as households in this study. While a family has a container for itself, individuals share the container with up to four people of the same sex and origin. The containers are equipped with a bathroom, cooking facilities and air conditioning. At the time of data collection an adult received 150 Euros per month for expenses such as food, clothing, telephone bills, hygiene items, and public transportation. In case of health complaints, a medical center with two medical doctors, nurses and two psychologists from the Greek national health service provided primary health services. The camp is located in a rural area. The nearest village with a small grocery store is 15 min walking distance. A town with an ATM, post office, clothing store, or the possibility to print documents is 16 kilometers away and can be reached by public transportation. While adults are not allowed to engage in paid work due to legal barriers, school-age children can attend public schools.

Based on the data provided by the site management, 1,376 residents lived in this camp in February 2021. Among them, 920 (67%) residents were aged 16 to 59 years, and 39% were women. The forcibly displaced population is diverse in terms of sociodemographic background. Most residents were from Afghanistan (45%) and Syria (25%), whereas the remaining 30% were from West Asian (11%), Sub-Saharan zone (17%), or other (2%) regions.

Participants

Eligible to participate in the study were individuals who (a) lived in the selected refugee camp, (b) were between 16 and 59 years old, (c) were able to read in English, Arabic, Farsi, or French, and (d) provided written informed consent. For ethical reasons, a broad age range was defined as an inclusion criterion, in order to enable as many as possible to participate in the sport and exercise activities of the intervention trial. The site management provided a list of camp residents sorted by language. Based on this list, potentially eligible households were screened for sociodemographic background. Recruitment was done by households to avoid exclusion of individuals from the same household. A random sample stratified by sex was finally drawn from all screened and eligible households. Additional households were drawn in case of non-appearance in order for the parent project to have a sufficient number of participants. A minimum sample size of 136 participants was estimated based on a power analysis to detect an intervention effect on PTSD symptoms (20).

Procedure

The screening, recruitment, and assessment processes were carried out in May 2021. At the beginning of the study, as many households as possible were screened to obtain an overview of the sociodemographic background of the camp population. Residents who were about to participate in the study were asked to provide written informed consent before data collection. Information about the purpose and procedure of the study was provided in writing and verbally. All participants were assured that participation is voluntary and that they could withdraw without any negative consequences, particularly concerning their asylum application. This approach protects participants from potential harm, coercion, and exploitation. However, cultural and language differences may lead to misunderstandings, with false expectations compromising voluntary participation (21). To mitigate such misunderstandings, the study recruited 10 research assistants from the camp residents based on the recommendation of the site management. These research assistants played a critical role in approaching residents, explaining the study, obtaining informed consent, translating, and assisting with data collection.

All measures were taken at the nearby Department of Physical Education and Sport Science of the University of Thessaly due to the availability of necessary facilities and equipment. Participants were informed about their results after the assessment and were referred to a specialist if a health risk was indicated. Participants received further compensation for their participation in the form of a meal and sport equipment. The highlighted measures ensured that the research provided reciprocal benefits for those participating in the study.

Measures

Trained research staff were responsible for the data collection of the outcomes (psychological well-being, PTSD symptom severity, and metabolic syndrome) and predictor variables (sociodemographic background, symptoms of depression, generalized anxiety disorder and insomnia, perceived stress, headache, anemia, cardiorespiratory fitness, and perceived fitness) by following a standard operating procedure. All questionnaires were provided in English, Arabic, Farsi, and French matching the native language background of most participants. Additionally, translators were present during the data assessment when needed. The measures have been previously used with forcibly displaced people (15, 22–28), have been validated in English, Arabic, Farsi, and French (29–50), and had acceptable or good internal consistency (Cronbach's alpha >0.7) in our pilot study

(51). We used clinically relevant cut-offs to determine prevalence rates of mental distress. A growing body of literature emphasizes that self-report symptom-based measures are likely to inflate the prevalence of mental distress in populations of forcibly displaced people (52–54). Therefore, more conservative cut-off values were chosen (36, 40, 43, 55). As the instruments for perceived stress, headache, and perceived fitness are not used for diagnostic purposes, the classification into high and low profiles was done *via* median split. Information on the sociodemographic background of the participants, including sex, age, origin, educational background, number of relatives in the camp, time fleeing (in months), and time in camp (in months) was collected with a questionnaire.

Mental health

Psychological well-being was assessed with the five-item World Health Organization Well-Being Index (WHO-5), which is specifically designed to measure mental well-being (29). Each of the 5 items is scored on a Likert scale from 0 (at no time) to 5 (all the time). Items were summed up and then multiplied by 4, resulting in an overall index between 0 and 100. Psychological well-being was finally dichotomized in high (>50) and low (≤50) well-being (56).

PTSD symptoms were assessed with the 22-item Impact of Event Scale-Revised (IES-R) (50). The instrument is internationally accepted and not culturally specific. The IES-R items refer to DSM-5 (57) and ICD-10 (58) criteria of PTSD. Items were answered on a five-point Likert scale from 0 (not at all) to 4 (extremely), resulting in an overall index between 0 and 88 points. The cut-off for a possible PTSD diagnosis is set at ≥46 (55).

Depressive symptoms were assessed with the 9-item Patient Health Questionnaire (PHQ-9) (36). Items of this instrument refer to DSM-5 criteria for major depression. Answers were given on a four-point Likert scale ranging from 0 (not at all) to 3 (nearly every day). The overall index varies between 0 and 27. A score of ≥15 indicates moderately severe or severe depressive symptoms (36).

Anxiety symptoms were assessed with the 7-item Generalized Anxiety Disorder scale (GAD-7) (40). The instrument refers to DSM-5 criteria for generalized anxiety disorder. Participants were asked to rate the frequency of anxiety symptoms on a four-point Likert scale from 0 (not at all) to 3 (nearly every day). The overall index ranges from 0 to 21, with a score of ≥15 being interpreted as more severe anxiety levels (40).

Insomnia symptoms were assessed with the Insomnia Severity Index (ISI) (43), a brief screening measure of insomnia and an outcome measure in treatment research, which takes into consideration the criteria for insomnia of the DSM-5. The instrument contains 7 items, which were answered on a five-point Likert scale from 0 (no problem) to 4 (very severe problem). The overall index is scored between 0 and 28. Values of ≥15 indicate possible moderate insomnia (43).

Perceived stress was assessed with the 10-item Perceived Stress Scale (PSS-10) (46). Participants were asked how often they find their lives overwhelming, uncontrollable, and unpredictable on a five-point Likert Scale from 0 (never) to 4 (very often). The score of the positively stated items (4, 5, 7, and 8) is reversed before summing up all items. The overall index ranges from 0 to 40, with higher scores indicating a higher level of perceived stress.

Physical health

Cardiovascular risk markers were assessed to determine metabolic syndrome. A flexible tape was used to determine waist circumference. Systolic and diastolic blood pressure was measured after the participant had rested for 5 min while seated. Blood pressure was measured three times within 5 min with an Omron® digital blood pressure monitor. Evidence for the validity of this device has been reported previously (59). The participants' finger was pricked once for all (capillary) blood analyzes to collect approximately 10 blood drops. One drop was used for the detection of anemia. Thus, hemoglobin (Hb) levels were measured with a HemoCue® Hb 301 system (HemoCue AB; Ängelholm, Sweden). The incidence of anemia was defined as <120 g/L for women and < 130 g/L for men (60). For the assessment of blood lipids (high-density-lipoprotein cholesterol, fasting plasma triglycerides) and average level of blood glucose over the past 3 months (glycosylated HbA1c), blood samples were analyzed with an Afinion 2 analyzer (Abbott, Wädenswil, Switzerland). One drop of blood was taken by the test strip and read by the analyzer. A good correlation exists between the Abbott 2 point-of-care analyzer results and reference laboratory tests for lipid levels and HbA1c (61, 62).

Cardiovascular risk factors and metabolic syndrome were defined according to the International Diabetes Federation (63). Markers and thresholds include abdominal obesity (waist circumference ≥ 80 cm for women or ≥ 94 cm for men), elevated fasting plasma triglycerides (>150 mg/dL), low HDL-C (<50 mg/dL for women or < 40 mg/dL for men), elevated fasting plasma glucose (>100 mg/dL) and hypertension (>130 mmHg systolic BP or > 85 mmHg diastolic BP). Elevated fasting plasma glucose was replaced with elevated HbA1c (>5.7%) (64). Metabolic syndrome is diagnosed if three or more criteria are fulfilled. The continuous metabolic syndrome score was calculated according to Eisenmann's method (65). First, we standardized the individual cardiovascular risk markers for sex, age, and origin. Since HDL-C is associated with a reduction in metabolic risk, it was multiplied by −1. Finally, we calculated the sum of the standardized residuals to determine the metabolic syndrome score. A higher score indicates a worse metabolic syndrome profile.

Headache over the last week was measured with the Visual Analog Scale for Pain (VAS) (66). The VAS consists of a 100 mm horizontal line with two extremes 0 mm (no pain) and 100 mm (severe pain). Evidence of the validity of the VAS has been reported previously (67).

Cardiorespiratory fitness

Cardiorespiratory fitness was measured with the (submaximal) Åstrand-Rhyming Indirect Test of Maximal Oxygen Uptake (68), performed on a bicycle ergometer. Maximal oxygen uptake (VO_2max) was calculated based on sex, a correction factor for age, body weight, mean steady state, and power output (69). The validity of the Åstrand-Rhyming test for deriving VO_2max has been documented previously (70). Sex and age-adjusted cut-offs distinguish between poor and fair or better cardiorespiratory fitness (71).

Perceived fitness was assessed with a 1-item fitness measure from 1 (poor fitness) to 10 (excellent fitness) (72). Previous studies showed that perceived fitness is moderately associated with objective fitness measures (73) and more closely with mental and physical health benefits (72).

Statistical analyzes

Data was double-entered, checked, and merged into a single data file. Outliers were then detected using the Inter Quartile Range. After checking for outliers, one implausible value of 91.9 for cardiorespiratory fitness was removed. The individual mean score was used to impute missing values for calculating the total test score in the self-reported measures. Overall, few data were missing for mental (3%) and physical health (4%). Several missing values were detected for cardiorespiratory fitness (21%), mainly due to knee complaints or injuries. Frequencies (n, %) describe the study sample and prevalence, while mean score (M), standard deviation (SD) and confidence interval (95% CI) outline the severity of the outcome variables across predictors. We performed independent t-tests and chi-square tests to examine whether the final sample differs in the sociodemographic background from the broader screened eligible households. Additionally, chi-square tests were used to examine relationships between primary outcomes and predictors. To determine the association between the outcome and predictor variables, we conducted binary and multiple logistic regressions using the individual odds ratio (95% CI). The level of significance was set at $p < 0.05$ across all analyzes. Variables were included in multiple logistic regression analyzes when they were associated with the outcome variable at $p < 0.10$ in binary analysis. To reduce the number of variables in the regression models, we summarized the variables for severe depressive, severe anxiety and moderate insomnia symptoms in a factor termed "psychiatric symptoms." Psychiatric symptoms were defined as scoring above the cut-off for a possible diagnosis of one or more mental disorders (depression, generalized anxiety disorder or insomnia). Sex, age, and origin were included in the multiple logistic regression models independently of their binary association with the outcome variable to control for sociodemographic background. Multicollinearity was checked after running the whole model. Statistical analyzes were performed with SPSS (Version 24, IBM, Armonk, United States) for both descriptive and inferential analysis.

Results

Sample

Information on participant flow is provided in Figure 1. The final sample consisted of 150 forcibly displaced individuals (75 female). The overall response rate was 79% ($n = 190$ invited individuals). Reasons for declining participation included illness, injury, refusal to take the legally required COVID-19 test, or reservations to leave the camp not to miss out on expected feedback from authorities. Characteristics of the study participants are presented in Table 1. The mean age of the total sample was 29.1 years (SD = 9.3). Most study participants were between 16 and 35 years old ($n = 113$, 79.0%), originated from Afghanistan ($n = 79$, 52.7%), and lived with one or more family members in the camp ($n = 98$, 66.2%). Overall, the mean stay in the camp was 14.8 months (SD = 10.2). Noticeable sex differences were the higher number of women without educational qualifications and the low number of university degrees ($n = 2$, 2.8%) compared to men ($n = 18$, 25.4%). Furthermore, no man in our sample had to care for a child alone, in contrast to the women ($n = 11$, 14.9%). After testing for group differences in sociodemographic background (age, origin, education, relatives in camp, time since flight and time in camp), the only difference found was that mean time since flight differed $t(382.4) = 2.156$, $p = 0.032$ between screened participants ($M = 43.4$, SD = 55.2) and the final sample ($M = 33.4$, SD = 36.5).

Psychological well-being

Summary statistics on psychological well-being across predictor variables are shown in Tables 2, 3. More than half of the participants scored above the cut-off for high psychological well-being. The mean score for psychological well-being was 53.9 (SD = 28.8) across the sample ($n = 149$, 1 missing). Descriptively, participants who were male, between 26 and 35 years old, or from Sub-Sahara Africa had higher mean scores in psychological well-being. However, differences were not statistically significant. In binary logistic regression analyzes, symptoms of depression, generalized anxiety disorder and insomnia, perceived stress, anemia, headache, and perceived fitness were

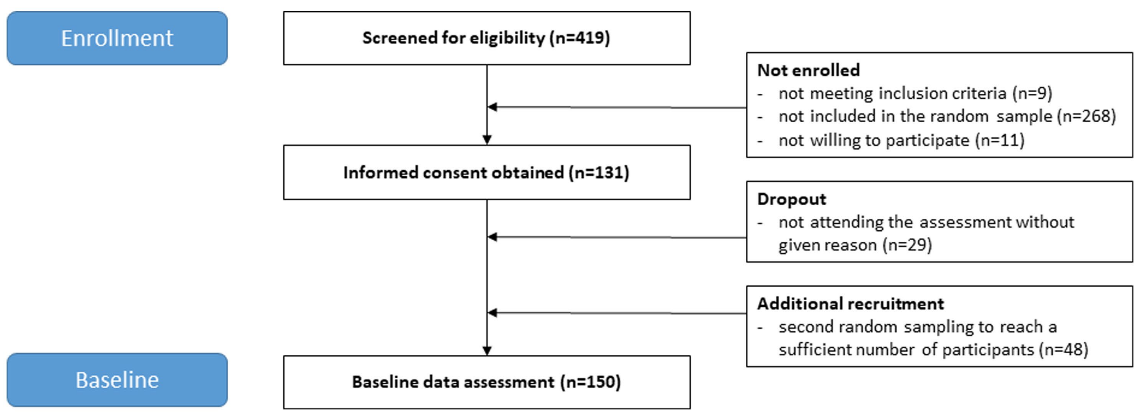

FIGURE 1
CONSORT flow diagram.

TABLE 1 Sociodemographic background of the study participants (n=150).

Sociodemographics	Total n (%)	Female n (%)	Male n (%)
Age			
16–25	58 (40.6)	29 (39.7)	29 (41.4)
26–35	55 (38.5)	26 (35.6)	29 (41.4)
>35	30 (21.0)	18 (24.7)	12 (17.1)
Origin			
Sub-Sahara Africa	48 (32.0)	25 (33.3)	23 (30.7)
Southwest Asia	102 (68.0)	50 (66.7)	52 (69.3)
Education			
None	36 (25.5)	24 (33.8)	12 (17.1)
Primary	52 (36.9)	29 (40.8)	23 (32.9)
High school and above	53 (37.6)	18 (25.4)	35 (50.0)
Relatives in camp			
Alone	50 (33.8)	18 (24.3)	32 (43.2)
Relatives ≥1	98 (66.2)	56 (75.7)	42 (56.8)
Time since flight (months)			
0–24	62 (48.1)	32 (50.8)	30 (45.5)
>24	67 (51.9)	31 (49.2)	36 (54.5)
Time in camp (months)			
0–12	71 (51.4)	37 (53.6)	34 (49.3)
>12	67 (48.6)	32 (46.4)	35 (50.7)

TABLE 2 Prevalence of mental distress and physical disorders in comparison with global mean.

	Total % (n)	Female % (n)	Male % (n)	Global mean %[b]
Mental health				
High psychological well-being (WHO-5)[a]	53.0 (79)	47.3 (35)	58.7 (44)	No reference
High PTSD symptoms (IES-R)[a]	35.3 (53)	44.0 (33)	26.7 (20)	3.9
Severe depressive symptoms (PHQ-9)[a]	33.3 (50)	41.3 (31)	25.3 (19)	12.0
Severe anxiety symptoms (GAD-7)[a]	27.9 (39)	38.5 (25)	18.7 (14)	16.0
Moderate insomnia symptoms (ISI)[a]	33.8 (47)	37.5 (24)	30.7 (23)	33.3
High perceived stress (PSS-10)[a]	52.2 (72)	65.6 (42)	40.5 (30)	No reference
Physical health				
Metabolic syndrome[a]	28.8 (40)	30.0 (21)	27.5 (19)	25.0
Abdominal obesity[a]	48.0 (71)	71.2 (52)	25.3 (19)	41.5
Dyslipidemia[a]	22.7 (30)	19.1 (13)	26.6 (17)	No reference
Hypertension[a]	38.9 (58)	21.6 (16)	56.0 (42)	31.1
Prediabetes[a]	13.1 (19)	13.7 (10)	12.5 (9)	15.3
Anemia[a]	27.3 (39)	31.9 (23)	22.5 (16)	23.7
High headache (VAS)[a]	47.8 (66)	56.3 (36)	40.5 (30)	No reference
Fitness				
Fair and higher VO_2max[a]	24.6 (29)	18.9 (10)	29.2 (19)	No reference
High perceived fitness[a]	55.9 (76)	42.2 (27)	68.1 (49)	No reference

[a]Cut-off: WHO-5 (≥50), IES-R (≥46), PHQ-9 (≥15), GAD-7 (≥15), ISI (≥15), PSS-15 (≥median), metabolic syndrome (≥3 out of 5), abdominal obesity (waist circumference ≥ 80 cm for women or ≥ 94 cm for men), dyslipidemia (fasting plasma triglycerides > 150 mg/d and HDL-C < 50 mg/dL for women or < 40 mg/dL for men), hypertension (>130 mmHg systolic BP or > 85 mmHg diastolic BP), prediabetes (HbA1c = 5.7–6.4%), anemia (women < 120 g/L or men < 130 g/L), VAS (≥median), VO_2max [based on ACSM guidelines (71)], perceived fitness (≥median).
[b]According to the literature (74–81).

associated with psychological well-being. There were no associations between psychological well-being, sociodemographic factors, and cardiorespiratory fitness. The results from the multiple logistic regression analysis of psychological well-being regressed on associated factors are shown in Table 4. Sex, age, origin, and all factors that were significantly associated with the outcome in the binary analyzes were included in the final model. In the final model, only psychiatric symptoms and perceived fitness remained significantly associated with psychological well-being. There is strong evidence that psychiatric symptoms were negatively (OR = 0.22, 95% CI 0.08–0.59, p = 0.003) and perceived fitness positively associated (OR = 1.35, 95% CI 1.11–1.63, p = 0.003) with high psychological well-being.

Mental distress

The prevalence of mental distress and high PTSD symptoms across sociodemographic and clinical variables are shown in Tables 2, 5. One out of three participants scored above the clinical cut-off for PTSD, depression, generalized anxiety disorder, and insomnia. Fifty-five (39.8%) participants had considerably elevated symptoms in at least one or more psychiatric disorders. The mean severity score for PTSD was 34.6 (SD = 22.4) in the whole sample (n = 150). Higher PTSD scores were found in female participants aged older than 35 years, originating from Southwest Asia, or living with one or more relatives in the camp. Notably, sex, origin, and living with one or more relatives in the camp were significantly associated with PTSD symptoms in binary logistic regression analyzes besides symptoms of depression, generalized anxiety disorder and insomnia, perceived stress, headache, and perceived fitness. On the contrary, education, time spent in the camp, anemia, and cardiorespiratory fitness were not associated with PTSD symptom severity. The final model of the multiple logistic regression analysis, including age and all associated factors from binary analyzes, is presented in Table 4. In the final model, psychiatric symptoms (OR = 3.27, 95% CI 1.10–9.74, p = 0.034) and perceived stress (OR = 1.13, 95% CI 1.05–1.23, p = 0.002) were associated with the occurrence of high PTSD severity.

Physical health

The summary statistics on the prevalence of cardiovascular risk factors, anemia, high level of headache, and metabolic syndrome

TABLE 3 Descriptive statistics of psychological well-being (WHO-5) dichotomized into high vs. low well-being.

	Index Score	High (≥50)	Low (<50)	χ^2
	M (95% CI)	*n* (%)	*n* (%)	
Sociodemographics				
Sex				0.164
Female	50.7 (43.9–57.5)	35 (47.3)	39 (52.7)	
Male	57.0 (50.5–63.5)	44 (58.7)	31 (41.3)	
Age				0.174
16–25	51.3 (43.9–58.7)	30 (51.7)	28 (48.3)	
26–35	59.2 (51.3–67.1)	33 (61.1)	21 (38.9)	
>35	47.2 (36.6–57.7)	12 (40.0)	18 (60.0)	
Origin				0.073
Sub-Sahara Africa	57.6 (48.8–66.5)	30 (63.8)	17 (36.2)	
Southwest Asia	52.1 (46.6–57.7)	49 (48.0)	53 (52.0)	
Education				0.828
None	54.6 (44.4–64.7)	18 (50.0)	18 (50.0)	
Primary	51.0 (43.0–58.9)	25 (49.0)	26 (51.0)	
High school and above	53.3 (45.7–60.8)	29 (54.7)	24 (45.3)	
Relatives in camp				0.149
Alone	55.7 (46.9–64.5)	31 (62.0)	19 (38.0)	
Relatives ≥1	53.7 (48.1–59.2)	48 (49.5)	49 (50.5)	
Time since flight (months)				0.358
0–24	55.1 (47.7–62.5)	35 (57.4)	26 (42.6)	
>24	51.9 (45.1–58.8)	33 (49.3)	34 (50.7)	
Time in camp (months)				0.673
0–12	52.2 (45.8–58.7)	37 (52.9)	33 (47.1)	
>12	52.6 (45.2–59.9)	33 (49.3)	34 (50.7)	
Mental health				
Severe depressive symptoms (PHQ-9)[a]				<0.001
Yes	35.7 (29.5–41.9)	11 (22.4)	38 (77.6)	
No	62.8 (57.2–68.3)	68 (68.0)	32 (32.0)	
Severe anxiety symptoms (GAD-7)[a]				<0.001
Yes	33.9 (27.3–40.5)	8 (20.5)	31 (79.5)	
No	58.5 (52.9–64.1)	61 (61.0)	39 (39.0)	
Moderate insomnia symptoms (ISI)[a]				<0.001
Yes	38.9 (31.8–46.1)	12 (26.1)	34 (73.9)	
No	57.4 (51.6–63.3)	56 (60.9)	36 (39.1)	
High perceived stress (PSS-10)[a]				<0.001
Yes	43.4 (37.4–49.4)	26 (36.6)	45 (63.4)	
No	59.5 (52.3–66.6)	41 (62.1)	25 (37.9)	
Physical health				
Anemia[a]				0.047
Yes	48.9 (39.0–58.8)	16 (41.0)	23 (59.0)	
No	57.0 (51.6–62.5)	62 (59.6)	42 (40.4)	
High headache (VAS)[a]				0.072
Yes	45.7 (38.9–52.5)	27 (41.5)	38 (58.5)	
No	56.4 (49.8–63.1)	41 (56.9)	31 (43.1)	

(Continued)

TABLE 3 (Continued)

	Index Score	High (≥50)	Low (<50)	χ^2
	M (95% CI)	*n* (%)	*n* (%)	
Fitness				
VO_2max[a]				0.991
Fair and above	57.8 (46.2–69.4)	16 (55.2)	13 (44.8)	
Poor and below	52.0 (46.2–57.8)	49 (55.1)	40 (44.9)	
High perceived fitness[a]				<0.001
Yes	60.0 (53.6–66.4)	48 (63.2)	28 (36.8)	
No	39.1 (33.0–45.1)	18 (30.5)	41 (69.5)	

[a]Cut-off: PHQ-9 (≥15), GAD-7 (≥15), ISI (≥15), PSS-10 (≥median), VAS (≥median), anemia (women ≤ 120 g/L or men ≤ 130 g/L), VO_2max [based on ACSM guidelines (71)], perceived fitness (≥median).

TABLE 4 Logistic models of high psychological well-being (WHO-5), high PTSD symptoms (IES-R), and metabolic syndrome regressed on sex, age, origin, and associated factors.

	Model high psychological well-being (≥50)[a]			Model high PTSD symptoms (≥46)[b]			Model metabolic syndrome (≥3 out of 5)[c]		
	OR	95% CI	*p*-value	OR	95% CI	*P*-value	OR	95% CI	*P*-value
Sociodemographics									
Sex									
Female	Reference			Reference			Reference		
Male	0.88	(0.32–2.45)	0.802	0.77	(0.29–2.07)	0.608	3.27	(0.90–11.97)	0.073
Age	1.00	(0.95–1.05)	0.916	1.00	(0.95–1.05)	0.951	1.02	(0.96–1.09)	0.496
Origin									
Sub-Sahara Africa	Reference			Reference			Reference		
Southwest Asia	0.76	(0.28–2.12)	0.604	1.99	(0.48–8.29)	0.345	4.02	(1.02–15.77)	0.046
Relatives in camp									
Alone				Reference					
Relatives 1 ≤				0.70	(0.17–2.91)	0.623			
Mental health									
Psychiatric symptoms[d]									
No	Reference			Reference					
Yes	0.22	(0.08–0.59)	0.003	3.27	(1.10–9.74)	0.034			
Perceived stress (PSS-10)	1.00	(0.93–1.06)	0.923	1.13	(1.05–1.23)	0.002			
Physical health									
Hemoglobin	1.02	(0.99–1.06)	0.184						
Headache	1.00	(0.98–1.02)	0.977	1.01	(1.00–1.03)	0.136			
Fitness									
VO_2max							0.92	(0.86–0.99)	0.021
Perceived fitness	1.35	(1.11–1.63)	0.003	0.93	(0.76–1.13)	0.453	0.80	(0.65–0.98)	0.031
Nagelkerkes R^2	0.36			0.47			0.20		

[a]Includes the variables sex, age, origin, psychiatric symptoms, perceived stress, hemoglobin, headache and perceived fitness.
[b]Includes the variables sex, age, origin, relatives in camp, psychiatric symptoms, perceived stress, headache and perceived fitness.
[c]Includes the variables sex, age, origin, VO2max and perceived fitness.
[d]Psychiatric symptoms is defined as having elevated symptoms in one or more mental disorder: PHQ-9 (≥15), GAD-7 (≥15), or ISI (≥15).

across predictors are shown in Tables 2, 6. Every fourth participant ($n = 139$, 11 missing) met the inclusion criteria for metabolic syndrome, and three out of four women scored above the cut-off for abdominal obesity. Apart from age, cardiorespiratory and perceived fitness, no other factor was associated with metabolic syndrome in the binary analyzes. The results of the final multiple logistic regression

TABLE 5 Descriptive statistics of PTSD (IES-R) dichotomized into high vs. low PTSD symptom severity.

	Index Score	High (≥46)	Low (<46)	χ^2
	M (95% CI)	*n* (%)	*n* (%)	
Sociodemographics				
Sex				0.026
Female	39.0 (33.8–44.1)	33 (44.0)	42 (56.0)	
Male	30.3 (25.3–35.4)	20 (26.7)	55 (73.3)	
Age				0.379
16–25	31.6 (25.6–37.6)	17 (29.3)	41 (70.7)	
26–35	36.2 (30.8–41.6)	23 (41.8)	32 (58.2)	
>35	39.1 (29.8–48.3)	11 (36.7)	19 (63.3)	
Origin				0.011
Sub-Sahara Africa	29.3 (23.0–35.4)	10 (20.8)	38 (79.2)	
Southwest Asia	37.2 (32.8–41.6)	43 (42.2)	59 (57.8)	
Education				0.107
None	36.8 (29.6–43.9)	14 (38.9)	22 (61.1)	
Primary	39.1 (32.5–45.6)	24 (46.2)	28 (53.8)	
High school and above	31.6 (25.7–37.5)	14 (26.4)	39 (73.6)	
Relatives in camp				0.012
Alone	28.7 (22.9–34.4)	11 (22.0)	39 (78.0)	
Relatives ≥1	37.9 (33.3–42.5)	42 (42.9)	56 (57.1)	
Time since flight (months)				0.743
0–24	34.8 (29.3–40.4)	23 (37.1)	39 (62.9)	
>24	34.7 (29.3–40.2)	23 (34.3)	44 (65.7)	
Time in camp (months)				0.933
0–12	36.0 (30.9–41.2)	26 (36.6)	45 (63.4)	
>12	35.7 (30.1–41.2)	25 (37.3)	42 (62.7)	
Mental health				
Severe depressive symptoms (PHQ-9)[a]				<0.001
Yes	49.8 (44.2–55.5)	33 (66.0)	17 (34.0)	
No	27.1 (23.2–31.0)	20 (20.0)	80 (80.0)	
Severe anxiety symptoms (GAD-7)[a]				<0.001
Yes	56.1 (50.9–61.4)	29 (74.4)	10 (25.6)	
No	28.0 (24.1–31.9)	24 (23.8)	77 (76.2)	
Moderate insomnia symptoms (ISI)[a]				<0.001
Yes	50.4 (44.9–55.9)	29 (61.7)	18 (38.3)	
No	28.6 (24.3–32.9)	24 (26.1)	68 (73.9)	
High perceived stress (PSS-10)[a]				<0.001
Yes	46.5 (41.7–51.2)	43 (59.7)	29 (40.3)	
No	25.0 (20.1–30.0)	10 (15.2)	56 (84.8)	
Physical health				
Anemia[a]				0.226
Yes	39.1 (31.5–46.7)	17 (43.6)	22 (56.4)	
No	33.7 (29.5–37.9)	34 (32.7)	70 (67.3)	
High headache (VAS)[a]				<0.001
Yes	45.9 (40.3–51.4)	37 (56.1)	29 (43.9)	
No	27.0 (22.5–31.4)	16 (22.2)	56 (77.8)	

(Continued)

TABLE 5 (Continued)

	Index Score	High (≥46)	Low (<46)	χ^2
	M (95% CI)	*n* (%)	*n* (%)	
Fitness				
VO_2max [a]				0.138
Fair and above	31.9 (24.2–39.6)	7 (24.1)	22 (75.9)	
Poor and below	35.4 (30.5–40.3)	35 (39.3)	54 (60.7)	
High perceived fitness[a]				0.019
Yes	31.1 (26.2–36.1)	23 (30.3)	53 (69.7)	
No	42.8 (37.1–48.6)	30 (50.0)	30 (50.0)	

[a]Cut-off: PHQ-9 (≥15), GAD-7 (≥15), ISI (≥15), PSS-10 (≥median), VAS (≥median), anemia (women ≤ 120 g/L or men ≤ 130 g/L), VO2 max [based on ACSM guidelines (71)], perceived fitness (≥median).

model are presented in Table 4. After including sex, origin, and all associated factors in the regression, only origin, cardiorespiratory and perceived fitness remained significantly associated with metabolic syndrome. Individuals from Southwest Asia (OR = 4.02, 95% CI 1.02–15.77, $p = 0.046$) were more likely to be affected with metabolic syndrome, whereas participants with higher levels of objectively measured (OR = 0.92, 95% CI 0.86–0.99, $p = 0.021$) and subjectively perceived fitness (OR = 0.80, 95% CI 0.65–0.98, $p = 0.031$) were less likely to be affected with metabolic syndrome.

Discussion

This study extends existing findings on health challenges of forcibly displaced people by assessing the psychological well-being, PTSD symptom severity, metabolic syndrome, and associated factors among people living in a refugee camp in Greece.

Only half of the study participants rated their psychological well-being as high. In comparison, forcibly displaced adults resettled in Sweden scored 7.1% (*M* = 57.7, SD = 27.1), and the broader population in Greece during the first year of the COVID-19 pandemic 23.4% (*M* = 66.5, SD = 22.7) higher (82, 83). Moreover, consistent with previous findings (7, 9, 10, 14, 53, 84, 85), there is a considerably elevated prevalence of mental and physical distress among forcibly displaced people in Greece. Compared to the global mean (74–81), the risk of being affected by PTSD is nine, depression three, and generalized anxiety disorder one and a half times higher among forcibly displaced people. No difference in prevalence was found for moderate or severe insomnia symptoms, metabolic syndrome, abdominal obesity, hypertension, prediabetes, and anemia. Our findings stand in contradiction to a recent large-scale study (86), which collected data at health clinics in Southern European reception centers and reported a prevalence of 0.7% for PTSD and 5.7% for cardiovascular disease. As highlighted by the authors, the discrepant results may be explained by an inadequate recording of health conditions by health professionals. In addition, low mental health help-seeking behavior has been found in this population. Constrained health services, limited health literacy, lack of trust in authorities or cultural barriers such as mental health stigmas could have discouraged individuals from voluntarily seeking a health check and lead to a higher number of unreported cases (87). Another reason for the conflicting results might be the different sociodemographic background of the participants, who, in contrast to our study, were predominantly male (77.7%) and without relatives in the camp (80.3%).

Forcibly displaced people represent a heterogeneous group with different personal traits, sociodemographic backgrounds, and lived experiences. Therefore, the question arises if individuals with specific characteristics are more strongly affected by certain conditions than others. Subgroup analyzes did not identify a specific target group with high mental well-being. However, female Southwest Asian people living with family members in the camp had higher PTSD symptom scores. The differences between sexes have been explained in previous studies (9, 84, 88), with women being at higher risk of sexual violence, childcare pressures, and exploitation. Unlike other results (89), being together with a family member was associated with higher PTSD symptom scores in our sample. This finding may be surprising, as social support has been shown to have a buffering effect against PTSD (90). Possible explanations for this could be that the family does not necessarily provide social support in the face of family conflict and violence (5). Moreover, caring for the whole family can pose an additional challenge and may trigger negative mental states. The life experience that caused the entire family to flee their country rather than as individuals may also explain the difference. However, these remain assumptions and should be further investigated in larger studies with increased statistical power and additional qualitative methods to identify subgroup differences and possible rationales.

Regarding cardiovascular risk factors, older age and origin from Southwest Asia were associated with metabolic syndrome. Similarly, a recent meta-analysis (10) reported a higher risk of cardiovascular disease among older forcibly displaced adults from the Middle East. The elevated risk has been attributed to psychological stress and acculturation processes such as changes in lifestyle and diet (7, 8). In our study, neither psychiatric symptoms nor time spent in the camp were associated with the occurrence of metabolic syndrome. The difference may be due to the fact that the two studies examined migrating populations in general and not exclusively forcibly displaced people who spent a shorter time in the host country. Living in the camp instead of within society may also have led to no or limited acculturation processes. Furthermore, the prevalence of the metabolic syndrome is generally significantly higher in the Eastern Mediterranean Region (91), suggesting that the increased risk is more related to the risk profile of the region of origin than to the specific experience of forced displacement. Overall, the associations between

TABLE 6 Descriptive statistics of metabolic syndrome dichotomized into present vs. absent metabolic syndrome.

	Index score[b]	Yes (≥3 out of 5)	No (<3 out of 5)	χ^2
	M (95% CI)	*n* (%)	*n* (%)	
Sociodemographics				
Sex				0.748
Female	0.05 (−0.66–0.76)	21 (30.0)	49 (70.0)	
Male	0.16 (−0.47–0.78)	19 (27.5)	50 (72.5)	
Age				0.001
16–25	0.50 (−0.16–1.16)	9 (17.0)	44 (83.0)	
26–35	−0.33 (−0.99–0.32)	14 (26.9)	38 (73.1)	
>35	0.20 (−1.27–1.66)	15 (55.6)	12 (44.4)	
Origin				0.171
Sub-Sahara Africa	−0.06 (−0.89–0.77)	9 (20.9)	34 (79.1)	
Southwest Asia	0.16 (−0.41–0.73)	31 (32.9)	65 (67.7)	
Education				0.185
None	−0.12 (−0.95–0.72)	6 (17.1)	29 (82.9)	
Primary	0.00 (−0.90–0.89)	13 (27.7)	34 (72.3)	
High school and above	0.32 (−0.44–1.08)	17 (35.4)	31 (64.6)	
Relatives in camp				0.582
Alone	0.37 (−0.41–1.16)	12 (25.5)	35 (74.5)	
Relatives ≥1	0.02 (−0.58–0.61)	27 (30.0)	63 (70.0)	
Time since flight (months)				0.994
0–24	0.10 (−0.63–0.83)	14 (25.5)	41 (74.5)	
>24	0.09 (−0.59–0.76)	16 (25.4)	47 (74.6)	
Time in camp (months)				0.209
0–12	−0.19 (−0.84–0.47)	20 (31.7)	43 (68.3)	
>12	0.30 (−0.43–1.02)	14 (21.9)	50 (78.1)	
Mental health				
Severe depressive symptoms (PHQ-9)[a]				0.271
Yes	−0.03 (−0.89–0.83)	16 (34.8)	30 (65.2)	
No	0.17 (−0.40–0.74)	24 (25.8)	69 (74.2)	
Severe anxiety symptoms (GAD-7)[a]				0.074
Yes	0.18 (−0.82–1.18)	15 (40.5)	22 (59.5)	
No	0.05 (−0.53–0.62)	23 (24.7)	70 (75.3)	
Moderate insomnia symptoms (ISI)[a]				0.165
Yes	0.34 (−0.41–1.10)	16 (36.4)	28 (63.6)	
No	−0.12 (−0.77–0.52)	21 (24.7)	64 (75.3)	
High perceived stress (PSS-10)[a]				0.961
Yes	−0.22 (−0.94–0.49)	19 (27.9)	49 (72.9)	
No	0.32 (−0.36–1.01)	17 (28.3)	43 (71.7)	
Physical health				
Anemia[a]				0.485
Yes	0.04 (−1.01–1.10)	9 (24.3)	28 (75.7)	
No	0.12 (−0.41–0.65)	31 (30.4)	71 (69.6)	
High headache (VAS)[a]				0.674
Yes	−0.13 (−0.87–0.62)	19 (30.6)	43 (69.4)	
No	0.25 (−0.41–0.91)	18 (27.3)	48 (72.7)	

(Continued)

TABLE 6 (Continued)

	Index score[b]	Yes (≥3 out of 5)	No (<3 out of 5)	χ^2
	M (95% CI)	*n* (%)	*n* (%)	
Fitness				
VO_2max[a]				0.005
Fair and above	−0.61 (−1.52–0.30)	1 (3.7)	26 (96.3)	
Poor and below	0.13 (−0.41–0.68)	25 (30.1)	58 (69.9)	
High perceived fitness[a]				0.044
Yes	−0.35 (−0.92–0.23)	15 (20.8)	57 (79.2)	
No	0.48 (−0.37–1.33)	20 (37.0)	34 (63.0)	

[a]Cut-off: PHQ-9 (≥15), GAD-7 (≥15), ISI (≥15), PSS-10 (≥median), VAS (≥median), anemia (women ≤ 120 g/L or men ≤ 130 g/L), VO2 max [based on ACSM guidelines (71)], perceived fitness (≥median).
[b]Index score is composed of continuous metabolic syndrome score.

sociodemographic background and mental and physiological outcomes, except for Asian origin, lose statistical significance in multivariable analyzes when the clinical factors are considered.

When living in a precarious situation, time itself does not seem to support recovery from PTSD symptom severity. To date, the mitigating effect of time on PTSD is controversially discussed and ranges from improvement to no effect till exacerbation of PTSD symptomatology (85, 86, 90). Different exposure to post-migration living difficulties could explain the contrasting results. In our study, perceived stress was associated with the occurrence of higher PTSD symptoms, while no relationship between the length of stay and PTSD symptoms was detected. These observations support recent findings (92) that post-migration stressors maintain the severity of PTSD symptoms. The decisive factors are ongoing daily stressors, especially lengthy asylum procedures, uncertain visa status, detention in refugee camps, or legal barriers to work (93).

Particularly noteworthy is that people who perceived their fitness level as higher had better overall health scores. Surprisingly, this did not apply to objectively measured cardiorespiratory fitness, which was associated only with metabolic syndrome. The association between perceived fitness and psychological well-being and metabolic syndrome remained statistically significant after controlling for confounding factors. This suggests that mental health is more closely associated with an individual's perceived subjective fitness than objective fitness measurement. As such, the process of meaning-making in relation to personal fitness appears to be of particular importance. Our findings add to the small body of knowledge, suggesting that perceived fitness is associated with both mental and physical health benefits (72, 94), pointing out that cognitive factors should be taken into account when studying the effect of sport and exercise activities implemented in a refugee camp. Importantly in the context of a refugee camp, perceived fitness was more strongly associated with psychological functioning and daily coping than cardiorespiratory fitness in a sample of psychology students (73). Furthermore, participants with high perceived fitness scored lower on insomnia, perceived higher sleep quality, and ruminated less about unresolved problems than participants who rated their fitness low (95). This last point requires particular attention because "thinking too much" expresses emotional and cognitive distress in certain Sub-Saharan and Southwest Asian cultures. For forcibly displaced people in a protracted situation, repetitive negative thinking can exacerbate psychological, physical, and social symptoms (96). People with high perceived fitness may be less affected by the cognitive loop about current life situations and past events, which may lead to higher overall well-being.

In line with the current findings of an increased risk for mental distress compared to the global population and the overall high prevalence of mental and physiological distress among people living in a refugee camp in Greece, organizations on-site criticize the lack of early measures (97). The lack of prevention or early treatment favors the development or consolidation of mental disorders and undermines the achievement of the health-related United Nations Sustainable Development Goals by 2030. Based on the results of this and previous studies (4, 5, 15, 92, 93), policies are urgently needed to reduce post-migration stressors and prevent mental health deterioration in Greek refugee camps. Prevention should be of priority, complemented by targeted programs to address population-based health needs and psychological well-being. The extent of diverse health needs and the heterogeneous composition of the population suggests that general health support should go beyond medical treatment and include a set of complementary measures to balance health inequities. These include access to education, a perspective on economic independence, social services, community capacity strengthening, health literacy promotion, and psychosocial activities. In light of the present findings, organized sport and exercise activities might be a favorable add-on intervention to address mental and physiological health.

While sport and exercise activities have successfully been implemented to address mental and physical health (12, 98–100), evidence for similar effects among forcibly displaced people is scarce (101). As these are substantially different contexts, future studies need to investigate the effect and feasibility of regular sport and exercise activities on mental and physiological health among people living in refugee camps. In addition, this study's results raise the question of whether improvements in perceived fitness are associated with improvements in mental and physical health and, which and how activities should be implemented to address perceived fitness.

Strengths and limitations

This study has certain strengths, such as providing a comprehensive perspective of health and its associated factors among forcibly displaced people living in a refugee camp in Greece. Given the recent developments in forcible displacement and since Greece is one of the main entry points in Europe, an essential contemporary context was studied. Furthermore, we addressed a population that is difficult to reach due to challenging living situations and restricted camp access. Our study is, to our knowledge, one of the first which examines the association of perceived fitness and mental and physiological health among forcibly displaced people within a refugee camp context. Lastly, the study applied methodological rigorousness by following a pre-registered study protocol (20). The shortage of sex-specific results (88) and the barriers to accessing health services, in particular mental health (87), was addressed by a random and stratified sample by sex, including the most represented ethnic groups in the camp.

Limitations include the cross-sectional nature of the present data and the small-to-moderate sample size, increasing the risk that minor associations were overseen. On the other hand, multiple testing might have increased the occurrence of Type I errors. Despite an acceptable response rate, one might assume that selection bias influenced the results. However, when analyzing group differences, only time since flight differed statistically significantly from the broader screened camp population. Generalizability to other settings might be limited, as post-migration life circumstances differ from context to context and significantly impact overall health (4). Expanding the study to other camps, particularly those on the Greek islands, which have been described as more restrictive (97), could therefore provide valuable insights to complement our findings. A key finding of the study was that cardiorespiratory fitness, unlike perceived fitness, was not associated with mental health outcomes. The considerable amount of missing values for cardiorespiratory fitness may have affected this finding. Moreover, recent literature suggests that self-report symptom-based measures tend to overestimate the prevalence of mental distress (52–54). This may also be caused by participants indicating higher initial values in the hope that this will positively influence their asylum procedure (89). These circumstances were addressed by information about study intentions and the use of more conservative, clinically relevant cut-offs. Validated instruments widely used in different cultural contexts have been implemented, though none have been developed explicitly for cross-cultural use (84). The universality of Western-based classification systems to describe mental distress in other contexts is accordingly questioned by some authors (52, 53, 84). Similarly, population-specific cut-offs for cardiovascular risk factors have been recommended (102). The International Diabetes Federation advocates ethnicity-specific cut-offs for central obesity (63). To date, however, these are not available for Sub-Saharan and Eastern Mediterranean populations. Instead, European reference values had to be used, which might lead to inaccuracies in our results.

Conclusion

The findings of this study underpin the call for urgent action to address the health needs of people living in refugee camps in Greece. Compared to the global population, forcibly displaced people in Greece have a considerably higher risk of being affected by mental distress. The prevalence of moderate or severe insomnia symptoms and physiological disorders is likewise elevated. However, they do not differ from the global mean. Therefore, the first priority should be to prevent the deterioration of health conditions by reducing post-migration stress. Second, population-centered programs must be developed to address mental health and non-communicable diseases. Sport and exercise programs could be a favorable adjunct, as perceived fitness, as a potentially protective factor, is associated with mental and physiological health benefits.

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 Research Ethics Committee of the University of Thessaly. The patients/participants provided their written informed consent to participate in this study.

Author contributions

AH, IM, and MG supervised the study. FK and KF coordinated the fieldwork. FK analyzed the data and drafted the initial manuscript. KF, AH, IM, ET, EH, HS, FC, SL, MM, DQ, YT, RK, UP, and MG contributed to revising and editing the final manuscript. All authors were involved in the design of the study or contributed to the refinement of methods and read and approved the final manuscript.

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Conflict of interest

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

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References

1. United Nations High Commissioner for Refugees. *Global report: The stories behind the numbers*. (2021). Available at: https://www.unhcr.org/the-global-report.html. (Accessed 6 Jan 2023).

2. Matlin SA, Depoux A, Schütte S, Flahault A, Saso L. Migrants' and refugees' health: towards an agenda of solutions. *Public Health Rev*. (2018) 39:27. doi: 10.1186/s40985-018-0104-9

3. United Nations High Commissioner for Refugees. *Global trends: a year of crises*. (2011). Available at: https://www.unhcr.org/statistics/country/4fd6f87f9/unhcr-global-trends-2011.html. (Accessed Jan 6, 2023).

4. Miller KE, Rasmussen A. The mental health of civilians displaced by armed conflict: an ecological model of refugee distress. *Epidemiol Psychiatr Sci*. (2017) 26:129–38. doi: 10.1017/S2045796016000172

5. Kiselev N, Pfaltz M, Schick M, Bird M, Pernille H, Sijbrandij M, et al. Problems faced by Syrian refugees and asylum seekers in Switzerland. *Swiss Med Wkly*. (2020) 150:w20381. doi: 10.4414/smw.2020.20381

6. Hynie M. The social determinants of refugee mental health in the post-migration context: a critical review. *Can J Psychiatr*. (2018) 63:297–303. doi: 10.1177/0706743717746666

7. Rosenthal T, Touyz RM, Oparil S. Migrating populations and health: risk factors for cardiovascular disease and metabolic syndrome. *Curr Hypertens Rep*. (2022) 24:325–40. doi: 10.1007/s11906-022-01194-5

8. World Health Organization. *World report on the health of refugees and migrants*. (2022). Available at: https://www.who.int/publications/i/item/9789240054462. (Accessed Jan 6, 2023).

9. Mesa-Vieira C, Haas AD, Buitrago-Garcia D, Roa-Diaz ZM, Minder B, Gamba M, et al. Mental health of migrants with pre-migration exposure to armed conflict: a systematic review and meta-analysis. *Lancet Public Health*. (2022) 7:e469–81. doi: 10.1016/S2468-2667(22)00061-5

10. Al-Rousan T, AlHeresh R, Saadi A, El-Sabrout H, Young M, Benmarhnia T, et al. Epidemiology of cardiovascular disease and its risk factors among refugees and asylum seekers: systematic review and meta-analysis. *Int J Cardiol Cardiovasc Risk Prev*. (2022) 12:200126. doi: 10.1016/j.ijcrp.2022.200126

11. Walker ER, McGee RE, Druss BG. Mortality in mental disorders and global disease burden implications: a systematic review and meta-analysis. *JAMA Psychiat*. (2015) 72:334–41. doi: 10.1001/jamapsychiatry.2014.2502

12. Pedersen BK, Saltin B. Exercise as medicine - evidence for prescribing exercise as therapy in 26 different chronic diseases. *Scand J Med Sci Sports*. (2015) 25:1–72. doi: 10.1111/sms.12581

13. Nilsson H, Gustavsson C, Gottvall M, Saboonchi F. Physical activity, post-traumatic stress disorder, and exposure to torture among asylum seekers in Sweden: a cross-sectional study. *BMC Psychiatry*. (2021) 21:452. doi: 10.21203/rs.3.rs-274063/v1

14. Morina N, Akhtar A, Barth J, Schnyder U. Psychiatric disorders in refugees and internally displaced persons after forced displacement: a systematic review. *Front Psych*. (2018) 9:433. doi: 10.3389/fpsyt.2018.00433

15. Malm A, Tinghög P, Narusyte J, Saboonchi F. The refugee post-migration stress scale (RPMS) - development and validation among refugees from Syria recently resettled in Sweden. *Confl Heal*. (2020) 14:2. doi: 10.1186/s13031-019-0246-5

16. World Health Organization. *Constitution of the World Health Organization*. (1946). Available at: https://www.who.int/about/governance/constitution. (Accessed Jan 6, 2023).

17. Poole DN, Hedt-Gauthier B, Liao S, Raymond NA, Bärnighausen T. Major depressive disorder prevalence and risk factors among Syrian asylum seekers in Greece. *BMC Public Health*. (2018) 18:908. doi: 10.1186/s12889-018-5822-x

18. Theofanidis D, Karavasileiadou S, Almegewly WH. Post-traumatic stress disorder among Syrian refugees in Greece. *Front Psych*. (2022) 13:911642. doi: 10.3389/fpsyt.2022.911642

19. Ben Farhat J, Blanchet K, Juul Bjertrup P, Veizis A, Perrin C, Coulborn RM, et al. Syrian refugees in Greece: experience with violence, mental health status, and access to information during the journey and while in Greece. *BMC Med*. (2018) 16:40. doi: 10.1186/s12916-018-1028-4

20. Gerber M, Colledge F, de Quervain D, Filippou K, Havas E, Knappe F, et al. Effects of an exercise and sport intervention among refugees living in a Greek refugee camp on mental health, physical fitness and cardiovascular risk markers: study protocol for the SALEEM pragmatic randomized controlled trial. *Trials*. (2021) 22:827. doi: 10.1186/s13063-021-05808-2

21. Mackenzie C, McDowell C, Pittaway E. Beyond 'Do no Harm': the challenge of constructing ethical relationships in refugee research. *J Refug Stud*. (2007) 20:299–319. doi: 10.1093/jrs/fem008

22. Morina N, Ehring T, Priebe S. Diagnostic utility of the impact of event scale-revised in two samples of survivors of war. *PLoS One*. (2013) 8:e83916. doi: 10.1371/journal.pone.0083916

23. Feyera F, Mihretie G, Bedaso A, Gedle D, Kumera G. Prevalence of depression and associated factors among Somali refugee at Melkadida camp, Southeast Ethiopia: a cross-sectional study. *BMC Psychiatry*. (2015) 15:171. doi: 10.1186/s12888-015-0539-1

24. Georgiadou E, Zbidat A, Schmitt GM, Erim Y. Prevalence of mental distress among Syrian refugees with residence permission in Germany: a registry-based study. *Front Psych*. (2018) 9:393. doi: 10.3389/fpsyt.2018.00393

25. Al-Smadi AM, Tawalbeh LI, Gammoh OS, Ashour A, Tayfur M, Attarian H. The prevalence and the predictors of insomnia among refugees. *J Health Psychol*. (2019) 24:1125–33. doi: 10.1177/1359105316687631

26. Alhalaiqa F, Masa'Deh R, Al-Yami M, Al-Ghabeesh S, Rayan A, Shawashreh A, et al. Perceived stress among university students: Syrian refugees versus Jordanians. *J Public Health (Berl)*. (2021) 29:1477–86. doi: 10.1007/s10389-020-01261-8

27. Hermansson AC, Thyberg M, Timpka T, Gerdle B. Survival with pain: an eight-year follow-up of war-wounded refugees. *Med Confl Surviv*. (2001) 17:102–11. doi: 10.1080/13623690108409564

28. Sundquist J, Hagströmer M, Johansson S-E, Sundquist K. Effect of a primary health-care-based controlled trial for cardiorespiratory fitness in refugee women. *BMC Fam Pract*. (2010) 11:55. doi: 10.1186/1471-2296-11-55

29. Blom EH, Bech P, Högberg G, Larsson JO, Serlachius E. Screening for depressed mood in an adolescent psychiatric context by brief self-assessment scales--testing psychometric validity of WHO-5 and BDI-6 indices by latent trait analyses. *Health Qual Life Outcomes*. (2012) 10:149. doi: 10.1186/1477-7525-10-149

30. Sibai AM, Chaaya M, Tohme RA, Mahfoud Z, Al-Amin H. Validation of the Arabic version of the 5-item WHO well being index in elderly population. *Int J Geriatr Psychiatry*. (2009) 24:106–7. doi: 10.1002/gps.2079

31. Dadfar M, Momeni Safarabad N, Asgharnejad Farid AA, Nemati Shirzy M, Abarghouie FGP. Reliability, validity, and factorial structure of the World Health Organization-5 well-being index (WHO-5) in Iranian psychiatric outpatients. *Trends Psychiatry Psychother*. (2018) 40:79–84. doi: 10.1590/2237-6089-2017-0044

32. Hochberg G, Pucheu S, Kleinebreil L, Halimi S, Fructuoso-Voisin C. WHO-5, a tool focusing on psychological needs in patients with diabetes: the French contribution to the DAWN study. *Diabetes Metab*. (2012) 38:515–22. doi: 10.1016/j.diabet.2012.06.002

33. Davey C, Heard R, Lennings C. Development of the Arabic versions of the impact of events scale-revised and the posttraumatic growth inventory to assess trauma and growth in middle eastern refugees in Australia. *Clin Psychol*. (2015) 19:131–9. doi: 10.1111/cp.12043

34. Iranmanesh S, Shamsi A, Dehghan M. Post-traumatic stress symptoms among Iranian parents of children during Cancer treatment. *Issues Ment Health Nurs*. (2015) 36:279–85. doi: 10.3109/01612840.2014.983622

35. Brunet A, St-Hilaire A, Jehel L, King S. Validation of a French version of the impact of event scale-revised. *Can J Psychiatr*. (2003) 48:56–61. doi: 10.1177/070674370304800111

36. Kroenke K, Spitzer RL, Williams JB. The PHQ-9: validity of a brief depression severity measure. *J Gen Int Med*. (2001) 16:606–13. doi: 10.1046/j.1525-1497.2001.016009606.x

37. AlHadi AN, AlAteeq DA, Al-Sharif E, Bawazeer HM, Alanazi H, AlShomrani AT, et al. An arabic translation, reliability, and validation of patient health questionnaire in a Saudi sample. *Ann General Psychiatry*. (2017) 16:32. doi: 10.1186/s12991-017-0155-1

38. Dadfar M, Kalibatseva Z, Lester D. Reliability and validity of the Farsi version of the patient health Questionnaire-9 (PHQ-9) with Iranian psychiatric outpatients. *Trends Psychiatry Psychother*. (2018) 40:144–51. doi: 10.1590/2237-6089-2017-0116

39. Arthurs E, Steele RJ, Hudson M, Baron M, Thombs BD. Are scores on English and French versions of the PHQ-9 comparable? An assessment of differential item functioning. *PLoS One*. (2012) 7:e52028. doi: 10.1371/journal.pone.0052028

40. Spitzer RL, Kroenke K, Williams JBW, Löwe B. A brief measure for assessing generalized anxiety disorder: the GAD-7. *Arch Int Med*. (2006) 166:1092–7. doi: 10.1001/archinte.166.10.1092

41. Omani-Samani R, Maroufizadeh S, Ghaheri A, Navid B. Generalized anxiety Disorder-7 (GAD-7) in people with infertility: a reliability and validity study. *Middle East Fertil Soc J*. (2018) 23:446–9. doi: 10.1016/j.mefs.2018.01.013

42. Micoulaud-Franchi J-A, Lagarde S, Barkate G, Dufournet B, Besancon C, Trébuchon-Da Fonseca A, et al. Rapid detection of generalized anxiety disorder and major depression in epilepsy: validation of the GAD-7 as a complementary tool to the

NDDI-E in a French sample. *Epilepsy Behav*. (2016) 57:211–6. doi: 10.1016/j.yebeh.2016.02.015

43. Morin CM, Belleville G, Bélanger L, Ivers H. The insomnia severity index: psychometric indicators to detect insomnia cases and evaluate treatment response. *Sleep*. (2011) 34:601–8. doi: 10.1093/sleep/34.5.601

44. Suleiman KH, Yates BC. Translating the insomnia severity index into Arabic. *J Nurs Scholarsh*. (2011) 43:49–53. doi: 10.1111/j.1547-5069.2010.01374.x

45. Yazdi Z, Sadeghniiat K, Zohal M, Elmizadeh K. Validity and reliability of the Iranian version of the insomnia severity index. *Malays J Med Sci*. (2012) 19:31–6.

46. Cohen S, Kamarck T, Mermelstein R. A global measure of perceived stress. *J Health Soc Behav*. (1983) 24:385–96. doi: 10.2307/2136404

47. Almadi T, Cathers I, Hamdan Mansour AM, Chow CM. An Arabic version of the perceived stress scale: translation and validation study. *Int J Nurs Stud*. (2012) 49:84–9. doi: 10.1016/j.ijnurstu.2011.07.012

48. Khalili R, Sirati Nir M, Ebadi A, Tavallai A, Habibi M. Validity and reliability of the Cohen 10-item perceived stress scale in patients with chronic headache: Persian version. *Asian J Psychiatr*. (2017) 26:136–40. doi: 10.1016/j.ajp.2017.01.010

49. Lesage F-X, Berjot S, Deschamps F. Psychometric properties of the French versions of the perceived stress scale. *Int J Occup Med Environ Health*. (2012) 25:178–84. doi: 10.2478/S13382-012-0024-8

50. Weiss DS, Marmar CR. The impact of event scale–revised In: JP Wilson and TM Keane, editors. *Assessing psychological trauma and PTSD*. New York: Guilford Press (1997). 399–411.

51. Knappe F, Colledge F, Gerber M. Impact of an 8-week exercise and sport intervention on post-traumatic stress disorder symptoms, mental health, and physical fitness among male refugees living in a Greek refugee camp. *Int J Environ Res Public Health*. (2019) 16:3904. doi: 10.3390/ijerph16203904

52. Charlson F, van Ommeren M, Flaxman A, Cornett J, Whiteford H, Saxena S. New WHO prevalence estimates of mental disorders in conflict settings: a systematic review and meta-analysis. *Lancet*. (2019) 394:240–8. doi: 10.1016/S0140-6736(19)30934-1

53. Charlson FJ, Flaxman A, Ferrari AJ, Vos T, Steel Z, Whiteford HA. Post-traumatic stress disorder and major depression in conflict-affected populations: an epidemiological model and predictor analysis. *Glob Ment Health (Camb)*. (2016) 3:e4. doi: 10.1017/gmh.2015.26

54. Grupp F, Piskernik B, Mewes R. Is depression comparable between asylum seekers and native Germans? An investigation of measurement invariance of the PHQ-9. *J Affect Disord*. (2020) 262:451–8. doi: 10.1016/j.jad.2019.11.055

55. Murphy D, Ross J, Ashwick R, Armour C, Busuttil W. Exploring optimum cut-off scores to screen for probable posttraumatic stress disorder within a sample of UK treatment-seeking veterans. *Eur J Psychotraumatol*. (2017) 8:1398001. doi: 10.1080/20008198.2017.1398001

56. World Health Organization. *Wellbeing measures in primary health care/the DepCare project*. Report on a WHO meeting: Stockholm, Sweden, 12–13 February 1998: World Health Organization. Regional Office for Europe (1998).

57. American Psychiatric Association. *Diagnostic and statistical manual of mental disorders*. *5th* ed. Washington, DC: American Psychiatric Association (2022).

58. World Health Organization. *The ICD-10 classification of mental and behavioural disorders: Diagnostic criteria for research*. Geneva: World Health Organization (1993).

59. Qi L, Wang G-L, Liu S, Zhang S, Wang H-F. Dissipation-induced topological phase transition and periodic-driving-induced photonic topological state transfer in a small optomechanical lattice. *Front Phys*. (2021) 16:3045. doi: 10.1007/s11467-020-0983-3

60. World Health Organization. *Haemoglobin concentrations for the diagnosis of anaemia and assessment of severity*. (2011). Availble at: https://apps.who.int/iris/handle/10665/85839. (Accessed Jan 6, 2023).

61. Abbai NS, Nyirenda M, Reddy T, Ramjee G. Good correlation between the Afinion AS100 analyser and the ABX Pentra 400 analyser for the measurement of glycosylated haemoglobin and lipid levels in older adults in Durban, South Africa. *S Afr Med J*. (2017) 108:50–5. doi: 10.7196/SAMJ.2017.v108i1.12548

62. Foerster V, Severn M. Point-of-care glycated hemoglobin testing to diagnose type 2 diabetes. *Issues Emerg Health Tech*. (2016). 156:1–8.

63. Kahn R, Buse J, Ferrannini E, Stern M. The metabolic syndrome: time for a critical appraisal. Joint statement from the American Diabetes Association and the European Association for the Study of diabetes. *Diabetologia*. (2005) 48:1684–99. doi: 10.1007/s00125-005-1876-2

64. Cavero-Redondo I, Martínez-Vizcaíno V, Álvarez-Bueno C, Agudo-Conde C, Lugones-Sánchez C, García-Ortiz L. Metabolic syndrome including glycated hemoglobin A1c in adults: is it time to change? *J Clin Med*. (2019). doi: 10.3390/jcm8122090

65. Eisenmann JC. On the use of a continuous metabolic syndrome score in pediatric research. *Cardiovasc Diabetol*. (2008) 7:17. doi: 10.1186/1475-2840-7-17

66. Huskisson EC. Measurement of pain. *Lancet*. (1974) 2:1127–31. doi: 10.1016/s0140-6736(74)90884-8

67. Carlsson AM. Assessment of chronic pain. I. Aspects of the reliability and validity of the visual analogue scale. *Pain*. (1983) 16:87–101. doi: 10.1016/0304-3959(83)90088-X

68. Åstrand PO, Rodahl K. *Textbook of work physiology: Physiological bases of exercise*. Champaign: Human Kinetics (2003).

69. Buono MJ, Roby JJ, Micale FG, Sallis JF. Predicting maximal oxygen uptake in children: modification of the Astrand-Ryhming test. *Pediatr Exerc Sci*. (1989) 1:278–83.

70. Macsween A. The reliability and validity of the Astrand nomogram and linear extrapolation for deriving VO2max from submaximal exercise data. *J Sports Med Phys Fitness*. (2001) 41:312–7.

71. American College of Sports Medicine. *ACSM's guidelines for exercise testing and prescription*. *8th* ed. Philadelphia, PA: Lippincott Williams & Wilkins (2010).

72. Plante TG, LeCaptain SE, McLain HC. Perceived fitness predicts daily coping better than physical activity. *J Appl Biobehav Res*. (2000) 5:66–79. doi: 10.1111/j.1751-9861.2000.tb00064.x

73. Plante TG, Lantis A, Checa G. The influence of perceived versus aerobic fitness on psychological health and physiological stress responsivity. *Int J Stress Manag*. (1998) 5:141–56. doi: 10.1023/A:1022936930992

74. Vos T, Lim SS, Abbafati C, Abbas KM, Abbasi M, Abbasifard M, et al. Global burden of 369 diseases and injuries in 204 countries and territories, 1990-2019: a systematic analysis for the global burden of disease study 2019. *Lancet*. (2020) 396:1204–22. doi: 10.1016/S0140-6736(20)30925-9

75. Koenen KC, Ratanatharathorn A, Ng L, McLaughlin KA, Bromet EJ, Stein DJ, et al. Posttraumatic stress disorder in the world mental health surveys. *Psychol Med*. (2017) 47:2260–74. doi: 10.1017/S0033291717000708

76. Perlis ML, Posner D, Riemann D, Bastien CH, Teel J, Thase M. Insomnia. *Lancet*. (2022) 400:1047–60. doi: 10.1016/S0140-6736(22)00879-0

77. Saklayen MG. The global epidemic of the metabolic syndrome. *Curr Hypertens Rep*. (2018) 20:12. doi: 10.1007/s11906-018-0812-z

78. Wong MCS, Huang J, Wang J, Chan PSF, Lok V, Chen X, et al. Global, regional and time-trend prevalence of central obesity: a systematic review and meta-analysis of 13.2 million subjects. *Eur J Epidemiol*. (2020) 35:673–83. doi: 10.1007/s10654-020-00650-3

79. Weisman A, Fazli GS, Johns A, Booth GL. Evolving trends in the epidemiology, risk factors, and prevention of type 2 diabetes: a review. *Can J Cardiol*. (2018) 34:552–64. doi: 10.1016/j.cjca.2018.03.002

80. Mills KT, Stefanescu A, He J. The global epidemiology of hypertension. *Nat Rev Nephrol*. (2020) 16:223–37. doi: 10.1038/s41581-019-0244-2

81. Kessler RC, Aguilar-Gaxiola S, Alonso J, Chatterji S, Lee S, Ormel J, et al. The global burden of mental disorders: an update from the WHO world mental health (WMH) surveys. *Epidemiol Psichiatr Soc*. (2009) 18:23–33. doi: 10.1017/S1121189X00001421

82. Long D, Bonsel GJ, Lubetkin EI, Yfantopoulos JN, Janssen MF, Haagsma JA. Health-related quality of life and mental well-being during the COVID-19 pandemic in five countries: a one-year longitudinal study. *J Clin Med*. (2022). doi: 10.3390/jcm11216467

83. Nissen A, Sengoelge M, Solberg Ø. Post-migration stressors and subjective well-being in adult Syrian refugees resettled in Sweden: a gender perspective. *Front Public Health*. (2021) 9:717353. doi: 10.3389/fpubh.2021.717353

84. Blackmore R, Boyle JA, Fazel M, Ranasinha S, Gray KM, Fitzgerald G, et al. The prevalence of mental illness in refugees and asylum seekers: a systematic review and meta-analysis. *PLoS Med*. (2020) 17:e1003337. doi: 10.1371/journal.pmed.1003337

85. Henkelmann J-R, de Best S, Deckers C, Jensen K, Shahab M, Elzinga B, et al. Anxiety, depression and post-traumatic stress disorder in refugees resettling in high-income countries: systematic review and meta-analysis. *BJPsych Open*. (2020) 6:e68. doi: 10.1192/bjo.2020.54

86. Zenner D, Méndez AR, Schillinger S, Val E, Wickramage K. Health and illness in migrants and refugees arriving in Europe: analysis of the electronic personal health record system. *J Travel Med*. (2022). doi: 10.1093/jtm/taac035

87. Byrow Y, Pajak R, Specker P, Nickerson A. Perceptions of mental health and perceived barriers to mental health help-seeking amongst refugees: a systematic review. *Clin Psychol Rev*. (2020) 75:101812. doi: 10.1016/j.cpr.2019.101812

88. Shishehgar S, Gholizadeh L, DiGiacomo M, Green A, Davidson PM. Health and socio-cultural experiences of refugee women: an integrative review. *J Immigr Minor Health*. (2017) 19:959–73. doi: 10.1007/s10903-016-0379-1

89. Steel Z, Silove D, Brooks R, Momartin S, Alzuhairi B, Susljik I. Impact of immigration detention and temporary protection on the mental health of refugees. *Br J Psychiatry*. (2006) 188:58–64. doi: 10.1192/bjp.bp.104.007864

90. Uysal B, Yanik M, Tastekne F, Tuzgen E, Altinisik E, Acarturk C. Psychological problems and resilience among Syrian adolescents exposed to war. *Eur J Trauma Dissociation*. (2022) 6:100258. doi: 10.1016/j.ejtd.2022.100258

91. Noubiap JJ, Nansseu JR, Lontchi-Yimagou E, Nkeck JR, Nyaga UF, Ngouo AT, et al. Geographic distribution of metabolic syndrome and its components in the general adult population: a meta-analysis of global data from 28 million individuals. *Diabetes Res Clin Pract*. (2022) 188:109924. doi: 10.1016/j.diabres.2022.109924

92. van de Wiel W, Castillo-Laborde C, Francisco Urzúa I, Fish M, Scholte WF. Mental health consequences of long-term stays in refugee camps: preliminary evidence from Moria. *BMC Public Health*. (2021) 21:1290. doi: 10.1186/s12889-021-11301-x

93. Hou WK, Liu H, Liang L, Ho J, Kim H, Seong E, et al. Everyday life experiences and mental health among conflict-affected forced migrants: a meta-analysis. *J Affect Disord*. (2020) 264:50–68. doi: 10.1016/j.jad.2019.11.165

94. Lang C, Brand S, Colledge F, Ludyga S, Pühse U, Gerber M. Adolescents' personal beliefs about sufficient physical activity are more closely related to sleep and psychological functioning than self-reported physical activity: a prospective study. *J Sport Health Sci*. (2019) 8:280–8. doi: 10.1016/j.jshs.2018.03.002

95. Gerber M, Brand S, Holsboer-Trachsler E, Pühse U. Fitness and exercise as correlates of sleep complaints: is it all in our minds? *Med Sci Sports Exerc*. (2010) 42:893–901. doi: 10.1249/MSS.0b013e3181c0ea8c

96. Backe EL, Bosire EN, Kim AW, Mendenhall E. "thinking too much": a systematic review of the idiom of distress in sub-Saharan Africa. *Cult Med Psychiatry*. (2021) 45:655–82. doi: 10.1007/s11013-020-09697-z

97. Médecins Sans Frontières. *Constructing crisis at Europe's borders: The EU plan to intensify its dangerous hotspot approach on Greek islands*. (2021). Available at: https://www.msf.ch/sites/default/files/2021-06/20210610_rep_greece_hotspot.pdf. (Accessed Jan 6, 2023).

98. Morres ID, Hatzigeorgiadis A, Stathi A, Comoutos N, Arpin-Cribbie C, Krommidas C, et al. Aerobic exercise for adult patients with major depressive disorder in mental health services: a systematic review and meta-analysis. *Depress Anxiety*. (2019) 36:39–53. doi: 10.1002/da.22842

99. Liang M, Pan Y, Zhong T, Zeng Y, Cheng ASK. Effects of aerobic, resistance, and combined exercise on metabolic syndrome parameters and cardiovascular risk factors: a systematic review and network meta-analysis. *Rev Cardiovasc Med*. (2021) 22:1523–33. doi: 10.31083/j.rcm2204156

100. Morres ID, Tzouma N-A, Hatzigeorgiadis A, Krommidas C, Kotronis KV, Dafopoulos K, et al. Exercise for perinatal depressive symptoms: a systematic review and meta-analysis of randomized controlled trials in perinatal health services. *J Affect Disord*. (2022) 298:26–42. doi: 10.1016/j.jad.2021.10.124

101. Hamilton A, Foster C, Richards J. A systematic review of the mental health impacts of sport and physical activity programmes for adolescents in post-conflict settings. *J Sport Dev*. (2016) 4:44–59.

102. Després J-P, Lemieux I. Abdominal obesity and metabolic syndrome. *Nature*. (2006) 444:881–7. doi: 10.1038/nature05488

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Hoosier Sport: a research protocol for a multilevel physical activity-based intervention in rural Indiana

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Introduction: Currently, only 1 in 4 children in the U.S. engage in the recommended amount of physical activity (PA) and disparities in PA participation increase as income inequities increase. Moreover, leading health organizations have identified rural health as a critical area of need for programming, research, and policy. Thus, there is a critical need for the development and testing of evidence-based PA interventions that have the potential to be scalable to improve health disparities in children from under-resourced rural backgrounds. As such, the present study utilizes human-centered design, a technique that puts community stakeholders at the center of the intervention development process, to increase our specific understanding about how the PA-based needs of children from rural communities manifest themselves in context, at the level of detail needed to make intervention design decisions. The present study connects the first two stages of the NIH Stage Model for Behavioral Intervention Development with a promising conceptual foundation and potentially sustainable college student mentor implementation strategy.

Methods: We will conduct a three-phase study utilizing human-centered community-based participatory research (CBPR) in three aims: (Aim 1) conduct a CBPR needs assessment with middle school students, parents, and teachers/administrators to identify perceptions, attributes, barriers, and facilitators of PA that are responsive to the community context and preferences; (Aim 2) co-design with children and adults to develop a prototype multi-level PA intervention protocol called Hoosier Sport; (Aim 3) assess Hoosier Sport's trial- and intervention-related feasibility indicators. The conceptual foundation of this study is built on three complementary theoretical elements: (1) Basic Psychological Needs mini-theory within Self-Determination Theory; (2) the Biopsychosocial Model; and (3) the multilevel Research Framework from the National Institute on Minority Health and Health Disparities.

Discussion: Our CBPR protocol takes a human-centered approach to integrating the first two stages of the NIH Stage Model with a potentially sustainable college student mentor implementation strategy. This multidisciplinary approach can be used by researchers pursuing multilevel PA-based intervention development for children.

KEYWORDS

human-centered design, youth, cardiovascular disease, multilevel intervention, physical activity, lifestyle intervention

Introduction

Cardiovascular disease (CVD) is the leading cause of death in the United States (US) and disproportionately impacts people from rural areas and lower socioeconomic backgrounds (1–4). While the impact of CVD is a critical public health issue, many of the risk factors for developing CVD are modifiable. Participating in physical activity (PA) is one of the most promising modifiable strategies to reduce CVD risk (5–7). However, currently only 1 in 4 children in the US engage in the recommended amount of PA (8). Furthermore, disparities in PA participation increase as income inequities increase (9). Since the progression of atherosclerosis begins in childhood and inactive children are likely to become inactive adults (10, 11), the promotion of PA should begin in childhood when prevention efforts may have optimal public health impact (12).

While the health consequences of physical inactivity affect all children, those from rural areas are disproportionately affected compared to urban children (13, 14). Children living within rural communities and from families with low-socioeconomic status (SES) often have less access and greater barriers to PA opportunities, lower health literacy, and less educational attainment, all of which are associated with lower PA participation rates and greater lifetime risk of developing CVD (4, 15, 16). Moreover, rural schools facing socioeconomic disadvantage are the least likely to offer policies (e.g., mandatory recess, economic development initiatives) and services (e.g., transportation, access to quality health services, and college and career readiness programs) that support PA programs (14, 17). Further, children from lower socioeconomic backgrounds are significantly more likely to feel unwelcome on school teams and not be able to afford to participate (16). Collectively, these challenges facing rural communities point to a critical need for intervention and align with the American Heart Association's Presidential Advisory calling for rural populations to become a national priority for programming, research, and policy (15).

As rural populations continue to bear disproportionate burdens of disease and adverse health conditions, there has been growing support for developing and piloting of novel community-derived multilevel interventions (18–21). Multilevel interventions take a broader approach to intervening on complex health behaviors by targeting change at multiple levels of influence (e.g., individual, interpersonal, community) and have the potential to impact health outcomes more than single-level interventions (19–21). Accordingly, as suggested by the NIH Stage Model for Behavioral Intervention Development, behavioral interventions in PA need to be based on a strong empirical foundation (22). While knowledge of population level data is helpful, there needs to be greater emphasis on increasing specific understanding about how the PA-based needs of children from rural communities manifest themselves in context (NIH Stage 0), at the level of detail needed to make intervention design decisions (NIH Stage 1A) and in piloting interventions to determine feasibility (NIH Stage 1B). Taking a novel approach, the proposed study protocol places children at the center of each of the three study phases to get at the specific understanding necessary for targeted intervention development. A recent review of child-focused health research found that less than 1% of published studies included any form of advice from children during the research process (23). This general lack of inclusion of children in the research process occurs despite the recognized unique perspectives and ideas children can contribute that are otherwise unavailable to adult researchers (24, 25). Taken together, these research gaps point to the need for inclusion of children in promising multilevel PA intervention development and testing.

The powerful influence that college students can have on role modeling and supporting the behaviors of children is well recognized (26–28). For instance, children tend to view young adults as being more credible and relatable than older adults, having a better understanding of the concerns of young people, and being able to convey PA messages through interpersonal relationships (i.e., role modeling) to increase the likelihood of behavior change (29–31). Additionally, incorporating trained college student mentors as facilitators of intervention/programs may support cost-effectiveness and sustainability through reduced staffing costs and a consistent pipeline of incoming students. In community-based participatory research (CBPR), community stakeholders often express frustration with programs, particularly because the programs or interventions are short-term, provide little long-term benefit, and do not provide the needed infrastructure to sustain efforts (32). To address these frustrations, our implementation strategy using college student mentors takes a long-term approach to work with the community and builds capacity through ongoing college student mentor development and delivery of interventions/programming.

Therefore, the present study utilizes human-centered design, a technique that puts community stakeholders' at the center of the intervention development and testing process (33). Human-centered design research is "*a systematic approach that holds empathy at its core and encourages its practitioners to return repeatedly to the context, emotions, needs, and desires of the key stakeholders they are developing their solutions for*" (34). Using a human-centered approach, the purpose of this three-phase study is to conduct a human-centered CBPR needs assessment (Aim 1; Stage 0), use participatory co-design with children and adults to develop a testable PA intervention protocol (Aim 2; Stage 1A), and to pilot/feasibility test the PA-based intervention, called *Hoosier Sport*, in a rural middle school (Aim 3; Stage 1B). Our primary hypotheses are that *Hoosier Sport* will be feasible as defined by multiple trial- and intervention-related feasibility indicators (e.g., recruitment capability, retention, fidelity, acceptability, attendance, compliance, cost, and appropriateness) (35).

This formative work will be conducted to guide refinement and future testing of *Hoosier Sport* in a clinical trial.

Methods and analysis

The following subsections describe the conceptual framework and each of the three phases of this study. Aim 1 is to conduct a community-based participatory research (CBPR) needs assessment with middle school students, parents, and teachers/administrators to identify perceptions, attributes, barriers, and facilitators of PA that are responsive to the community context and preferences. Aim 2 is to co-design with children and adults to develop a prototype multi-level PA intervention protocol called *Hoosier Sport*. Aim 3 is to assess *Hoosier Sport's* trial- and intervention-related feasibility indicators in a sample of 6th grade middle school students. The present study defines PA in line with the Centers for Disease Control and Prevention as any bodily movement that is produced by the contraction of skeletal muscle and that substantially increases energy expenditure (36). We selected 6th grade students as the target population to balance the desire to intervene early in life (10, 11) with selecting a group that was mature enough for more advanced intervention strategies than elementary school students and aligned well with our research team's behavioral expertise. Our overall hypothesis is that the three phases of the present study will lead to a feasible intervention protocol.

Conceptual framework

The conceptual foundation of this study is built on three complementary theoretical elements (i.e., theory, model, and framework): (1) Basic Psychological Needs mini-theory within Self-Determination Theory (SDT) (37); (2) the Biopsychosocial Model (38); and (3) the National Institute on Minority Health and Health Disparities (NIMHD) Research Framework (39). These three conceptual models were each used to guide the methodology development for each of the three aims. Basic psychological needs will help the research team predict and examine the factors that influence our outcomes; the Biopsychosocial Model will support the description and interpretation of our findings but not predict outcomes; and the NIMHD Research Framework will help us conceptualize multilevel factors involved in understanding and reducing health disparities in our low-socioeconomic rural setting (Figure 1).

The first theoretical element of the present study, basic psychological needs, posits that increasing autonomy, competence, and relatedness will increase child well-being (37, 40–42). Inclusion of the psychological needs mini-theory will help guide our prediction of exploratory pilot/feasibility study outcomes (37). Aim 1 will include the validated Basic Psychological Needs in Exercise Scale to assess psychological needs within the exercise/PA context (43–45). Aim 2 co-design sessions include open-ended discussion questions designed to probe autonomy, competence, and relatedness. For example, an open-ended question targeting autonomy for children and adults will be "what physical activities are most appealing to you (your child)?"

The second theoretical element of the present study, the Biopsychosocial Model, allows for recognition of the interconnectedness between biological, psychological, and social factors in shaping an individual's health and well-being (38). The Biopsychosocial Model informed our protocol development for our Aim 1 survey design, Aim 2 co-design guiding questions/themes, and the Aim 3 intervention evaluation plan. The Biopsychosocial Model will also help frame results within the larger biological, psychological, and social context. Specific examples of integrating the Biopsychosocial Model into the present study include designing and evaluating: (1) exploratory biological/physical outcomes (e.g., physical activity levels, blood pressure), (2) psychological components (e.g., psychometric scale evaluating autonomy, competence, and relatedness in PA context), and (3) social support strategies for PA (e.g., peer student and/or family support).

Lastly, the study also aligns with the NIMHD Research Framework that provides a system for targeting multiple levels of influence (e.g., individual, interpersonal, and community) (39). The PA-related barriers facing rural communities are complex and exist at multiple levels of influence. Utilizing the NIMHD Research Framework will

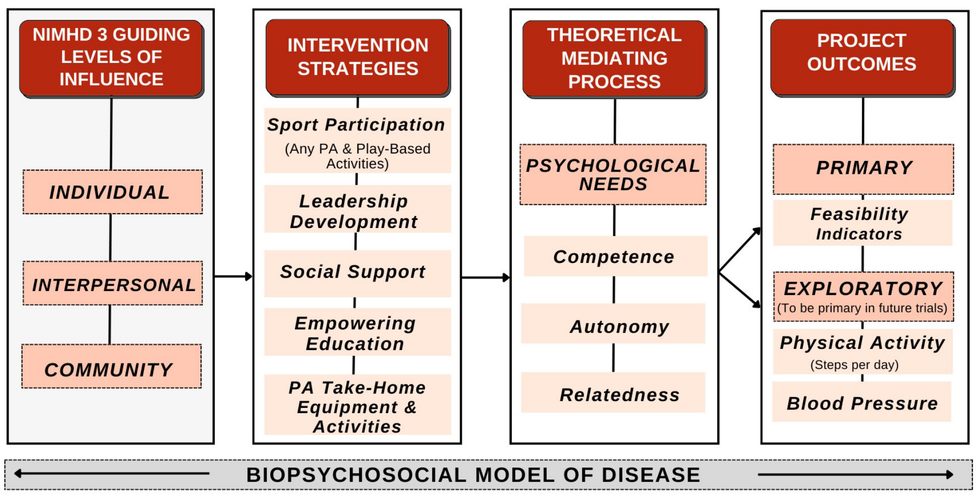

FIGURE 1
Conceptual framework.

assist Aim 3 assessment of progress, gaps, and opportunities. The following sections describe each Aim.

> Aim 1 (Needs Assessment): Conduct a community-based participatory research (CBPR) needs assessment with middle school students, parents, and teachers/administrators to identify perceptions, attributes, barriers, and facilitators of PA that are responsive to the community context and preferences.

Design

The study's first phase is a CBPR needs assessment (NIH Stage 0) to identify the community's physical activity-related needs, goals, opportunities, and assets. Despite knowledge of PA-based needs from a population level, we need to develop specific understanding of how the needs manifest themselves in context at the level of detail needed to make intervention design decisions. To conduct the PA-related needs assessment, we will survey children, parents, and teachers/administrators using a multi-level survey design targeting individual, interpersonal, and community levels of influence. This CBPR needs assessment will serve as a starting point for examining the PA context (e.g., school, home, weekdays, weekends) in the current school partner and inform future CBPR needs assessments with additional school partners.

Setting and sample

We partnered with a rural Midwestern middle school with a population that is predominantly White and from low-SES backgrounds (the entire student body is eligible for free-and-reduced meals due to the school district's high poverty). Data collection will include a survey sample of $n = 40$ students, $n = 40$ parents, and $n = 15$ teachers/administrators (total $n = 95$). The proposed sample size was selected to be feasible while having a large enough sample to have approximately normal distributions in our outcomes based on the central limit theorem (46–48). Inclusion criteria for children: (1) enrolled in the middle school; (2) entering 6th or 7th grade in fall 2023 semester; (3) have a parent/guardian willing to provide consent to participate; (4) willing to participate in the survey (assent). Inclusion criteria for parents/guardians: (1) Parent/guardian of a student currently enrolled at the school in 6th or 7th grade; (2) willing to participate in the survey. Inclusion criteria for teachers/administrators: (1) currently employed by the school; (2) willing to participate in the survey. We will purposively sample to ensure a balanced representation of male and female participants and diverse physical activity interests, including those who do not participate in much PA.

Procedure

Child survey

After receiving consent from parents, we will obtain assent from children before they participate in the study to ensure children fully understand the assent document information, including the purpose of the study, study requirements, and potential risks or benefits. Parental consent will be collected remotely through an informed consent document distributed through Qualtrics survey software. Child assent and survey administration will be conducted through Qualtrics and occur in-person to increase compliance and understanding. The survey measures will include demographics, the Physical Activity Questionnaire for Children (PAQ-C) (49–52), Expanded Food and Nutrition Education Program (EFNEP) Food and Physical Activity Behaviors Questionnaire (53), Basic Psychological Needs in Exercise Scale (BPNES) (43, 44), and child-tailored/appropriate questions related to Policy-Systems-Environment (PSE) (54).

Parent/guardian survey (hereafter referred to as the adult survey)

For the adult survey, we will obtain consent and administer the survey remotely. Similar to the child survey, the adult surveys will include demographics, questions from the EFNEP Food and Physical Activity Behaviors Questionnaire (53), BPNES (43, 44), and select PSE questions from prior PA research (54). Both surveys will include pilot survey debriefing questions developed by survey methodologists from the Indiana University Center for Survey Research, encouraging participant feedback on survey methodology and assessing potential areas for improvement in future surveys. A more comprehensive understanding of the community's PA landscape can be achieved by conducting separate surveys for the adults and children. See the *Measures* section for additional details and see Supplementary files 1, 2 for the complete child and adult surveys, respectively.

Measures

Physical activity

The Physical Activity Questionnaire for Children (PAQ-C) will be used to assess self-reported physical activity behaviors in children (49, 52). The PAQ-C assesses PA during physical education class, recess, lunch, right after school, evening, weekends, and spare time. The PAQ-C consists of 10 items scored on a 5-point scale ranging from "*no*" activity being a 1 and "*7 times or more*" being a 5. In children, the PAQ-C has demonstrated good internal consistency, acceptable validity, and an adequate Cronbach's alpha coefficient of 0.72–0.88 (50, 51). For the adult survey, PA-related questions are being asked about programming and PA equipment they would like to see offered at the school.

Nutrition

Questions from the Expanded Food and Nutrition Education Program (EFNEP) Food and Physical Activity Behaviors Questionnaire will be used to assess dietary intake. Questions covered nutritional behaviors "*over the last 7 days*" and "*yesterday*." Of the original 30 questions on the questionnaire, the research team selected eight questions for children and 10 questions for adults to help ensure the survey will be feasible in terms of respondent burden. Response options allow participants to select how often they consume various food and drink options. The EFNEP began in 1969, serves all states and U.S. territories, and reaches 450,000 low-income youth and 200,000 low-income adults each year (53, 55). The EFNEP consistently shows more than 90% of adults and 80% of youth report improved nutritional practices (55, 56).

Psychological needs

Children and adults will rate the satisfaction of their psychological needs in exercise settings with the Basic Psychological Needs in Exercise Scale (BPNES). The BPNES measures psychological needs satisfaction in an exercise context based on autonomy, competence, and relatedness (43, 44, 57). The BPNES consists of 11 items with scores on a 5-point Likert scale ranging from "*I do not agree at all*" to "*I completely agree*." Four items assessed autonomy, four for competence, and three for relatedness (57). In adults, the BPNES has demonstrated adequate internal consistency with Cronbach's alpha coefficients of 0.84 for autonomy, 0.81 for competence, and 0.92 for relatedness, as well as acceptable discriminant and predictive validity (44). The scale scores are also largely unaffected by social desirability bias and have demonstrated stability over a 4-week period (44).

Policy-systems-environment

The adult survey will include questions addressing the PSE level of influence. Questions will assess adults' interest in PA, nutrition, positive behavioral programming, and perceptions of current school PA policies and interest in new school PA policies. PA environmental questions were informed by past research on perceived environmental variables that may influence PA (54). As PA behaviors exist within an array of settings and levels of influence, questions focus on gaining an understanding of PA behaviors in various settings such as homes, neighborhoods, PA facilities, and parks. See Supplementary files 1, 2 for complete versions of the adult and child surveys, respectively.

Data analysis

For descriptive statistics, we will compute frequencies and percentages for each categorical variable and calculate means and standard deviations for continuous variables. Quantitative analyses will be performed in R 4.0.3 (58). In collaboration with the Indiana University Center for Survey Research, the research team will review qualitative responses to identify general patterns and main themes. Results of the qualitative analysis will be reviewed by the research team and considered for incorporation into future school surveys. Results from Aim 1 will be used to inform Aim 2 co-design session topics and to guide open-ended question design.

> Aim 2 (Participatory Co-design): Co-design with children and adults to develop a prototype multi-level PA intervention protocol, called *Hoosier Sport*.

Design

The study's second phase is to co-design a prototype of the *Hoosier Sport* intervention protocol (NIH Stage 1A) to understand the unique PA-based needs of youth from primarily low-SES rural backgrounds by targeting individual, interpersonal, and school levels of influence. We will conduct a 5-step participatory co-design protocol that includes the following 5 session sequence: (1) problem identification; (2) solution generation; (3) solution evaluation; (4) operationalization; and (5) prototype evaluation. The participatory co-design process in our study context is designed to empower children and adults (i.e., parents/teachers/administrators) to provide input into the prototype *Hoosier Sport* PA intervention protocol. Based on preliminary school stakeholder input and previous PA intervention literature (59), the five preliminary intervention topics we anticipate designing are: (1) sport/PA participation (60); (2) leadership development (61); (3) social support for PA (62); (4) empowering education (63); (5) PA take-home equipment & activities (64). School administrators have requested that the *Hoosier Sport* intervention be designed to be conducted during physical education class. We will recruit two separate co-design teams, with one group consisting of $n = 5$ adults and one group of $n = 5$ children. Completion of the participatory co-design sessions will result in a testable prototype intervention protocol to be deployed in Aim 3. The intervention title *Hoosier Sport* was selected because *Hoosier* is a term of pride among many Indiana residents and integrating *sport* into the intervention is part of the "hook" to encourage children to participate in programming (Figure 2).

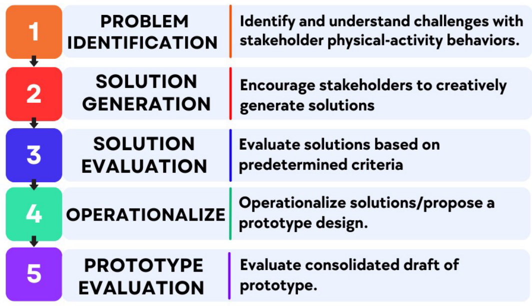

FIGURE 2
Participatory co-design sessions.

Setting and sample

We will assemble two groups of co-designers, including one group of adults (parents, teachers/administrators) and one group of children, each with $n = 5$ individuals, which aligns with the standard range of participants needed for a participatory design (65). The odd number of participants allows for a majority vote to break ties between design alternatives within the group. Adults and children will be recruited via parent/guardian meetings and weekly newsletters distributed by school administrators. Due to the limited sample size and time commitment required for the co-design, we will use convenience sampling but will attempt to enroll approximately 50% female and 50% male and include participants who regularly participate in PA and those that do not. To be eligible for inclusion, children must be: (1) enrolled in the middle school; (2) entering 6th grade; (3) have parent/guardian consent to participate; (4) willing to participate in all 5 co-design sessions. To be eligible for inclusion, adults must be: (1) a parent/guardian of a student currently enrolled at the school in 6th or 7th grade or a teacher/administrator employed at the school; and (2) willing to participate in all 5 co-design sessions.

Procedure

The two design teams will complete a series of five co-design sessions across 3 months, with approximately 2-weeks between sessions. The child group will begin the process, and in parallel, the adult group will have alternating sessions between the child sessions (e.g., child session, adult session, child session, etc.). The adult group will co-design with the study team to review and revise the child-developed prototype while striving to maintain as many child-derived components as possible. This parallel and alternating co-design process will allow children to have a sense of autonomy in the process to include important concepts to them (e.g., fun, enjoyment) while allowing the adults to refine the intervention protocol to increase the likelihood of feasibility and practicality.

The sessions will be facilitated by an experienced research team member with training in facilitating group coaching and discussions. The research team will develop open-ended questions to guide each session that are aligned with each session's goals. For instance, in session 1, the design session agenda focuses on understanding challenges with children's PA-related behaviors. The design process is an iterative process where we begin by coming to a common understanding of the challenges with PA-related behaviors, then collaboratively develop numerous divergent solution ideas for (1) sport/PA participation; (2) leadership development; (3) social support for PA; (4) empowering education; and (5) PA take-home equipment & activities. Then, we progressively move toward a detailed and high-fidelity intervention protocol. During each session, the facilitator will encourage discussion, interpretation, and respectful debate among design team members while ensuring progress. PA-based needs, goals, opportunities, and assets identified in Aim 1 will be integrated throughout the design session discussions by providing survey results to co-designers during session agenda development and finalization.

The research team will collect observation notes and audio recordings to analyze the design teams' work as it is produced. These records will capture the co-design sessions, allowing for a detailed examination of the participants' conversations, thought processes, and collaborative efforts in generating and grouping intervention design solutions. During the co-design sessions, the facilitators will help guide the participants' conversation and thought process in generating and collaborating on intervention protocol design solutions. Each session will last for 60–90 min. Sessions will be audio recorded, and observation notes will analyze the design team's work. In session 5, the teams will evaluate the prototype *Hoosier Sport* protocol feasibility, acceptability, and appropriateness on the Feasibility of Intervention Measure (FIM), Acceptability of Intervention Measure (AIM), and Intervention Appropriateness Measure (IAM) (66), each adapted to our study context and described in subsequent sections.

Measures

The FIM, AIM, and IAM are four-item measures of implementation outcomes that are considered indicators of implementation success (66, 67). These measures can be used to prospectively determine the extent to which stakeholders believe *Hoosier Sport* will be feasible, acceptable, and appropriate (66, 67). The FIM, AIM, and IAM demonstrated adequate content validity, discriminant content validity, reliability, structural validity, structural invariance, and responsiveness to change (66).

Data analysis

During the approximately 2-week periods between sessions, the research team will analyze the audio recording and observation notes of the sessions using the Rapid Identification of Themes from Audio-recordings (RITA) method (68). The RITA method allows for reliably coding and analyzing qualitative data without time-consuming transcription (68). We will apply descriptive statistics to analyze summative quantitative data from the FIM, AIM, and IAM used in session 5. At the conclusion of the analysis from session 5, we will have a detailed draft of an intervention protocol to pilot/feasibility test in Aim 3.

> Aim 3 (Pilot Testing): Assess *Hoosier Sport's* trial- and intervention-related feasibility indicators.

Design

The third phase of the study is to assess intervention feasibility by testing the *Hoosier Sport* intervention with 6th grade students from one rural middle school twice per week for 8-weeks during physical education class (NIH Stage 1B). We will assess recommended trial- and intervention-related feasibility measures for pilot/feasibility studies (35). As exploratory outcomes, we will also assess PA levels (steps per day using Axivity AX3 accelerometers (69, 70)), blood pressure, and psychological needs using the BPNES (57). After the first pilot/feasibility test of *Hoosier Sport*, we will adopt a "traffic light" system of *a priori* progression criteria for feasibility outcomes (e.g., recruitment, retention) to guide intervention revisions and retesting *Hoosier Sport* the following semester. *Hoosier Sport* college student mentors will work alongside the research team to deliver the intervention (additional details in the next section). The college student mentors will be upper division undergraduate and graduate students enrolled in public health majors. To enhance intervention fidelity and as a part of the academic course, college student mentors will participate in 4-weeks of training classes prior to being deployed to the middle school, where they will receive course credit for hours spent delivering the intervention. Hypotheses for Aim 3 include the following: (3a) achieve full enrollment ($n = 20$); (3b) 85% retention at the end of the intervention; (3c) 75% attendance rate; (3d) mean score of ≥16 (a "good" score) on the FIM; (3e) mean score of ≥16 (a "good" score) on the AIM; (3f) mean scores of ≥16 (a "good" score) on the IAM; (3 g) 80% fidelity with intervention procedures.

College student mentor implementation strategy for pilot/feasibility testing

Hoosier Sport college student mentors will be recruited through a service-learning course developed by the research team, titled "*Introduction to Youth Sport Development*," and housed within the Department of Kinesiology at the Indiana University School of Public Health-Bloomington. This course includes topics such as effective mentoring techniques, communication strategies, and administering safety protocols. College student mentor models have been used to engage youth in PA, attain knowledge, and apply healthy behaviors, transferrable life skills, and academic enrichment (29–31). College students can provide personal support and guidance to overcoming environmental, social, and psychological barriers, leading to improved adherence to PA and increased peer resources to sustain PA (71, 72). Serving as role models, college students provide a dual intervention effect by gaining professional and practical experience while facilitating an environment that promotes positive youth development. Additionally, the constant influx of college students into the university has the potential to fulfill the delivery of PA-based interventions while being cost effective, potentially sustainable, and scalable (29–31).

Setting and sample

We will recruit $n = 20$ 6th grade students to participate in the pilot study. A sample size of at least 12 is considered adequate for intervention feasibility studies, but we will recruit more to account for potential dropout (48). The sample size of 20 was also selected within our resource limitations, initial staffing availability, and based on feasible recruitment estimates. Similar to Aim 2, we will use convenience sampling but strive for diversity of biological sex and physical activity participation. We will attempt to enroll approximately 50% female and 50% male participants and look to include participants who regularly participate in physical activity and those that do not. Inclusion criteria: (1) currently enrolled in 6th grade at the school; (2) have parental consent to participate; (3) agree to study participation (assent); (4) plan to attend all school days during the intervention period; (5) be available for baseline and post-intervention data collection.

Procedure

The research team will introduce the initial study recruitment information via email and newsletter. A Qualtrics survey link with additional study information will be provided to those adults who express interest in having their child(ren) join the study. The research team will confirm eligibility via email/phone. Consent from parents to have their child(ren) join will populate a list of children who are eligible to be approached for assent. The research team will then host a study information and recruitment session for children at the school site. At this session, child participants will be provided with study information and a Qualtrics-based assent survey in appropriate and understandable terms for 6th grade students. Children will be provided with an opportunity to ask questions and informed that they can discontinue participation at any time during the study.

Enrolled participants will be mailed their initialized Axivity AX3 accelerometer (69, 70) and an instruction sheet. Participants' PA will be collected using Axivity AX3 accelerometers for the 14 days at baseline (7 days pre-intervention and the first 7 days of the intervention) and another 14 days at the end of the intervention (the last 7 days of the intervention and 7 days immediately post-intervention). Participants who successfully return their accelerometer will be provided with their choice of sporting equipment (options: over-the-door basketball hoop, kick ball, or soccer ball). Blood pressure (BP) will be measured at the pre- and post-time points using an automatic Omron HEM 907XL blood pressure monitor (73) following American Heart Association protocols (e.g., three measurements 1 min apart, no caffeine or exercise within 30 min of assessment, and measuring at the same time each day). Participation will take place at their school during 2 days per week for 8-weeks. The pre- and post-data collection will take place during the lunch periods. The research team will schedule additional data collection for each time point to account for participants who miss the data collection event.

Measures

In line with recently published NIH-funded pilot/feasibility research (35), we will assess two types of feasibility measures: (1) trial- and (2) intervention-related feasibility indicators. For trial-related feasibility indicators, we will measure recruitment capability and retention. For intervention-related feasibility indicators, we will measure treatment fidelity (i.e., assessing whether intervention components are delivered accurately, consistently, and with quality), acceptability, attendance, compliance (e.g., accelerometer usage), cost, and appropriateness (i.e., evaluating setting, cultural norms, or specific requirements). Measures will be collected at two time points (mid- and post-intervention) and recorded via Qualtrics using mobile devices.

Recruitment capability

Recruitment capability will be determined based on (1) the number of children successfully enrolled into *Hoosier Sport* (consent from parent/guardian and assent from child) and (2) the number of college students successfully enrolled into the "*Introduction to Sport-Based Youth Development*" course.

Retention

Retention will be measured based on (1) the number of children who participate in the post-intervention data collection event and (2) the number of college students who successfully completed their service-learning hours at the middle school. A make-up post-intervention event will be scheduled for child participants who miss the post-intervention data collection event.

Treatment fidelity

Three groups of stakeholders (children, college students, and the research team) will assess treatment fidelity using self-report measures at two time points (mid- and post-intervention) to explore whether the intervention was delivered accurately, consistently, and with quality. Assessment of fidelity will be guided by three questions from past school-based PA implementation research (74): (1) *to what extent was the intervention delivered as planned?* (2) *in what ways, if any, did the college student mentors adjust the program?* (3) *what were the reasons for any adjustments?*

Acceptability, appropriateness, feasibility

Children who participate in *Hoosier Sport* will rate the feasibility, acceptability, and appropriateness of the intervention using the FIM, AIM, and IAM, respectively (each described in Aim 2).

Compliance

Accelerometer compliance will be assessed for each of the two PA data collections by determining the number of days accelerometers collected data compared to the target.

Cost

Cost of the intervention will be monitored throughout the study period and determined in comparison to the prospective study budget.

Data analysis

Quantitative analysis of survey measures

For analysis, we will check the completeness and distributions of all variables. Normalizing transformations will be applied as needed for non-normally distributed variables. Internal consistencies of scaled scores are assessed with Cronbach's alpha. Analyses of primary outcomes (i.e., feasibility indicators) and exploratory outcomes (i.e., PA, BP, BPNES) will be descriptive with means and standard deviations (SD).

Discussion

Health interventions incorporating evidence and engaging key community members in the planning process generate more effective outcomes (34, 75, 76). As such, the World Health Organization has recognized human-centered design as a key strategy to address various health challenges and promote equitable healthcare solutions (77). Prior research has demonstrated that participatory co-design is an effective strategy for designing innovative interventions with unique populations (e.g., rural low-SES communities) (78, 79). Our human-centered protocol provides a foundation to yield a feasible intervention in accordance with Stages 0, 1A, and 1B of the NIH Stage Model for Behavioral Intervention Development. This protocol can be broadly applied by researchers who are developing and piloting PA-based interventions in schools.

The published participatory co-design approach employed by the present study has been shown to lead to effective intervention development (78, 80–82). Co-designed interventions are likely to be more engaging, satisfying, and useful to participants (83), and while co-design has been done in under-resourced PA contexts with children (84, 85), the field remains in its relative infancy. Our planned methods will consider the unique PA-related needs, goals, opportunities, and assets of rural children, parents, and teachers/administrators and are likely to lead to PA-based intervention that is uniquely responsive to the target middle school community. By including both trial- and intervention-related feasibility measures, the proposed protocol aligns with current literature on improving reporting of feasibility measures in pilot/feasibility studies (35) and may be more likely to lead to effectively informing future revisions to Stage 1B or subsequent Stage 2/3 efficacy clinical trials. A recent scoping review of behavioral pilot/feasibility studies found that *trial-related* feasibility was reported in many studies (i.e., recruitment and/or retention); however, important *intervention-related* feasibility indicators were not widely reported (i.e., fidelity, acceptability, attendance, compliance, cost, appropriateness) (35). Additionally, the implementation strategy utilizing a pipeline of college student mentors presents a potentially promising approach to addressing an often expressed weakness in CBPR research – frustration with programs, particularly because the programs/interventions are short-term, provide little long-term benefit, and do not provide the needed infrastructure to sustain efforts (32).

In sum, successfully completing the aims will lead to a feasible *Hoosier Sport* intervention poised for refinement or expansion in a Stage 2/3 efficacy clinical trial, powered to test changes in physical activity, with secondary outcomes of other cardiovascular disease risk factors (e.g., blood pressure, high-sensitivity C-reactive protein). Findings will also help inform other academic institutions practicing CBPR and aiming to partner with local schools. Ultimately, *Hoosier Sport* should be feasible and adaptable to a range of school contexts that could benefit immediately from partnerships with major academic institutions with the college student service-learning workforce to deliver programming at scale.

Ethics statement

The studies involving human participants were reviewed and approved by Indiana University Institutional Review Board. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

SG and KK designed the initial study protocol and drafted the manuscript. SG, PF, VM, CC, KP, TE, AG, JE, NW, and KK contributed to the conceptualization and design of the study protocol. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1243560/full#supplementary-material

References

1. Tsao CW, Aday AW, Almarzooq ZI, Alonso A, Beaton AZ, Bittencourt MS, et al. Heart disease and stroke statistics—2022 update: a report from the American Heart Association. *Circulation*. (2022) 145:e153–639. doi: 10.1161/CIR.0000000000001052

2. World Health Organization. Data from: Global Health estimates 2020: deaths by cause, age, sex, by country and by region, 2000-2019. (2020).

3. National Institutes of Health. Risk of developing heart failure much higher in rural areas vs urban. (2023). Available at: https://www.nih.gov/news-events/news-releases/risk-developing-heart-failure-much-higher-rural-areas-vs-urban

4. Cross SH, Mehra MR, Bhatt DL, O'Donnell CJ, Califf RM, Warraich HJ, et al. Rural-urban differences in cardiovascular mortality in the US, 1999-2017. *JAMA*. (2020) 323:1852–4. doi: 10.1001/jama.2020.2047

5. Scicluna N, Hamer M, Blodgett JM. Associations between adolescent sport and exercise participation and device-assessed physical activity in adulthood: evidence from the 1970 British cohort study. *J Phys Act Health*. (2023) 1(aop):1-11:1–11. doi: 10.1123/jpah.2022-0605

6. Jones RA, Hinkley T, Okely AD, Salmon J. Tracking physical activity and sedentary behavior in childhood: a systematic review. *Am J Prev Med*. (2013) 44:651–8. doi: 10.1016/j.amepre.2013.03.001

7. Berra K, Rippe J, Manson JE. Making physical activity counseling a priority in clinical practice: the time for action is now. *JAMA*. (2015) 314:2617–8. doi: 10.1001/jama.2015.16244

8. Office of Disease Prevention and Health Promotion. Healthy People 2030. (n.d.). Available at: https://health.gov/healthypeople/objectives-and-data/browse-objectives/diabetes.

9. Sfm C, Van Cauwenberg J, Maenhout L, Cardon G, Lambert E, Van Dyck D. Inequality in physical activity, global trends by income inequality and gender in adults. *Int J Behav Nutr Phys Act*. (2020) 17:1–8. doi: 10.1186/s12966-020-01039-x

10. Hong YM. Atherosclerotic cardiovascular disease beginning in childhood. *Kor Circul J*. (2010) 40:1–9. doi: 10.4070/kcj.2010.40.1.1

11. Raitakari O, Pahkala K, Magnussen CG. Prevention of atherosclerosis from childhood. *Nat Rev Cardiol*. (2022) 19:543–54. doi: 10.1038/s41569-021-00647-9

12. Carson V, Hunter S, Kuzik N, Wiebe SA, Spence JC, Friedman A, et al. Systematic review of physical activity and cognitive development in early childhood. *J Sci Med Sport*. (2016) 19:573–8. doi: 10.1016/j.jsams.2015.07.011

13. Craggs C, Corder K, van Sluijs EM, Griffin SJ. Determinants of change in physical activity in children and adolescents: a systematic review. *Am J Prev Med*. (2011) 40:645–58. doi: 10.1016/j.amepre.2011.02.025

14. Umstattd Meyer MR, Moore JB, Abildso C, Edwards MB, Gamble A, Baskin ML. Rural active living: a call to action. *J Public Health Manag Pract*. (2016) 22:E11–20. doi: 10.1097/phh.0000000000000333

15. Harrington RA, Califf RM, Balamurugan A, Brown N, Benjamin RM, Braund WE, et al. Call to action: rural health: a presidential advisory from the American Heart Association and American Stroke Association. *Circulation*. (2020) 141:e615–44. doi: 10.1161/CIR.0000000000000753

16. Tandon PS, Kroshus E, Olsen K, Garrett K, Qu P, McCleery J. Socioeconomic inequities in youth participation in physical activity and sports. *Int J Environ Res Public Health*. (2021) 18:6946. doi: 10.3390/ijerph18136946

17. Hill JL, Waters CN, Kolivras KN, Estabrooks PA, Zoellner JM. Do the features, amenities, and quality of physical activity resources differ between city and county areas of a large rural region? *Fam Commun Health*. (2016) 39:273–82. doi: 10.1097/fch.0000000000000119

18. National Institutes of Health. NIMHD exploratory/developmental research Grant program (R21 - clinical trial optional). (2023). Available at: https://grants.nih.gov/grants/guide/pa-files/PAR-23-111.html.

19. Agurs-Collins T, Persky S, Paskett ED, Barkin SL, Meissner HI, Nansel TR, et al. Designing and assessing multilevel interventions to improve minority health and reduce health disparities. *Am J Public Health*. (2019) 109:S86–93. doi: 10.2105/AJPH.2018.304730

20. Brown AF, Ma GX, Miranda J, Eng E, Castille D, Brockie T, et al. Structural interventions to reduce and eliminate health disparities. *Am J Public Health*. (2019) 109:S72–8. doi: 10.2105/AJPH.2018.304844

21. Stevens J, Pratt C, Boyington J, Nelson C, Truesdale KP, Ward DS, et al. Multilevel interventions targeting obesity: research recommendations for vulnerable populations. *Am J Prev Med*. (2017) 52:115–24. doi: 10.1016/j.amepre.2016.09.011

22. Onken LS, Carroll KM, Shoham V, Cuthbert BN, Riddle M. Reenvisioning clinical science: unifying the discipline to improve the public health. *Clin Psychol Sci*. (2014) 2:22–34. doi: 10.1177/2167702613497932

23. Sellars E, Pavarini G, Michelson D, Creswell C, Fazel M. Young people's advisory groups in health research: scoping review and mapping of practices. *Arch Dis Child*. (2021) 106:698–704. doi: 10.1136/archdischild-2020-320452

24. Dennehy R, Cronin M, Arensman E. Involving young people in cyberbullying research: the implementation and evaluation of a rights-based approach. *Health Expect*. (2019) 22:54–64. doi: 10.1111/hex.12830

25. Larsson I, Staland-Nyman C, Svedberg P, Nygren JM, Carlsson IM. Children and young people's participation in developing interventions in health and well-being: a scoping review. *BMC Health Serv Res*. (2018) 18:507. doi: 10.1186/s12913-018-3219-2

26. Black MM, Hager ER, Le K, Anliker J, Arteaga SS, Diclemente C, et al. Challenge! Health promotion/obesity prevention mentorship model among urban, black adolescents. *Pediatrics*. (2010) 126:280–8. doi: 10.1542/peds.2009-1832

27. Petosa R, Smith LH. Peer mentoring for health behavior change: a systematic review. *Am J Health Educ*. (2014) 45:351–7. doi: 10.1080/19325037.2014.945670

28. Petosa RL, Smith L. Effective recruitment of schools for randomized clinical trials: role of school nurses. *J Sch Nurs*. (2018) 34:430–4. doi: 10.1177/1059840517717592

29. DuBois DL, Karcher MJ. Youth mentoring in contemporary perspective In: . *Handbook of Youth Mentoring*, vol. 2 (2014). 3–15.

30. Karcher M. Increases in academic connectedness and self-esteem among high school students who serve as cross-age peer mentors. *Prof Sch Couns*. (2009) 12:2156759X0901200. doi: 10.1177/2156759X0901200403

31. Smith LH. Cross-age peer mentoring approach to impact the health outcomes of children and families. *J Spec Pediatr Nurs*. (2011) 16:220–5. doi: 10.1111/j.1744-6155.2011.00286.x

32. Smith LH, Petosa RL. Effective practices to improve recruitment, retention, and partnerships in school-based studies. *J Pediatr Health Care*. (2016) 30:495–8. doi: 10.1016/j.pedhc.2016.05.004

33. Harvard Business School. What is human-centered design? (2020). Available at: https://online.hbs.edu/blog/post/what-is-human-centered-design (Accessed May 19, 2023).

34. Matheson GO, Pacione C, Shultz RK, Klugl M. Leveraging human-centered design in chronic disease prevention. *Am J Prev Med*. (2015) 48:472–9. doi: 10.1016/j.amepre.2014.10.014

35. Pfledderer CD, von Klinggraeff L, Burkart S, Wolfenden L, Ioannidis JPA, Beets MW. Feasibility indicators in obesity-related behavioral intervention preliminary studies: a historical scoping review. *Pilot Feasibility Stud*. (2023) 9:46. doi: 10.1186/s40814-023-01270-w

36. Centers for Disease Control and Prevention. National Health Interview Survey Glossary. (2017). Available at: https://www.cdc.gov/nchs/nhis/physical_activity/pa_glossary.htm#:~:text=Physical%20activity%3A%20Any%20bodily%20movement,that%20substantially%20increases%20energy%20expenditure.

37. Deci EL, Ryan RM. The general causality orientations scale: self-determination in personality. *J Res Pers*. (1985) 19:109–34. doi: 10.1016/0092-6566(85)90023-6

38. Engel GL. The need for a new medical model: a challenge for biomedicine. *Science*. (1977) 196:129–36. doi: 10.1126/science.847460

39. National Institute on Minority Health and Health Disparities. NIMHD research framework. (2018). Available at: https://www.nimhd.nih.gov/about/overview/research-framework/nimhd-framework.html

40. Deci EL, Ryan RM. *Intrinsic motivation and self-determination in human behavior*. New York, NY: Springer Science & Business Media (2013).

41. Sebire SJ, Jago R, Fox KR, Edwards MJ, Thompson JL. Testing a self-determination theory model of children's physical activity motivation: a cross-sectional study. *Int J Behav Nutr Phys Act*. (2013) 10:111. doi: 10.1186/1479-5868-10-111

42. Sharma M, Nahar VK. Promoting physical activity in upper elementary children using multi-theory model (MTM) of health behavior change. *J Prev Med Hyg*. (2018) 59:E267–76. doi: 10.15167/2421-4248/jpmh2018.59.4.847

43. Costa LCA, Maroco J, Vieira LF. Validation of the basic psychological needs in exercise scale (BPNES). *J Phys Educ*. (2018) 28:28. doi: 10.4025/jphyseduc.v28i1.2847

44. Vlachopoulos SP, Michailidou S. Development and initial validation of a measure of autonomy, competence, and relatedness in exercise: the basic psychological needs in exercise scale. *Meas Phys Educ Exerc Sci*. (2006) 10:179–201. doi: 10.1207/s15327841mpee1003_4

45. van Aart I, Hartman E, Elferink-Gemser M, Mombarg R, Visscher C. Relations among basic psychological needs, PE-motivation and fundamental movement skills in 9–12-year-old boys and girls in physical education. *Phys Educ Sport Pedagog*. (2017) 22:15–34. doi: 10.1080/17408989.2015.1112776

46. Ghasemi A, Zahediasl S. Normality tests for statistical analysis: a guide for non-statisticians. *Int J Endocrinol Metab*. (2012) 10:486–9. doi: 10.5812/ijem.3505

47. Pallant J. *SPSS survival manual: A step by step guide to data analysis using IBM SPSS*. London, England: McGraw-hill education (2020).

48. Julious SA. Sample size of 12 per group rule of thumb for a pilot study. *Pharm Stat J Appl Stat Pharm Ind*. (2005) 4:287–91. doi: 10.1002/pst.185

49. Crocker PR, Bailey DA, Faulkner RA, Kowalski KC, McGrath R. Measuring general levels of physical activity: preliminary evidence for the physical activity questionnaire for older children. *Med Sci Sports Exerc*. (1997) 29:1344–9. doi: 10.1097/00005768-199710000-00011

50. Janz KF, Lutuchy EM, Wenthe P, Levy SM. Measuring activity in children and adolescents using self-report: PAQ-C and PAQ-A. *Med Sci Sports Exerc*. (2008) 40:767–72. doi: 10.1249/MSS.0b013e3181620ed1

51. Marasso D, Lupo C, Collura S, Rainoldi A, Brustio PR. Subjective versus objective measure of physical activity: a systematic review and meta-analysis of the convergent validity of the physical activity questionnaire for children (PAQ-C). *Int J Environ Res Public Health*. (2021) 18:3413. doi: 10.3390/ijerph18073413

52. Kowalski KC, Crocker PR, Donen RM. The physical activity questionnaire for older children (PAQ-C) and adolescents (PAQ-A) manual. *Coll Kinesiol Univ Saskatchewan*. (2004) 87:1–38.

53. Murray EK, Auld G, Baker SS, Barale K, Franck K, Khan T, et al. Methodology for developing a new EFNEP food and physical activity behaviors questionnaire. *J Nutr Educ Behav*. (2017) 49:777–783.e1. doi: 10.1016/j.jneb.2017.05.341

54. Sallis JF, Johnson MF, Calfas KJ, Caparosa S, Nichols JF. Assessing perceived physical environmental variables that may influence physical activity. *Res Q Exerc Sport*. (1997) 68:345–51. doi: 10.1080/02701367.1997.10608015

55. United states department of agriculture national institute of food and agriculture. About EFNEP. (2023). Available at: https://www.nifa.usda.gov/grants/programs/capacity-grants/efnep/about-efnep

56. United States Department of Agriculture National Institute of Food and Agriculture. Expanded Food and Nutrition Education Program (EFNEP) FY2022 National Reports. (2023). Available at: https://www.webneers.net/national_reports/2022.html.

57. Vlachopoulos SP, Ntoumanis N, Smith AL. The basic psychological needs in exercise scale: translation and evidence for cross-cultural validity. *Int J Sport Exerc Psychol*. (2010) 8:394–412. doi: 10.1080/1612197X.2010.9671960

58. R Core Team. *R: A language and environment for statistical computing R foundation for statistical computing*. Vienna: (2020) Available at: https://wwwR-projectorg/.

59. Heath GW, Parra DC, Sarmiento OL, Andersen LB, Owen N, Goenka S, et al. Evidence-based intervention in physical activity: lessons from around the world. *Lancet*. (2012) 380:272–81. doi: 10.1016/S0140-6736(12)60816-2

60. Harrison PA, Narayan G. Differences in behavior, psychological factors, and environmental factors associated with participation in school sports and other activities in adolescence. *J Sch Health*. (2003) 73:113–20. doi: 10.1111/j.1746-1561.2003.tb03585.x

61. Barr-Anderson DJ, Laska MN, Veblen-Mortenson S, Farbakhsh K, Dudovitz B, Story M. A school-based, peer leadership physical activity intervention for 6th graders: feasibility and results of a pilot study. *J Phys Act Health*. (2012) 9:492–9. doi: 10.1123/jpah.9.4.492

62. Conroy DE, Coatsworth JD. Assessing autonomy-supportive coaching strategies in youth sport. *Psychol Sport Exerc*. (2007) 8:671–84. doi: 10.1016/j.psychsport.2006.12.001

63. Ntoumanis N. A prospective study of participation in optional school physical education using a self-determination theory framework. *J Educ Psychol*. (2005) 97:444–53. doi: 10.1037/0022-0663.97.3.444

64. Yu H, Kulinna PH, Mulhearn SC. The effectiveness of equipment provisions on rural middle school students' physical activity during lunch recess. *J Phys Act Health*. (2021) 18:287–95. doi: 10.1123/jpah.2019-0661

65. Simonsen J, Robertson T. *Routledge international handbook of participatory design*, vol. *711*. New York: Routledge (2013).

66. Weiner BJ, Lewis CC, Stanick C, Powell BJ, Dorsey CN, Clary AS, et al. Psychometric assessment of three newly developed implementation outcome measures. *Implement Sci*. (2017) 12:1–12. doi: 10.1186/s13012-017-0635-3

67. Proctor E, Silmere H, Raghavan R, Hovmand P, Aarons G, Bunger A, et al. Outcomes for implementation research: conceptual distinctions, measurement challenges, and research agenda. *Admin Pol Ment Health*. (2011) 38:65–76. doi: 10.1007/s10488-010-0319-7

68. Neal JW, Neal ZP, VanDyke E, Kornbluh M. Expediting the analysis of qualitative data in evaluation: a procedure for the rapid identification of themes from audio recordings (RITA). *Am J Eval*. (2015) 36:118–32. doi: 10.1177/1098214014536601

69. Hedayatrad L, Stewart T, Duncan S. Concurrent validity of ActiGraph GT3X+ and Axivity AX3 accelerometers for estimating physical activity and sedentary behavior. *J Meas Phys Behav*. (2020) 4:1–8. doi: 10.1123/jmpb.2019-0075

70. Narayanan A, Stewart T, Mackay L. A dual-accelerometer system for detecting human movement in a free-living environment. *Med Sci Sports Exerc*. (2020) 52:252–8. doi: 10.1249/MSS.0000000000002107

71. Leenstra T, Keeler L, Arthur-Cameselle J, Russell K. The peer mentor experience in a physical activity intervention for mental health. *Mentor Tutor Partnership Learn*. (2019) 27:68–87. doi: 10.1080/13611267.2019.1583410

72. Smith LH, Petosa RL, Shoben A. Peer mentor versus teacher delivery of a physical activity program on the effects of BMI and daily activity: protocol of a school-based group randomized controlled trial in Appalachia. *BMC Public Health*. (2018) 18:1–14. doi: 10.1186/s12889-018-5537-z

73. Ostchega Y, Nwankwo T, Sorlie PD, Wolz M, Zipf G. Assessing the validity of the Omron HEM-907XL oscillometric blood pressure measurement device in a national survey environment. *J Clin Hypertens*. (2010) 12:22–8. doi: 10.1111/j.1751-7176.2009.00199.x

74. Campbell R, Rawlins E, Wells S, Kipping RR, Chittleborough CR, Peters TJ, et al. Intervention fidelity in a school-based diet and physical activity intervention in the UK: active for life year 5. *Int J Behav Nutr Phys Act*. (2015) 12:1–14. doi: 10.1186/s12966-015-0300-7

75. Fernandez ME, Ruiter RA, Markham CM, Kok G. Intervention mapping: theory- and evidence-based health promotion program planning: perspective and examples. *Front Public Health*. (2019) 7:209. doi: 10.3389/fpubh.2019.00209

76. McEachan RR, Lawton RJ, Jackson C, Conner M, Lunt J. Evidence, theory and context: using intervention mapping to develop a worksite physical activity intervention. *BMC Public Health*. (2008) 8:326. doi: 10.1186/1471-2458-8-326

77. World Health Organization. Human-centered design for tailoring immunization programmes. (2022). Available at: https://apps.who.int/iris/bitstream/handle/10665/354457/9789240049130-eng.pdf?sequence=1 (Accessed May 17, 2023).

78. Werner NE, Campbell NL, Boustani M, Ganci A, Holden RJ. Helping the helpers – a research protocol for user-centered technology to aid caregiver management of medications for people with Alzheimer's disease and related dementias. *Res Soc Adm Pharm*. (2022) 18:3680–6. doi: 10.1016/j.sapharm.2022.03.014

79. Beck AM, Eyler AA, Aaron Hipp J, King AC, Tabak RG, Yan Y, et al. A multilevel approach for promoting physical activity in rural communities: a cluster randomized controlled trial. *BMC Public Health*. (2019) 19:126. doi: 10.1186/s12889-019-6443-8

80. Chui MA, Berbakov ME, Gilson AM, Morris AO, Stone JA. Effectiveness and sustainment of a tailored over-the-counter medication safety intervention in community pharmacies: a randomized controlled trial. *Res Soc Adm Pharm*. (2022) 18:3953–63. doi: 10.1016/j.sapharm.2022.06.008

81. Holden RJ, Boustani MA. "Design and usability methods: Agile innovation and evaluation of interventions for patients and families," in *The Patient Factor*. Boca Raton, Florida: CRC Press (2021). 179–95.

82. Toscos T, Daley C, Wagner S, Coupe A, Ahmed R, Holden RJ, et al. Patient responses to daily cardiac resynchronization therapy device data: a pilot trial assessing a novel patient-centered digital dashboard in everyday life. *Cardiovasc Digit Health J*. (2020) 1:97–106. doi: 10.1016/j.cvdhj.2020.09.003

83. Thabrew H, Fleming T, Hetrick S, Merry S. Co-design of eHealth interventions with children and young people. *Front Psych*. (2018) 9:481. doi: 10.3389/fpsyt.2018.00481

84. Hardt J, Canfell OJ, Walker JL, Webb KL, Brignano S, Peu T, et al. Healthier together: co-design of a culturally tailored childhood obesity community prevention program for Maori & Pacific Islander children and families. *Health Promot J Austr*. (2021) 32:143–54. doi: 10.1002/hpja.438

85. McQuinn S, Belton S, Staines A, Sweeney MR. Co-design of a school-based physical activity intervention for adolescent females in a disadvantaged community: insights from the girls active project (GAP). *BMC Public Health*. (2022) 22:615. doi: 10.1186/s12889-022-12635-w

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High sedentary behavior and low physical activity among adults in Afghanistan: results from a national cross-sectional survey

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Objective: The study aimed to evaluate the prevalence and correlates of sedentary behavior and combination of sedentary behavior and low physical activity among adults in Afghanistan in 2018.

Methods: This was a national representative cross-sectional study. The study utilized the data from Afghanistan STEPS survey 2018, where 3,956 adults (ages between 18 and 69 years) were interviewed at community-dwelling level. Using the Global Physical Activity Questionnaire, we have calculated the sedentary behavior and physical inactivity. Logistic regression was applied to investigate factors associated high sedentary behavior and low physical activity.

Results: Approximately half of the participants (49.8%) exhibited high levels of sedentary behavior, 40.3% low physical activity and 23.5% had both high sedentary behavior and low physical activity. Adjusted logistic regression analysis revealed that individuals who were employed (AOR: 0.34, 95% CI: 0.13–0.88) or self-employed (AOR: 0.60, 95% CI: 0.38–0.94) had significantly lower odds of both high SB and low physical activity than those whose work status was unpaid. Furthermore, older age (AOR: 1.75, 95% CI: 1.35–2.28), urban residence (AOR: 3.17, 95% CI: 1.72–6.05), having 4 or 5 adult household members (AOR: 1.77, 95% CI: 1.21–2.58) and being underweight (AOR: 1.78, 95% CI: 1.02–3.12) were found to be associated with high sedentary behavior. Moreover, factors such as female sex, having 4 or 5 or 6 or more adult household members, urban residence, overweight, and diabetes were positively associated, and male sex (AOR: 0.24, 95% CI: 0.12–0.51), being employed (AOR: 0.34, 95% CI: 0.13–0.88) or self-employed (AOR: 0.60, 95% CI: 0.38–0.94) were negatively associated with the occurrence of combination of high sedentary behavior and low physical activity.

Conclusion: Half of the participants had high sedentary behavior, and one in four had both high sedentary behavior and low physical activity together. These findings emphasize the importance of targeted interventions aimed at reducing sedentary behavior and promoting physical activity, particularly among vulnerable populations such as females, individuals from lower socioeconomic background, urban residents, and those with chronic conditions. Addressing these factors can contribute to improving public health outcomes and reducing negative health impacts of sedentary behavior in Afghanistan.

KEYWORDS

sedentary behavior, low physical activity, adults, Afghanistan, STEPS survey

Introduction

Sedentary behavior (SB) has been described as "any waking behavior characterized by an energy expenditure of 1.5 metabolic equivalents (METS) or lower while sitting, reclining, or lying" (1). The significance of this problem extends beyond its mere prevalence; it encompasses a complex web of adverse health outcomes and socioeconomic implications that necessitates careful consideration. SB is not an isolated issue but a contributor to spectrum of health problems. Independent of individual's physical activity (PA), SB has been identified as a critical factor in the development of several health conditions such a type 2 diabetes, cardio-metabolic risks, hypertension, high cholesterol (2–4). Its influence on this condition is profound leading to increased morbidity and mortality rates. In addition, there is an increasing negative impact of combination of SB and low PA on morbidity and mortality (5–7).

In studies in high-income countries, for example, among adults in Japan the prevalence of high SB (≥8 h/day) was 25.3% (8), and among adults across 28 European countries, the prevalence of high SB (>7.5 h/day) was 18.5% (9). Among adults in Australia, 8.9% had combination of high SB and low PA (10), and among adults in the USA the combination of high SB and low PA prevalence was 5.5% (11). In middle-income countries, for example, among adults in Armenia the prevalence of SB (≥8 h/day) was 13.2% (12), among adults in Bhutan, 8.2% (≥6 h/day) (13), among adults in South Africa 13.3% (≥8 h/day) (14), and among adults in six low-and middle-income countries (LMIC), the prevalence of high SB (≥8 h/day) was 8.3% (15).

Understanding the correlates of high SB and the combination of high SB and low PA is crucial for the development of appropriate interventions (8). Correlates of SB in high-income countries may include, for example in Japan, higher socioeconomic status, and higher body mass index (BMI) (≥25 kg/m^2) (8), in Australia male sex, higher education, higher BMI and lower self-rated health (10). Correlates of SB in LMIC may include, for example, in Bhutan higher socioeconomic status, urban residence, low PA and diabetes (13), in South Africa, older age, cognitive impairment, hypertension and stroke (14), and in six LMIC, unemployment, tobacco use, low PA, functional disability, poorer mental and physical health status (15). Correlates for combination of high SB and low PA, for example among adults in Mexico, include sociodemographic factors including higher socioeconomic status, higher education, urban residence, and lower age (16).

In high-income countries, comprehensive research has highlighted the far-reaching consequences of SB and the pressing need for interventions. Some school-based programs in high income countries that encourage performing regular activity and avoids prolonged sitting, have demonstrated positive outcomes (17). Additionally, another initiative known as "Active School" program, implemented in Canada, which emphasize on high-quality physical education and actively encourages students to engage in 60 min or more of moderate- to vigorous PA, resulted in a significant impact on the health and well-being of participating students (18).

The extent to which these social and health correlates apply to adults in Afghanistan remains unclear, and requires further investigation. There is little information available on the epidemiology and associated factors of SB and combination of SB and low PA in LMIC, particularly in Afghanistan, which reduces our ability to design effective interventions (19). To address this research gap, we in this study aimed to evaluate the prevalence and correlates of SB and combination of SB and low PA among adults in Afghanistan. By clarifying the problem's magnitude and underpinning its consequences, this research seeks to inform policy makers, public health practitioners, and the global health community about the urgent need for targeted interventions. In a country striving to rebuild its health systems and improve the well-being of its citizens, this study will serve as empirical evidence which will guide the development of evidence-based strategies aiming to reduce sedentary behavior and promoting PA, which ultimately will enhance the quality of life and well-being of the population.

Methods

Sample and procedure

This analysis used secondary data from a national cross-sectional household survey in Afghanistan in 2018 (20). By using a multistage cluster approach, a nationally representative sample of individuals aged 18–69 years was generated (21). The primary sampling units were 55 districts randomly selected from 417 districts, followed by selection of households from these districts proportionate to the size of district (see Figure 1). One person from each household was randomly selected (21). The STEPS recommended 3 age groups per gender of 18–29, 30–44, and 45–69 years were used to calculate the sample size for the 6 different

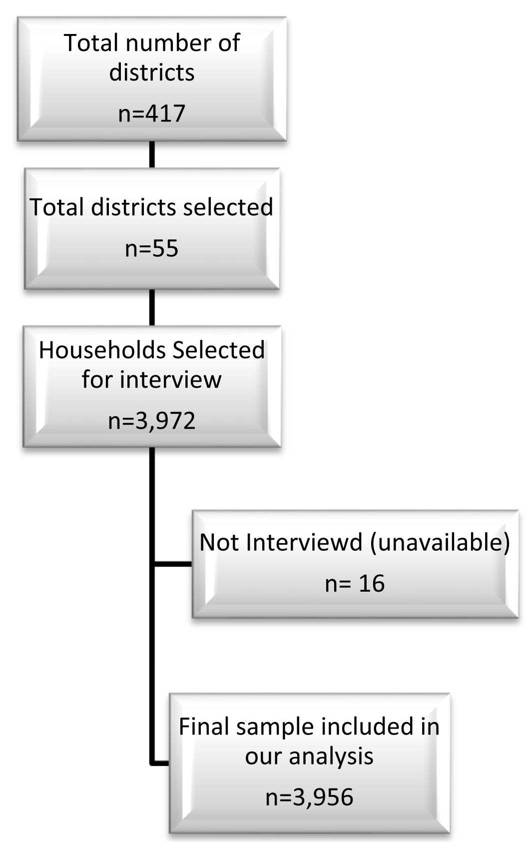

FIGURE 1
Flowchart of the sample selection.

strata of populations. Using a confidence level of 95%, a margin of error of 5%, 0.5p, and 0.5q, the resulting sample size was 384. With a design effect of 1.5 and a non-response rate of 15%, the sample size was adjusted to 662 for each strata of the age-sex group. The adjusted sample size was multiplied by six gender groups (662*6) to get the final sample size of 3,972 households. In the end, 3,972 households (male and female) were selected for data collection in 55 randomly selected districts of Afghanistan. The dataset lacked 16 households, so the final sample size included in the analysis included 3,956 households (21).

Inclusion criteria were household permanent residents aged 18–69 (50% male and 50% females) and willingness to participate in the study (21). To insure the cultural sensitivity, interviews were conducted by trained interviewers of the same gender, with male interviewers for males participants and female interviewers for female participants (21). In the sedentary behaviors measurement, there were 24 (0.6%) missing observations and for PA, there were 36 (0.5%) missing observations. Calculating the difference in characteristics between the excluded subjects and the included subjects, we could not find any significant differences ($p > 0.05$). Ethical approval for the original survey was obtained from the "Ministry of Public Health Ethics Board" in Afghanistan, and participants provided written informed consents.

Data collection followed the "WHO STEPS methodology: step 1 included administrating a structured questionnaire (sociodemographics, medical history, medication use, and health risk behaviors), step 2 entailed measuring blood pressure and anthropometric indicators, and step 3 encompassed conducting biochemical tests (blood glucose and blood lipids assessments)" (21).

Measures

Outcome variables

SB was assessed with one item from the "Global Physical Activity Questionnaire (GPAQ)" (22), as follows:

"The following question is about sitting or reclining at work, at home, getting to and from places, or with friends including time spent sitting at a desk, sitting with friends, traveling in car, bus, train, reading, playing cards or watching television, but do not include time spent sleeping. How much time do you usually spend sitting or reclining on a typical day?" (Hours/min).

High SB was classified as 8 or more hours per day, following a previous classification for all-time mortality risk (23). Data truncation was applied when sedentary duration was 960 min/day (16 h) or more (22).

Physical activity levels were classified into low, moderate, and high PA (<600, 600–1,500, and > 1,500 MET-minutes/week, respectively) according to the GPAQ guidelines (22). Data truncation was applied when the activity reported within any domain or intensity was 960 min/day (16 h) or more (22). Occurrence of high SB and low PA together was defined as combination of SB and low PA.

Social and demographic informations included, age, sex, education, number of adult household members (as a proxy for socioeconomic status) (24), and residence status. Past 12-month work status was grouped into 1 = employee (government employee, or non-government employee), 2 = self-employed, and 3 = unpaid (student, unemployed, homemaker, non-paid, or retired) (21).

Behavioral covariates included current tobacco use, and daily servings of vegetable and fruit intake.

Biological variables included BMI, blood pressure, blood sugar, hypercholesterolemia, and heart attack. BMI level was classified as "<18.5 kg/m^2 underweight, 18.5–24.9 kg/m^2 normal weight, 25–29.9 kg/m^2 overweight and ≥30 kg/m^2 obesity" (25). *Hypertension* was defined as "systolic blood pressure (BP) ≥140 mmHg and/or diastolic BP ≥90 mm Hg or where the participant is currently on antihypertensive medication" (26). *Diabetes* was defined as "fasting plasma glucose levels ≥7.0 mmol/L (126 mg/dL); or using insulin or oral hypoglycemic drugs; or having a history of diagnosis of diabetes" (27). Raised total cholesterol (TC) was defined as "fasting TC ≥5.0 mmol/L or currently on medication for raised cholesterol" (27). History of heart attack or stroke was assessed from the question, "Have you ever had a heart attack or chest pain from heart disease (angina) or a stroke (cerebrovascular accident or incident)?" (21).

Data analysis

Analysis weights were calculated by taking the inverse of the probability of selection of each participant adjusted for differences in the age-sex composition of the sample population as compared to the target population (21). Descriptive statistics were used to provide the distribution of sociodemographic and health information of the sample. Unadjusted and adjusted logistic regression was applied to investigate associated factors (sociodemographic and health variables) of high SB and combination of high SB and low PA. Variables significant in univariate analyses were subsequently included in the multivariable logistic regression. Taylor linearization methods were applied in statistical procedures accounting for sample weight and multi-stage sampling. Only complete cases were included (<0.5% missing on outcome variables SB and PA) in the analysis and significance was established at $p < 0.05$. Statistical procedures were done using "Stata software version 15.1 (Stata Corporation, College Station, TX, United States)," and considering the complex study approach of multi-stage sampling and weighting of the data.

Results

Sample characteristics

The sample consisted of 3,956 adults (18–69 years), with a median age of 35 years (interquartile range 24–60), 51.9% of the participants were men. Majority (61.1%) had no formal education, 42.3% were living with six or more adult household members, and 57.8% lived in urban areas. Approximately half of the participants (49.8%) had high SB, 40.3% low PA, and 23.5% had both high SB and low PA. Further sociodemographic details and information about health variables are shown in Table 1.

Associations with high sedentary behavior

In univariable analyses, older age, having 4–5 adult household members, urban residence, overweight, obesity, and type 2 diabetes were positively associated with high SB, while male sex, being self-employed and high PA were negatively associated with high SB. In the multivariable analysis, older age (30–69 years) (AOR: 1.75, 95% CI: 1.35–2.28), having 4–5 adult household members (AOR: 1.77, 95% CI:

TABLE 1 Sample and sedentary behavior (SB) and low physical activity (PA) characteristics among adults in Afghanistan, 2018.

Variable	Sample	SB	Low PA	SB and low PA
	N[a] (%)[b]	%[b]	%[b]	%[b]
All	3,956	49.8	40.3	23.5
Age in years				
18–29	1879 (47.9)	46.7	40.0	21.9
30–69	2046 (52.1)	54.0	40.7	25.6
Sex				
Female	1930 (48.1)	58.9	62.9	39.2
Male	2022 (51.9)	41.5	19.5	9.0
Education				
None	2,225 (61.1)	53.0	48.6	30.2
≤Primary	681 (15.8)	48.9	37.8	19.1
≥Secondary	1,047 (23.1)	42.2	20.1	8.8
Adult household members				
1–3	1,412 (23.8)	40.3	33.2	15.7
4–5	1,286 (34.0)	55.0	37.8	23.0
≥6	1,255 (42.3)	51.1	46.3	28.3
Work status				
Unpaid	2,134 (55.9)	55.3	55.6	35.2
Employee	346 (8.4)	41.9	20.6	9.4
Self-employed	1,457 (35.7)	48.0	16.0	6.4
Residence				
Rural	1877 (42.2)	33.6	31.5	14.3
Urban	2078 (57.8)	61.7	46.7	30.2
Body mass index				
Normal	1774 (49.5)	42.8	32.0	16.7
Underweight	264 (7.8)	56.6	37.3	21.4
Overweight	1,071 (25.5)	51.0	40.6	24.6
Obesity	636 (17.2)	54.7	52.8	29.6
Current tobacco use	870 (26.2)	49.0	27.2	15.3
Daily servings of fruit/vegetables intake				
≤1	2,523 (59.8)	48.6	43.0	26.0
2	925 (28.9)	54.4	35.1	20.6
≥3	508 (11.3)	44.6	39.3	17.6
Hypertension	1,193 (29.2)	51.6	47.1	28.4
Type 2 diabetes	408 (9.2)	59.7	59.1	39.6
Raised cholesterol	707 (18.0)	56.4	47.1	32.4
Heart disease or stroke	293 (8.8)	40.7	27.3	14.2

[a]Unweighted, [b]weighted.

1.21–2.58), urban residence (AOR: 3.23, 95% CI: 1.72–6.05) and being underweight (AOR: 1.78, 95% CI: 1.02–3.12) were significantly positively associated with high SB, and being male (AOR: 0.50, 95% CI: 0.29–0.91) was inversely associated with high SB (see Table 2).

Associations with low physical activity

In univariable analyses, having 6 or more adult household members, urban residence, overweight, obesity, hypertension and type 2 diabetes were positively associated with low PA, while male sex, higher education, being employed or self-employed, current tobacco use and having a history of heart attack or stroke were negatively associated with low PA. In the multivariable analysis, having 6 or more adult household members (AOR: 1.88, 95% CI: 1.24–2.84), urban residence (AOR: 2.12, 95% CI: 1.34–3.38), and being overweight (AOR: 1.36, 95% CI: 1.04–1.78) were significantly positively associated with low PA, and being male (AOR: 0.22, 95% CI: 0.10–0.50), having secondary or higher education (AOR: 0.58, 95% CI: 0.36–0.93), and being employed (AOR: 0.34, 95% CI: 0.16–0.71) were inversely associated with low PA (see Table 3).

TABLE 2 Association of sociodemographic and health variables with high sedentary behavior among adults in Afghanistan, 2018.

Variable	CrOR (95% CI)	*p*	AOR (95% CI)	*p*
Sociodemographic variables				
Age in years				
18–29	1 (Reference)		1 (Reference)	
30–69	1.34 (1.02, 1.76)	0.036	1.75 (1.35, 2.28)	<0.001
Sex				
Female	1 (Reference)		1 (Reference)	
Male	0.50 (0.27, 0.92)	0.025	0.50 (0.29, 0.91)	0.023
Education				
None	1 (Reference)		1 (Reference)	
≤Primary	0.85 (0.59, 1.22)	0.375	0.98 (0.71, 1.35)	0.890
≥Secondary	0.65 (0.38, 1.12)	0.119	0.92 (0.62, 1.37)	0.680
Adult household members				
1–3	1 (Reference)		1 (Reference)	
4–5	1.81 (1.18, 2.79)	0.007	1.77 (1.21, 2.58)	0.003
≥6	1.55 (0.91, 2.65)	0.131	1.27 (0.80, 2.00)	0.312
Work status				
Unpaid	1 (Reference)		1 (Reference)	
Employee	0.75 (0.34, 1.65)	0.465	1.56 (0.84, 2.90)	0.163
Self-employed	0.58 (0.35, 0.98)	0.040	1.31 (0.84, 2.03)	0.227
Residence				
Rural	1 (Reference)		1 (Reference)	
Urban	3.17 (1.92, 5.24)	<0.001	3.23 (1.72, 6.05)	<0.001
Health variables				
Body mass index				
Normal	1 (Reference)		1 (Reference)	
Underweight	1.74 (0.99, 3.04)	0.052	1.78 (1.02, 3.12)	0.042
Overweight	1.39 (1.04, 1.85)	0.026	1.24 (0.90, 1.70)	0.192
Obesity	1.61 (1.18, 2.20)	0.003	1.26 (0.89, 1.80)	0.197
Physical activity				
Low	1 (Reference)		1 (Reference)	
Moderate	0.68 (0.40, 1.18)	0.242	1.28 (0.73, 2.27)	0.388
High	0.53 (0.30, 0.94)	0.043	0.86 (0.54, 1.36)	0.520
Current tobacco use	0.95 (0.59, 1.84)	0.844	1.35 (0.99, 1.85)	0.054
Daily servings of fruit/vegetables intake				
≤1	1 (Reference)		1 (Reference)	
2	1.26 (0.83, 1.91)	0.271	1.29 (0.89, 1.87)	0.177
≥3	0.85 (0.51, 1.40)	0.521	0.80 (0.47, 1.35)	0.401
Hypertension	1.09 (0.86, 1.39)	0.482	1.01 (0.77, 1.33)	0.915
Type 2 diabetes	1.62 (1.06, 2.49)	0.026	1.19 (0.78, 1.81)	0.423
Raised cholesterol	1.44 (0.95, 2.18)	0.082	1.08 (0.75, 1.55)	0.683
Heart disease or stroke	0.67 (0.34, 1.32)	0.242	0.67 (0.33, 1.36)	0.268

CrOR, Crude Odds Ratio; AOR, Adjusted Odds Ratio.

Associations with combination of high sedentary behavior and low physical activity

In univariable analyses, having six or more adult household members, urban residence, overweight, obesity, hypertension, type 2 diabetes, and raised cholesterol were positively associated with combination of SB and low PA, while male sex, higher education, being employed or self-employed, current tobacco use and having heart disease or stroke were negatively associated. In multivariable analysis, compared to participants whose work status was unpaid, the odds of combination of high SB and low PA was significantly lower in employees (AOR: 0.34, 95% CI: 0.13–0.88), and those self-employed (AOR: 0.60, 95% CI: 0.38–0.94). Furthermore, the male gender (AOR: 0.24, 95% CI: 0.12–0.51) and consumption of 3 or more servings of fruit and vegetables a day (AOR: 0.50, 95% CI: 0.28–0.88) exhibited negative

TABLE 3 Association of sociodemographic and health variables with low physical activity among adults in Afghanistan, 2018.

Variable	CrOR (95% CI)	*p*	AOR (95% CI)	*p*
Sociodemographic variables				
Age in years				
18–29	1 (Reference)		1 (Reference)	
30–69	1.03 (0.82, 1.31)	0.790	1.01 (0.70, 1.46)	0.958
Sex				
Female	1 (Reference)		1 (Reference)	
Male	0.24 (0.08, 0.26)	<0.001	0.22 (0.10, 0.50)	<0.001
Education				
None	1 (Reference)		1 (Reference)	
≤Primary	0.64 (0.43, 0.96)	0.031	0.92 (0.57, 1.50)	0.745
≥Secondary	0.27 (0.18, 0.40)	<0.001	0.58 (0.36, 0.93)	0.023
Adult household members				
1–3	1 (Reference)		1 (Reference)	
4–5	1.22 (0.81, 1.86)	0.342	1.27 (0.91, 1.78)	0.164
≥6	1.73 (1.12, 2.67)	0.013	1.88 (1.24, 2.84)	0.003
Work status				
Unpaid	1 (Reference)		1 (Reference)	
Employee	0.15 (0.08, 0.29)	<0.001	0.34 (0.16, 0.71)	0.004
Self-employed	0.20 (0.12, 0.34)	<0.001	0.60 (0.32, 1.10)	0.100
Residence				
Rural	1 (Reference)		1 (Reference)	
Urban	1.91 (1.04, 3.50)	0.036	2.12 (1.34, 3.38)	0.002
Health variables				
Body mass index				
Normal	1 (Reference)		1 (Reference)	
Underweight	1.26 (0.75, 2.14)	0.378	1.09 (0.65, 1.85)	0.741
Overweight	1.45 (1.15, 1.84)	0.002	1.36 (1.04, 1.78)	0.023
Obesity	2.38 (1.66, 3.40)	<0.001	1.50 (0.95, 2.35)	0.079
High sedentary behavior	1.70 (0.98, 2.93)	0.059	1.02 (0.64, 1.62)	0.945
Current tobacco use	0.46 (0.26, 0.78)	0.004	1.22 (0.73, 2.04)	0.451
Daily servings of fruit/vegetables intake				
≤1	1 (Reference)	0.151	1 (Reference)	0.234
2	0.75 (0.50, 1.11)	0.635	0.79 (0.53, 1.17)	0.381
≥3	0.88 (0.51, 1.51)		0.83 (0.55, 1.26)	
Hypertension	1.91 (1.04, 3.50)	0.003	1.25 (0.95, 1.64)	0.114
Type 2 diabetes	2.67 (1.58, 4.52)	<0.001	1.83 (0.98, 3.42)	0.057
Raised cholesterol	1.49 (0.98, 2.25)	0.062	0.81 (0.54, 1.22)	0.313
Heart disease or stroke	0.53 (0.30, 0.92)	0.025	0.70 (0.36, 1.35)	0.114

CrOR, Crude Odds Ratio; AOR, Adjusted Odds Ratio.

correlations, whereas, having 6 or more adult household members (AOR: 2.39, 95% CI: 1.42–4.04), residing in urban areas (AOR: 2.77, 95% CI: 1.60–4.81), being overweight (AOR: 1.45, 95% CI: 1.05–1.99), and having type 2 diabetes (AOR: 2.02, 95% CI: 1.20–3.43) were positively associated with the co-occurrence of high SB and low PA (see Table 4).

Discussion

We found that the proportion of high SB (49.2%) in Afghanistan was higher compared to some national community-based surveys using similar self-reported measures in low resourced countries, such as in Armenia (13.2%) (12), in

TABLE 4 Association of sociodemographic and health variables with combination of high sedentary behavior and low physical activity among adults in Afghanistan, 2018.

Variable	CrOR (95% CI)	*p*	AOR (95% CI)	*p*
Sociodemographic variables				
Age in years				
18–29	1 (Reference)		1 (Reference)	
30–69	1.23 (0.91, 1.64)	0.175	1.42 (0.99, 2.03)	0.054
Sex				
Female	1 (Reference)		1 (Reference)	
Male	0.15 (0.09, 0.28)	<0.001	0.24 (0.12, 0.51)	<0.001
Education				
None	1 (Reference)		1 (Reference)	
≤Primary	0.54 (0.34, 0.86)	0.013	0.80 (0.45, 1.42)	0.440
≥Secondary	0.22 (0.13, 0.38)	<0.001	0.72 (0.40, 1.30)	0.274
Adult household members				
1–3	1 (Reference)		1 (Reference)	
4–5	1.60 (0.99, 2.61)	0.057	1.78 (1.10, 2.88)	0.018
≥6	2.12 (1.28, 2.50)	0.004	2.39 (1.42, 4.04)	<0.001
Work status				
Unpaid	1 (Reference)		1 (Reference)	
Employee	0.13 (0.06, 0.27)	<0.001	0.34 (0.13, 0.88)	0.026
Self-employed	0.19 (0.11, 0.33)	<0.001	0.60 (0.38, 0.94)	0.025
Residence				
Rural	1 (Reference)		1 (Reference)	
Urban	2.60 (1.39, 4.87)	<0.001	2.77 (1.60, 4.81)	<0.001
Health variables				
Body mass index				
Normal	1 (Reference)		1 (Reference)	
Underweight	1.36 (0.73, 2.55)	0.327	1.40 (0.74, 2.67)	0.304
Overweight	1.63 (1.22, 2.17)	<0.001	1.45 (1.05, 1.99)	0.023
Obesity	2.10 (1.36, 3.25)	<0.001	1.06 (0.65, 1.74)	0.813
Current tobacco use	0.50 (0.28, 0.91)	0.024	1.36 (0.69, 2.67)	0.377
Daily servings of fruit/vegetables intake				
≤1	1 (Reference)		1 (Reference)	0.593
2	0.74 (0.47, 1.16)	0.190	0.88 (0.56, 1.39)	0.016
≥3	0.61 (0.37, 1.01)	0.054	0.50 (0.28, 0.88)	
Hypertension	1.46 (1.05, 2.13)	0.026	1.35 (0.96, 1.90)	0.085
Type 2 diabetes	2.51 (1.49, 4.25)	<0.001	1.88 (1.10, 2.88)	0.021
Raised cholesterol	1.90 (1.24, 2.89)	0.003	1.08 (0.74, 1.58)	0.672
Heart disease or stroke	0.51 (0.27, 0.99)	0.045	0.63 (0.33, 1.22)	0.170

CrOR, Crude Odds Ratio; AOR, Adjusted Odds Ratio.

South Africa (13.3%) (14), and in Bhutan (8.2%) (13, 15), and community-based studies in some high-income countries, for example, in Japan (25.3%) (8), and 28 countries in Europe (18.5%) (9). In small cross-sectional population-based studies among adults in urban Afghanistan, e.g., in Kandahar city in 2019 also a high rate of daily sitting time (average 10.4 h, compared to 6.8 h in this study) has been reported (28) and in Jalalabad city the prevalence of sitting 3 or more hours a day was 35.1% (29). The prevalence of low PA (40.3%) in this study was higher than in a cross-sectional study among hospital patients in Kandahar city (27%) (30). Regarding the prevalence of the combination of high SB and low PA (23.5%) in Afghanistan, the observed rates were found to be significantly higher compared to previous national community-based studies conducted in other regions, such as in Australia (8.9%) (10), and the USA during the 2017/2018 period (5.5%) (11). The elevated prevalence of SB and the co-occurrence of high SB and low PA in Afghanistan can be attributed to various factors such as urbanization, changes in occupational patterns involving more SB, and an increase in less active transportation in both urban and rural areas (19). Among the obstacles to participation in PA in Afghanistan are the lack of time, being too tired, a lack of confidence in participating in certain types of PA, the type of clothing often worn during exercise, the lack of single-sex facilities, the inability to participate in PA with men and the need to be completely covered outside the house (31). Furthermore, recent government actions have intensified the issue, with bans on women's access to work, education and specifically public parks. These restrictions which further exacerbates sedentary behavior necessitates immediate attention and the implementation of transformative interventions to promote PA.

It is crucial to implement interventions that specifically target SB and the combined occurrence of SB and low PA. The interventions may include public awareness campaigns, normalizing PA, national PA campaigns, national mass participation events on PA, improving access to sport and other PA facilities, including single-sex facilities, brief intervention on PA in primary care, and apart from already promoting PA in public open spaces, PA can be promoted in workplaces, childcare, school and university setting, through community sports, through walking and cycling, for older adults and for people with disability (19, 31–33).

Our study revealed several factors that were associated with increased odds of high SB and co-occurrence of high SB and low PA. These factors included non-work status, older age, urban residence and being underweight which were all positively associated with high SB. Furthermore, non-work status, female sex, lower socioeconomic status, urban residence, being overweight, lower fruit and vegetable intake and having diabetes were associated with the odds of having both high SB and low PA. Consistent with previous studies (8, 12, 13, 16, 34–37) we found that older age, female sex, and urban residence were positively associated with high SB and/or combination of high SB and low PA. The higher prevalence of SB, low PA and combination of high SB and low PA among women than men, "could be related to cultural issues in the Afghan context such as access to physical exercise facilities and restriction of female movement outside the home" (19). Cities in Afghanistan may be exposed to increased traffic and crime and increased use of motorized transport, leading to increased SB (15). These results support the implementation of interventions aimed at reducing SB among women residing in urban areas of Afghanistan (15). The finding that lower fruit and vegetable intake was associated with the odds of having both high SB and low PA may be explained by clustering of risk factors of non-communicable diseases (29).

While some research (10, 13, 16, 35) found a positive association between higher socioeconomic status and high SB, we found no consistent significant association between higher socioeconomic status (higher education, lower number of adult household members), and a negative association between higher socioeconomic status (lower number of adult household members) and high SB and/or combination of high SB and low PA, and those with higher education had lower odds of low PA. Furthermore, compared to participants who had an unpaid work status, the odds of combination of high SB and low PA was significantly lower in those who were employed or self-employed. People who are employed or self-employed, have better education and have better economic status may be more aware of the importance of PA and have more opportunities to engage in PA (15).

In terms of health-related factors, our findings were consistent with previous research (10, 13–15), indicating that overweight, and diabetes were associated with combination of high SB and low PA. Individuals who are overweight may experience a decline in mobility that reduces their energy expenditure, leading to weight gain. This weigh gain, in turn, further reduces mobility and promotes sedentary lifestyle (38, 39). It is also plausible that high levels of SB and low PA contribute to chronic conditions (15). Our findings, however, suggest that SB interventions should consider persons with chronic conditions, such as overweight, and diabetes (15).

In unadjusted analysis, high PA, current tobacco use, and history of heart disease or stroke were negatively associated with high SB and/or combination of SB and low PA. Conversely, raised cholesterol levels and hypertension were positively associated with these outcomes. Previous research (13, 15) has also shown an association between low PA and high SB. Our study found that current tobacco use was marginally associated with high SB, which is in consistence with previous studies (10, 13, 15). It is worth noting that SB can contribute to decreased cardiorespiratory fitness and an increased risk of hypertension, coronary heart disease, and stroke (40). In a previous study a high prevalence of SB was found in stroke survivors (41). Engaging stroke survivors in PA may be difficult to achieve, but it would be important to develop adapted possible strategies of PA in this group (42).

Study limitations

The cross-sectional nature of our survey hinders us in drawing causal conclusions. For example, the direction of the association between overweight and combination of high SB and low PA could be bi-directional, meaning that combination of high SB and low PA could lead to overweight and overweight could lead to combination of high SB and low PA. Additionally certain data in our study relied on self-report measures, including SB and PA, which may have introduced response bias potentially leading to underestimation of SB time (43). Furthermore, we only assessed overall SB, instead of assessing separate SB domains, such as leisure time, transport and work.

Conclusion

Half of adults in Afghanistan had high SB, two in five low PA and one in four had both high SB and low PA. Older age, female sex, urban residence, having 4 or 5 adult household members, and being underweight increased the odds of high SB. Furthermore, non-work status, female sex, lower socioeconomic status, urban residence, overweight, lower intake of fruit and vegetables, and diabetes increased the odds of combination of high SB and low PA. Interventions aimed at reducing SB and promoting PA should target specific subgroups such as females, older individuals, urban residents, those with chronic conditions (underweight, overweight, and diabetes) and those with lower socioeconomic status.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: WHO NCD Microdata Repository (URL: https://extranet.who.int/ncdsmicrodata/index.php/catalog).

Ethics statement

The studies involving humans were approved by Ethics approval for the STEPS survey was obtained from the "Ministry of Public Health Ethics Board" and participants provided informed consent. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

SP, AN, and KP conceived and designed the research, performed statistical analysis, drafted the manuscript, and made critical revision of the manuscript for key intellectual content. All authors fulfil the criteria for authorship, read and approved the final version of the manuscript, and agreed to authorship and order of authorship for this manuscript.

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Conflict of interest

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

Publisher's note

References

1. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, et al. Sedentary behavior research network (SBRN) - terminology consensus project process and outcome. *Int J Behav Nutr Phys Act*. (2017) 14:75. doi: 10.1186/s12966-017-0525-8

2. Chau JY, Grunseit AC, Chey T, Stamatakis E, Brown WJ, Matthews CE, et al. Daily sitting time and all-cause mortality: a meta-analysis. *PLoS One*. (2013) 8:e80000. doi: 10.1371/journal.pone.0080000

3. De Rezende LF, Rey-López JP, Matsudo VK, do Carmo Luiz O. Sedentary behavior and health outcomes among older adults: a systematic review. *BMC Public Health*. (2014) 14:333. doi: 10.1186/1471-2458-14-333

4. Thorp AA, Owen N, Neuhaus M, Dunstan DW. Sedentary behaviors and subsequent health outcomes in adults a systematic review of longitudinal studies, 1996-2011. *Am J Prev Med*. (2011) 41:207–15. doi: 10.1016/j.amepre.2011.05.004

5. Cristi-Montero C, Steell L, Petermann F, Garrido-Méndez A, Díaz-Martínez X, Salas-Bravo C, et al. Joint effect of physical activity and sedentary behaviour on cardiovascular risk factors in Chilean adults. *J Public Health (Oxf)*. (2018) 40:485–92. doi: 10.1093/pubmed/fdx134

6. Celis-Morales C, Lyall DM, Anderson J, Iliodromiti S, Fan Y, Ntuk UE, et al. The association between physical activity and risk of mortality is modulated by grip strength and cardiorespiratory fitness: evidence from 498,135 UK biobank participants. *Eur Heart J*. (2016) 38:ehw249–22. doi: 10.1093/eurheartj/ehw249

7. Ekelund U, Steene-Johannessen J, Brown WJ, Fagerland MW, Owen N, Powell KE, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. *Lancet*. (2016) 388:1302–10. doi: 10.1016/S0140-6736(16)30370-1

8. Kitayama A, Koohsari MJ, Ishii K, Shibata A, Oka K. Sedentary time in a nationally representative sample of adults in Japan: prevalence and sociodemographic correlates. *Prev Med Rep*. (2021) 23:101439. doi: 10.1016/j.pmedr.2021.101439

9. Loyen A, van der Ploeg HP, Bauman A, Brug J, Lakerveld J. European sitting championship: prevalence and correlates of self-reported sitting time in the 28 European Union member states. *PLoS One*. (2016) 11:e0149320. doi: 10.1371/journal.pone.0149320

10. Bennie JA, Pedisic Z, van Uffelen JG, Gale J, Banting LK, Vergeer I, et al. The descriptive epidemiology of total physical activity, muscle-strengthening exercises and sedentary behaviour among Australian adults--results from the National Nutrition and physical activity survey. *BMC Public Health*. (2016) 16:73. doi: 10.1186/s12889-016-2736-3

11. Ussery EN, Whitfield GP, Fulton JE, Galuska DA, Matthews CE, Katzmarzyk PT, et al. Trends in self-reported sitting time by physical activity levels among US adults, NHANES 2007/2008-2017/2018. *J Phys Act Health*. (2021) 18:S74–83. doi: 10.1123/jpah.2021-0221

12. Tcymbal A, Andreasyan D, Whiting S, Mikkelsen B, Rakovac I, Breda J. Prevalence of physical inactivity and sedentary behavior among adults in Armenia. *Front Public Health*. (2020) 8:157. doi: 10.3389/fpubh.2020.00157

13. Dendup T, Zhao Y, Edi Putra IGN, Dorji T, Tenzin C. Correlates of sedentary behavior among Bhutanese adults: findings from the 2014 Bhutan STEPS survey data. *Korean J Fam Med*. (2021) 42:288–96. doi: 10.4082/kjfm.20.0059

14. Peltzer K, Phaswana-Mafuya PS. Prevalence and correlates of sedentary behaviour among a national sample of 15-98 years old individuals in South Africa. *AJPHES*. (2018) 24:286–98. Available at: https://hdl.handle.net/10520/EJC-10ee165fa1.

15. Koyanagi A, Stubbs B, Vancampfort D. Correlates of sedentary behavior in the general population: a cross-sectional study using nationally representative data from six low- and middle-income countries. *PLoS One*. (2018) 13:e0202222. doi: 10.1371/journal.pone.0202222

16. Medina C, Jáuregui A, Hernández C, Shamah T, Barquera S. Physical inactivity and sitting time prevalence and trends in Mexican adults. Results from three national surveys. *PLoS One*. (2021) 16:e0253137. doi: 10.1371/journal.pone.0253137

17. Yuksel HS, Şahin FN, Maksimovic N, Drid P, Bianco A. School-based intervention programs for preventing obesity and promoting physical activity and fitness: a systematic review. *Int J Environ Res Public Health*. (2020) 17:347. doi: 10.3390/ijerph17010347

18. Hohn T, James L, Mckinley G.. Case 5: active schools: a method to combat sedentary behaviour?. In: *Western public health casebooks* (2019). Available at: https://ir.lib.uwo.ca/cgi/viewcontent.cgi?article=1097&context=westernpublichealthcases (Accessed August 26, 2023).

19. Saeed KMI, Rasooly MH, Nejaby M. Profile of risk factors for noncommunicable diseases in major cities of Afghanistan: WHO STEPwise approach. *East Mediterr Health J*. (2020) 26:388–99. doi: 10.26719/emhj.20.005

20. World Health Organization (2018). *STEPwise approach to surveillance (STEPS)*. Available at: https://www.who.int/ncds/surveillance/steps/en/ (Accessed October 2, 2021).

21. JS Consultancy Services. *Non-communicable disease risk factor survey country report for Afghanistan*. Available at: https://extranet.who.int/ncdsmicrodata/index.php/catalog/782 (Accessed October 2, 2021).

22. Armstrong T, Bull F. Development of the World Health Organization global physical activity questionnaire (GPAQ). *J Public Health*. (2006) 14:66–70. doi: 10.1007/s10389-006-0024-x

23. van der Ploeg HP, Chey T, Korda RJ, Banks E, Bauman A. Sitting time and all-cause mortality risk in 222 497 Australian adults. *Arch Intern Med*. (2012) 172:494–500. doi: 10.1001/archinternmed.2011.2174

24. Melki IS, Beydoun HA, Khogali M, Tamim H, Yunis KA. National collaborative perinatal neonatal network (NCPNN). Household crowding index: a correlate of socioeconomic status and inter-pregnancy spacing in an urban setting. *J Epidemiol Communiy Health*. (2004) 58:476–80. doi: 10.1136/jech.2003.012690

25. World Health Organization-Europe *Body mass index*. Available at: https://www.euro.who.int/en/health-topics/disease-prevention/nutrition/a-healthy-lifestyle/body-mass-index-bmi (Accessed September 20, 2020).

26. Chobanian AV, Bakris GL, Black HR, Cushman WC, Green LA, Izzo JL Jr, et al. Seventh report of the joint national committee of prevention, detection, evaluation, and treatment of high blood pressure. *Hypertension*. (2003) 42:1206–52. doi: 10.1161/01.HYP.0000107251.49515.c2

27. World Health Organization *WHO STEPS surveillance manual*. Available at: https://www.who.int/ncds/surveillance/steps/STEPS_Manual.pdf (Accessed October 10, 2021).

28. Sahrai MS, Huybrechts I, Biessy C, Rinaldi S, Ferrari P, Wasiq AW, et al. Determinants of obesity and metabolic health in the Afghan population: protocol, methodology, and preliminary results. *J Epidemiol Glob Health*. (2022) 12:113–23. doi: 10.1007/s44197-021-00026-0

29. Saeed KMI. Prevalence of hypertension and associated factors in Jalalabad City, Nangarhar Province, Afghanistan. *Cent Asian J Glob Health*. (2015) 4:134. doi: 10.5195/cajgh.2015.134

30. Farooqi K, Fazli N. Prevalence of NCDs risk factors in Kandahar City, Afghanistan. *J Hypertens*. (2019) 8:260.

31. Safi A, Myers T. Barriers to physical activity: a comparison of Afghans living in the UK and Afghanistan. *Adv Phys Educ*. (2021) 11:103–17. doi: 10.4236/ape.2021.111008

32. World Health Organization. *Physical activity Afghanistan 2022 country profile* (2022). Available at: https://www.who.int/publications/m/item/physical-activity-afg-2022-country-profile (Accessed August 24, 2023).

33. Neyazi N, Mosadeghrad AM, Afshari M, Isfahani P, Safi N. Strategies to tackle non-communicable diseases in Afghanistan: a scoping review. *Front Public Health*. (2023) 11:982416. doi: 10.3389/fpubh.2023.982416

34. Prince SA, Reed JL, McFetridge C, Tremblay MS, Reid RD. Correlates of sedentary behaviour in adults: a systematic review. *Obes Rev*. (2017) 18:915–35. doi: 10.1111/obr.12529

35. Müller AM, Chen B, Wang NX, Whitton C, Direito A, Petrunoff N, et al. Correlates of sedentary behaviour in Asian adults: a systematic review. *Obes Rev*. (2020) 21:e12976. doi: 10.1111/obr.12976

36. Chastin SF, Buck C, Freiberger E, Murphy M, Brug J, Cardon G, et al. Systematic literature review of determinants of sedentary behaviour in older adults: a DEDIPAC study. *Int J Behav Nutr Phys Act*. (2015) 12:127. doi: 10.1186/s12966-015-0292-3

37. O'Donoghue G, Perchoux C, Mensah K, Lakerveld J, van der Ploeg H, Bernaards C, et al. A systematic review of correlates of sedentary behaviour in adults aged 18-65 years: a socio-ecological approach. *BMC Public Health*. (2016) 16:163. doi: 10.1186/s12889-016-2841-3

38. Motuma A, Gobena T, Roba KT, Berhane Y, Worku A. Sedentary behavior and associated factors among working adults in eastern Ethiopia. *Front Public Health*. (2021) 9:693176. doi: 10.3389/fpubh.2021.693176

39. Middelbeek L, Breda J. Obesity and sedentarism: reviewing the current situation within the WHO European region. *Curr Obes Rep*. (2013) 2:42–9. doi: 10.1007/s13679-013-0054-y

40. World Health Organization (2018). *Physical activity*. Available at: https://www.who.int/newsroom/fact-sheets/detail/physical-activity (Accessed May 2, 2021).

41. Joseph C, Conradsson D, Hagströmer M, Lawal I, Rhoda A. Objectively assessed physical activity and associated factors of sedentary behavior among survivors of stroke living in Cape Town, South Africa. *Disabil Rehabil*. (2018) 40:2509–15. doi: 10.1080/09638288.2017.1338761

42. Vancampfort D, Stubbs B, Hallgren M, Lundin A, Firth J, Koyanagi A. Correlates of sedentary behaviour among adults with hazardous drinking habits in six low- and middle-income countries. *Psychiatry Res*. (2018) 261:406–13. doi: 10.1016/j.psychres.2018.01.025

43. Van Cauwenberg J, Van Holle V, De Bourdeaudhuij I, Owen N, Deforche B. Older adults' reporting of specific sedentary behaviors: validity and reliability. *BMC Public Health*. (2014) 14:734. doi: 10.1186/1471-2458-14-734

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Socioeconomic status and health behavior in children and adolescents: a systematic literature review

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Socioeconomic status affects individuals' health behaviors and contributes to a complex relationship between health and development. Due to this complexity, the relationship between SES and health behaviors is not yet fully understood. This literature review, therefore, aims to assess the association between socioeconomic status and health behaviors in childhood and adolescence. Preferred Reporting for Systematic Review and Meta-Analysis protocol guidelines were used to conduct a systematic literature review. The electronic online databases EBSCO Host, PubMed, Web of Science, and Science Direct were utilized to systematically search published articles. The Joanna Briggs Institute's critical appeal tool was used to assess the quality of included studies. Eligibility criteria such as study context, study participants, study setting, outcome measures, and key findings were used to identify relevant literature that measured the association between socioeconomic status and health behaviors. Out of 2,391 studies, only 46 met the final eligibility criteria and were assessed in this study. Our review found that children and adolescents with low socioeconomic status face an elevated risk of unhealthy behaviors (e.g., early initiation of smoking, high-energy-dense food, low physical activity, and involvement in drug abuse), in contrast to their counterparts. Conversely, children and adolescents from higher socioeconomic backgrounds exhibit a higher prevalence of health-promoting behaviors, such as increased consumption of fruit and vegetables, dairy products, regular breakfast, adherence to a nutritious diet, and engagement in an active lifestyle. The findings of this study underscore the necessity of implementing specific intervention measures aimed at providing assistance to families from disadvantaged socioeconomic backgrounds to mitigate the substantial disparities in health behavior outcomes in children and adolescents.

KEYWORDS

socioeconomic status, health behavior, childhood, adolescence, systematic literature review

1. Introduction

Health behavior constitutes a fundamental facet of individuals' holistic well-being, exerting a substantial influence on their physical health, mental well-being, and overall longevity (1–5). Over the past decades, considerable attention has been directed toward comprehending health behaviors and cultivating healthy lifestyles (6–9). However, socioeconomic status (SES) (e.g., income, education, occupation, social position) pose a significant obstacle to achieving these objectives (10). Thus, people from low-SES backgrounds are more likely to exhibit a higher rate of smoking tobacco, drinking alcohol, excess weight gain, and a sedentary lifestyle, which has been consistently identified as a pivotal determinant of premature and preventable morbidity and mortality compared to their counterparts (11–13).

The literature reveals that children and adolescents' health and health behaviors primarily depend on their parental SES backgrounds (14–18). It is well documented that children and adolescents from high parental SES backgrounds have more access to education, housing, food, clothing, health services, and social services (19–23). These advantageous services enhance self-confidence, self-esteem, and self-efficacy, which promotes a healthy lifestyle and reduces the risk of stress in youngsters (14, 15, 17). In contrast, parental support, healthy parental lifestyle, medical services, and social networks are less open to children and adolescents with low parental SES (21, 24–27). Hence, poor availability of goods and services increases the likelihood of physical and mental health issues and encourages them to adopt risky behaviors (e.g., smoking, drinking alcohol, illicit drug use, gambling) to deal with their concerns (28–33). Therefore, parental social, cultural, and economic status are fundamental determinants of health and health behaviors in children and adolescents, which are apparent from the early stages of life and persist into adolescence (34, 35).

Globally, millions of children, particularly those with low socioeconomic profiles, do not start their lives in a healthy state (36, 37). This could be due to insufficient goods and services, which are the primary causes of impairment in children's neuro-biological development, resulting in poor social, emotional, psychological, and physiological outcomes (38, 39). Thus, focusing on improving support for deprived and underserved populations is a powerful strategy to establish the roots of healthy behaviors in childhood and adolescent development (40). Therefore, it is recommended that every government adopt a health and health equity policy program to promote positive health behaviors among its population (41–44).

Numerous studies have been documented in the international literature to determine (45), analyze (46), and explored (47, 48) the relationship between SES and health behaviors in children and adolescents. For example, in a study conducted by Liu et al. (49), adolescents hailing from families with lower parental SES exhibited a significantly higher likelihood of [OR = 2.12, 95% CI, 1.49–3.01] cigarette smoking than those from middle and high SES backgrounds. Melotti et al. (50) explored the association between parental SES and alcohol consumption among adolescents. They discovered an inverse association, revealing that adolescents with low SES had higher odds (OR: 1.26, 95% CI, 1.05–1.52) of consuming alcohol compared to those with high SES backgrounds. Furthermore, a seminal study by Krist et al. (51) investigated the impact of parental SES on physical activity levels in children and adolescents. The results indicated that those from lower parental SES backgrounds were less likely to engage in regular physical activity (OR = 0.90, 95% CI 0.63–1.29) in comparison to their peers from higher SES backgrounds. Collectively, this extensive body of evidence underscores the pivotal role played by parental SES in shaping the multifaceted landscape of health behaviors among children and adolescents. These disparities in health behaviors often contribute to adverse health outcomes, including a heightened prevalence of chronic diseases such as obesity, diabetes, and cardiovascular diseases (52).

Given the evidence above, examining the association between parental SES and health behaviors of children and adolescents holds profound scientific significance and societal consequences. Thus, a good understanding of how parental SES influences health behaviors among young individuals enables the identification of vulnerable populations at an early stage, allowing for targeted interventions and preventive measures to combat socioeconomic comorbidities and their consequences during childhood and adolescence. However, to the best of our knowledge, the existing body of literature examining the association between SES and health behaviors (e.g., protective health behaviors and damaging health behaviors) among children and adolescents remains limited (45–47, 53, 54). To address this gap in the literature, this review comprehensively examines the association between SES and health behaviors in children and adolescents aged 3–18 years, utilizing the literature on SES and health behaviors. In this review, health behaviors were examined in two ways: (i) protecting health behaviors and (ii) impairing health behaviors among children and adolescents. Protecting health behaviors is defined as the consumption of fruit vegetables, consumption of dairy products, regular breakfast, and involvement in physical activity during leisure time (55). Consumption of high-fatty foods (e.g., chips, noodles), high sugary drinks (e.g., fruit juice, Coco Cola, cordial) and engagement in smoking (i.e., tobacco, cannabis), illicit drugs, alcohol consumption, and sedentary activities during their leisure time are defined as unhealthy behaviors exhibited by children and adularescent (56). In this review study, we were particularly interested to examining two important research questions: (i) Does low socioeconomic status influence risky or impair health behavior patterns among children and adolescents compared to their counterparts? (ii) What is the association between SES and health behaviors in children and adolescents? Through an exploration of these research questions, this study will help to better understand the relationship between SES and health behaviors in children and adolescents. By doing so, this study seeks to provide valuable insights that can inform potential policy interventions aims at enhancing the health behavior outcomes of children and adolescents, particularly those who come from underserved and disadvantaged socioeconomic backgrounds.

2. Methods

This review article followed the Preferred Reporting for Systematic Review and Meta-Analysis Protocol (PRISMA-P) guidelines in order to identify studies that were screened, included and excluded in this review (57). PRISMA-P helps to provide a guideline for development of protocol for systematic review, and meta-analysis in order to

Abbreviations: JBI, Joanna Briggs Institute; PA, Physical Activity; PRISMA, Preferred Reporting for Systematic Review and Meta-analysis; SES, Socioeconomic Status; SUMARI, System for the Unified Management of the Assessment and Review of Information.

improve the quality and transparency of the studies (58, 59). In this review, we used the PRIMA checklist shown in Supplementary Table S3.

2.1. Data sources and literature search

To identify relevant articles on SES and health behaviors in childhood and adolescence, different electronic databases of various disciplines were searched, including Academic Search, APA PsycArticles, APA PsycInfo, Cumulative Index of Nursing and Allied Health Literature (CINAHL), Health Source, Nursing/Academic Edition, Psychology and Behavioral Sciences Collection, Sociology Source, Sociology Source Ultimate, PubMed, Web of Science, and Science Direct. These electronic databases were searched using the keywords: socioeconomic, "socio-economic," "health behavior," "health behavior," "health behaviors," "health behaviors," teen*, adolescent*, and child*" (see Supplementary Table S1). The articles were subsequently exported using EndNote citation manager X9 version.

2.2. Criteria of included studies

In this systematic literature review, we included studies that reported an association between SES and health behaviors. Additionally, we considered studies that had at least one specific health behavior, either protecting or impairing health behaviors, such as smoking, drinking alcohol, illicit drugs, physical exercise, consumption of fruit and vegetables, and dietary habits. Consequently, all peer-reviewed prospective, retrospective, quantitative studies from both developed and developing countries, published in the English language were included. Subsequently, national representative surveys (cross-national and longitudinal) consisting of more than 500 samples from the sampled population (i.e., children and adolescents aged 3–18 years) were also included. In this study, we considered children (i.e., 3–12 years) and adolescents (13–18 years of age) as defined by the US Department of Health and Johns Hopkins Medicine, respectively (60, 61). In summary, the inclusion criteria for this review study were structured in accordance with the PICOS model, where: "P" = Population (i.e., children and adolescents aged 3 to 18 years old), "I" = intervention (we do not have intervention in this review study), "C" = comparator (i.e., high SES and low SES backgrounds), "O" = Outcome of this study (i.e., health behavior either protecting or impairing health behaviors), and "S" = study design (i.e., cross-sectional, longitudinal only).

2.3. Criteria of excluded studies

Based on predefined eligibility criteria, we evaluated the titles and abstracts of the identified studies. In cases where the studies were found relevant to our review, we thoroughly assessed the full text. However, if the studies were not relevant to our study, such as national income inequalities and health behavior or national per-capita income inequalities and health behaviors in childhood and adolescence, we excluded such studies. Additionally, if the study did not meet the eligibility criteria such as population, comparator, outcome, and study design, we excluded the paper from this study. For example, review articles, pilot studies, reports, dissertations, books, symposia, supplementary, prospective, or intervention studies, and articles published in other languages. Articles published before 2000 were also excluded from this study, primarily because their full-text versions were not readily accessible. Furthermore, articles with a sample size of less than 500 were excluded from the analysis. The decision to exclude studies with a sample size less than 500 was driven by a combination of methodological constraints. Two articles had sample sizes of 246 and 310, respectively; however, these studies found no association between SES and health behaviors in adolescents. Therefore, we decided to exclude them from the final analysis.

2.4. Data extraction

The data extraction was done by two independent reviewers using a data extraction table. The data extraction was based on the Joanna Briggs Institute (JBI) checklist (e.g., country, study setting/context, participant characteristics, outcome measures, and key findings). The final data extraction was based on the phase two screening of studies (i.e., 46 studies) by NG following the PRISMA guidelines (57), while GD, MMR, and RK approved data extraction.

2.5. Quality assessment of study

The Joanna Briggs Institute (JBI) and System for the Unified Management of the Assessment and Review of Information (SUMARI) is an appraisal tools assist in evaluation of the trustworthiness outcomes of the included studies (62–64). For the cross-sectional studies, JBI SUMARI apprise as follows: (i) inclusion criteria were clearly defined for the study population; (ii) study subject and study setting were clearly explained; (iii) exposures were scientifically measured; (iv) standard criteria and objectives were used to assess the measurement of the study; (v) confounding factors were identified; (vi) a strategic plan was developed to address the confounding factors; (vii) the results of the studies were reliable and valid; (viii) an appropriate statistical method was used to analyze the study. On the other hand, cohort studies were evaluated as follows: (i) the sample was recruited from the study population; (ii) exposures were measured equally between the exposed and unexposed groups; (iii) exposures were measured in a valid and reliable way; (iv) confounding factors were identified; (v) the statistical plan was used to address the confounding factors; (vi) at the beginning of the study, the sampled population was free from exposures; (vii) outcomes of the study were measured in a valid and reliable way; (viii) follow-up time was sufficiently reported; (ix) follow-up was completed, and if not, reasons were well explained; (x) plans were explored to address the issue of those in the sample lost to follow-up; (xi) the standard statistical method to analyze the study was used. To establish the credibility of our findings, every included study was apprised using the JBI SUMARI and provided the score for each study by two independent reviewers. Studies were included in this review if they had gained a score of 60 percent or above, while studies with a score of less than 60 percent were excluded. However, in the context of this study appraisal, none of the papers met the criteria for a score below 60 percent. As a result, it was not necessary to exclude any studies through the application of the JBI SUMARI appraisal tools (see

Supplementary Table S4). In alignment with these principles, our review study also employed the JBI SUMARI to contribute to the overall reliability and quality of the review findings (65, 66).

Furthermore, the risk of bias in the included studies was evaluated using the 10-item grading scale for prevalence studies developed by Hoy et al. (67). The study methodology, case definition, prevalence periods, sampling, data collection, reliability, and validity of the investigations were thoroughly scrutinized. Each study was categorized as exhibiting either a low risk of bias (shown by affirmative replies to domain questions) or a high risk of bias (indicated by negative responses to domain questions). In each study, a binary scoring system was used to assign a value of 1 (indicating presence) or 0 (indicating absence) to each domain. The cumulative sum of these domain values was used to derive the overall study quality score. The assessment of bias risk was performed by calculating the total number of high-risk biases in each study. Studies were categorized as having a low risk of bias if they had two or fewer high-risk biases, moderate risk of bias if they had three or four high-risk biases, and high risk of bias if they had five or more high-risk biases. To resolve discrepancies among the reviewers, a consensus-based approach was employed for the final categorization of the risk of bias (see Supplementary Table S5).

2.6. Outcome measurement of the study

The outcomes of this study were health behaviors, either through health-protective behaviors (e.g., consumption of fruit and vegetables, consumption of a healthy diet, physical exercise) or impairing health behaviors (e.g., smoking, drinking alcohol, high sedentary lifestyle and illicit drug use), in children and adolescents (68). Childhood and adolescence are two distinct stages of life that are characterized by diverse features in the respective age groups (e.g., physical and psychological) (69, 70). Childhood is a time of rapid and remarkable development, encompassing significant strides in the physical, cognitive, social, and emotional dimensions that outpace the progress seen in other life stages. During this period, children's innate intellectual curiosity flourishes, driving them to explore the world around them and actively engage in interactive experiences (71, 72). On the other hand, adolescence is widely acknowledged as a transformative phase known as the "storm and stress" period, characterized by profound changes in biological, cognitive, psychosocial, and emotional realms (73). These transformative shifts often give rise to a range of adjustment challenges, including mood swings, propensity for risk-taking behaviors, and conflicts with both parental figures and peers (73). Thus, considering the relationship between health behaviors in childhood and adolescence is pivotal, therefore, this review study examined the association between parental SES and health behaviors in children and adolescents separately.

2.7. Measure of socioeconomic status (SES)

SES is a multidimensional construct and is measured objectively by income, education, and occupation, or subjectively by prestige, place of residence, ethnic origin, or religious background, covering both objective and subjective measures of SES (74–76). The stratification of SES into subgroups (e.g., low SES and high SES) was predicted based on goods and materials consumed by the individual in a household, including durable goods such as televisions, bicycles, and vehicles, as well as housing-related attributes such as access to drinking water, food, bathroom facilities, and agricultural and flooring materials (77). Households that possessed adequate provision of food, water, hand-washing materials, agricultural products, fields for production, and other consumer items for a duration of merely 6 months were categorized as having low-income or low- SES backgrounds. On the other hand, families that possessed an ample supply of food and other products, including consumer goods, to sustain themselves for a period of 12 months or more were classified as affluent or wealthy or high SES backgrounds (77, 78). Based on previous literature (21, 22, 77, 79, 80), our study defined low SES and high SES backgrounds and examined the association between SES and health behaviors in children and adolescents.

3. Results

3.1. Description of the study

In this systematic literature review, 2,391 articles were initially retrieved, and 585 duplicates were removed before entering the first phase of screening. A total of 1806 articles were assessed in the first phase of screening based on their titles and abstracts. Thus, in the first screening phase, we retained only 146 articles and rejected 1,660 articles. Consequently, in phase two of the screening, we assessed 146 papers based on their full text. Of these, only 46 articles met the inclusion criteria for further evaluation. Hence, these 46 articles were eligible in our final review, which is shown in Figure 1.

A total of 46 articles were assessed to examine the association between SES and health behaviors in childhood and adolescence. Most of the studies were from Europe ($n=36$), followed by Asia ($n=9$), North America ($n=5$), and Africa ($n=2$). There has been a noticeable increase in studies on SES and health behavior in childhood and adolescence in the past decade (i.e., 2010 to 2020). From a total of 46 studies, 13 studies (79, 81–92) were published between 2000 to 2010, while 33 studies (25, 47–51, 53, 93–118) were published from 2011 to 2022.

3.2. Parental socioeconomic status and smoking

3.2.1. Parental socioeconomic status and smoking among children

From a total of 46 studies, 18 studies (25, 47, 49, 50, 53, 79, 81, 84, 86–88, 93, 96, 97, 104, 105, 107, 109) showed an association between SES and smoking behavior in children and adolescents. Out of 18 studies, five reported a positive association between low SES and smoking behavior in children, implying that children with low SES had a greater risk of exposure to early smoking, and experimenting with smoking, compared to those who were from a high SES background (25, 49, 53, 104, 105).

3.2.2. Parental socioeconomic status and smoking among adolescents

From a total of 18 studies, 12 studies showed a positive association between low SES and smoking behaviors in adolescents, indicating

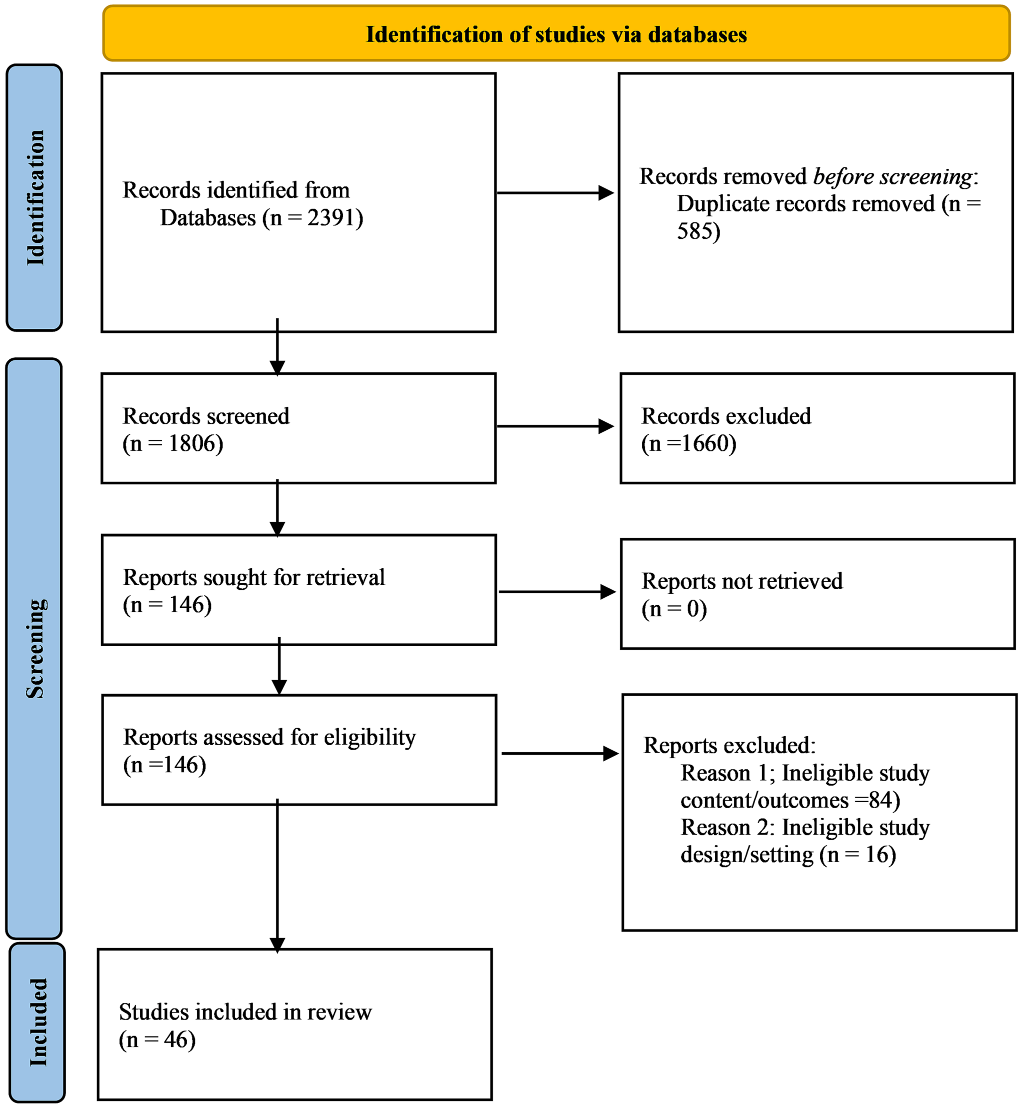

FIGURE 1
PRISMA flow diagram.

that adolescents with low SES had a higher risk of smoking behaviors than those with a high SES background (50, 79, 81, 84, 86–88, 93, 96, 97, 107, 109), while one study found a negative association between low SES and smoking behavior (47). In summary, a majority of 17 studies (94.44%) supported that children (5 studies, 27.77%) and adolescents (12 studies, 66.66%) from low SES backgrounds were more likely to be exposed to, have tried, or smoked daily, compared to those with high SES (see Table 1).

3.3. Parental socioeconomic status and drinking alcohol

3.3.1. Parental socioeconomic status and drinking alcohol among children

Out of 46 studies, 18 studies (25, 47, 50, 53, 79, 83–85, 91, 97, 100–102, 104, 105, 107, 108, 115) assessed the association between SES and drinking alcohol. Of them, seven studies reported a positive association between high SES and drinking alcohol in children (25, 53, 83, 102, 104, 105, 115). This implies that younger children from higher SES backgrounds are more likely to experiment with drinking alcohol compared with their counterparts. One study found a negative association between drinking alcohol and high SES (100).

3.3.2. Parental socioeconomic status and drinking alcohol among adolescents

With regard to SES and drinking alcohol by adolescents, from 18 studies, six reported a negative association between drinking alcohol and high SES (50, 85, 91, 101, 107, 108). Conversely, three studies reported a positive association between drinking alcohol and high SES (47, 79, 97). This positive association indicates that adolescents from a high SES background were found to have a higher chance of drinking alcohol than their counterparts. Moreover, a study by Richter et al. (84) reported that adolescents from Western, Northern, Southern (except Spain), Central and Eastern (except Latvia) Europe, and from a low SES background, were found to have a lower chance of drinking alcohol

TABLE 1 Studies examining the association between parental SES and smoking.

SN	Authors	Methodology description						Findings	Key strengths and limitations	Quality score
		Study design	Sample size (n)	Continent/ country	Age range	SES measure	Method of analysis			
1	Moore and Littlecott (2015)	Cross-sectional, National representative	9,194	Wales	11–16 years	SES	The mixed-effects logistic regression model	Adolescents from high SES were less likely (OR: 0.88, 95% CI, 0.81 to 0.95) to smoke than those from low SES.	High parental SES was linked to healthier behaviors in children and adolescents. Yet, this cross-sectional study, potential self-reporting bias, and the lack of established causation limit definitive conclusions regarding the high SES and reduced adolescent smoking relationship.	8
2	Liu et al. (2016)	Cross-national study	3,690	China and Finland	11–15 years	SES	Logistic regression	In China, low SES adolescents (boys: OR 2.12, 95% CI 1.49–3.01; girls: OR 1.07, 95% CI 0.64–1.81) were more likely to ever smoke compared to those from middle/high SES. In Finland, low SES adolescents (boys: OR 1.17, 95% CI 0.77–1.79; girls: OR 1.68, 95% CI 1.07–2.65) were more likely to smoke weekly than their middle/ high SES counterparts.	Social, economic, and cultural factors influence smoking behaviors among children and adolescents. However, this study used only FAS as the SES measure due to limited common indicators between Chinese and Finnish surveys, suggesting a need to include perceived family wealth for cross-country comparisons.	8
3	Simetin et al. (2013)	Cross-sectional, national representative	1,601	Croatia	15 years	SES	Multi-level logistic regression	Adolescents from high SES were 1.56 times more likely to smoke than those from medium and low SES.	Disposable income, different peer influences, parental attitudes, and access to resources are associated with smoking in adolescents. However, the association between socioeconomic factors and risk behaviors may be influenced by adolescents' relative resilience to socioeconomic inequalities.	8
4	Levin et al. (2014)	Cross-sectional, National representative	2,692	Scotland	15 years	SES	The multilevel logistic regression model	Low SES adolescents had higher odds of smoking, current smoking, daily smoking (Boys: OR smoking 1.58, 95% CI 0.97–2.56; OR current smoking 1.69, 95% CI 0.87–3.29; OR daily smoking 1.82, 95% CI 0.82–4.03; Girls: OR smoking 1.26, 95% CI 0.97–1.64; OR current smoking 1.63, 95% CI 1.18–2.25; OR daily smoking 1.56, 95% CI 1.03–2.25) compared to high SES peers. Low SES adolescents (boys and girls) were also more likely to smoke weekly (OR boys: 1.14, 95% CI 1.00–1.31; OR girls: 1.17, 95% CI 1.02–1.32) than those from high SES.	Lack of educational awareness, and cultural factors contribute to smoking behaviors. However, a study has a low sample size for geographic comparison in ever smoking. Therefore, results might not be conclusive.	8
5	Richter et al. (2009a)	Cross-national survey	97,721	33 countries consisting of Asia ($n = 1$), Europe ($n = 30$), and North America ($n = 2$)	13–15 years	SES	The multilevel logistic regression model	Adolescents from low SES backgrounds had higher weekly smoking rates (Boys: OR 1.14, 95% CI 1.00–1.31; Girls: OR 1.17, 95% CI 1.02–1.32) compared to their high SES counterparts.	Economic stress and parental smoking behaviors are more common in low SES backgrounds. However, interpreting adolescent behavioral patterns obtained from self-reports can be challenging due to the potential influence of social desirability bias, especially in the case of health behaviors like smoking.	8

(Continued)

TABLE 1 (Continued)

SN	Authors	Methodology description						Findings	Key strengths and limitations	Quality score
		Study design	Sample size (n)	Continent/ country	Age range	SES measure	Method of analysis			
6	Doku et al. (2010)	Longitudinal	96,747	Europe (Finland)	12–18 years	Parental occupation, parental educational level	Logistic regression	Adolescents (boys and girls) with fathers in blue-collar occupations had a higher likelihood of smoking (Boys: OR 1.3, 95% CI 1.2–1.4; Girls: OR 1.4, 95% CI 1.3–1.5). Similarly, adolescents (boys and girls) with lower levels of maternal education had a higher chance of smoking (Boys: OR 1.5, 95% CI 1.3–1.6; Girls: OR 1.5, 95% CI 1.4–1.7) compared to those with high maternal educational levels.	Lower occupations and educational levels are often associated with smoking behaviors in children and adolescents. However, this study has a higher non-response rate.	8
7	Richter et al. (2009)	Cross-national	86,667	Europe (*n* = 26) North America (*n* = 2)	13–15 years	Parental occupation, and SES	Logistic regression	European adolescents (from West, North, South, Central, and East regions) with low SES and parental occupation were more likely to smoke compared to those with high or middle SES. Similarly, adolescents in Canada and the USA with low SES had a higher likelihood of smoking than their high or middle-SES peers, particularly when their parents had lower occupational status	Adolescent smoking behaviors were largely determined by low parental SES backgrounds. However, methodological constraints limit findings.	9
8	Poulain, et al. (2019)	Longitudinal	992	German	3–18 years	SES	Mixed-effect model	Children and adolescents aged 10 to 18 with mothers having higher education (OR: 0.86, 95% CI 0.74–0.99), higher occupational status (OR: 0.61, 95% CI 0.47–0.79), and high SES (OR: 0.77, 95% CI 0.58–1.02) had a reduced likelihood of smoking compared to their peers.	Educational influence and role models provide their children with accurate information about the health consequences of smoking. However, this study potentially lacks representativeness in the distribution of socioeconomic classes which may restrict the applicability of the study's results to the broader population.	8
9	Melotti et al. (2011)	Longitudinal	5,699	UK	13 years	Maternal education and parental social status	Multiple logistic regression model	Adolescents with mothers lacking education, lower social class, or low family income had higher odds of ever smoking (OR: 1.14, 95% CI 0.95–1.38; OR: 1.15, 95% CI 0.81–1.60; OR: 1.17, 95% CI 0.92–1.48) compared to their counterparts.	Limited awareness and education associated with risks associated with smoking in adolescents. However, the study has large missing data which might influence the findings.	9
10	Moor et al. (2015)	Cross-national	52,709	35 countries (33 in Europe, North-America and Israel)	15 years	SES	Multilevel regression model	Adolescents with low parental SES had a higher risk of smoking compared to those with higher SES, with more pronounced differences among girls (Boys: OR 1.14, 95% CI 1.05–1.23; Girls: OR 1.36, 95% CI 1.26–1.46).	Social class and peer influence increases the likelihood of smoking. The study measures family SES by material consumption. This may lead to the misclassification of parental social class.	10
11	Park and Hwang (2017)	Cross-sectional	72,435	South-Korea	13–18 years	SES	Multivariate logistic regression	Adolescents from low parental SES had a slightly higher chance of smoking (OR: 1.027, 95% CI 0.929–1.136) compared to those from high parental SES.	Economic instability and stressful events contribute to an increased probability of engaging in smoking behavior. However, the study has some methodological constraints.	8

(Continued)

TABLE 1 (Continued)

SN	Authors	Methodology description						Findings	Key strengths and limitations	Quality score
		Study design	Sample size (n)	Continent/ country	Age range	SES measure	Method of analysis			
12	Johansen et al. (2006)	Cross-sectional	3,458	Denmark	14–16 years	Maternal occupation	GEE logistic regression	Adolescents with unemployed mothers had a slightly higher risk of daily smoking (OR: 1.10, 95% CI 0.77–1.56) compared to their counterparts.	Parental unemployment can increase the probability of smoking in a family, including their children. However, the study did not provide a clear pattern of how SES contributes to smoking.	8
13	Kislitsyna et al. (2010)	Cross-sectional	815	Russia	12–17 years	SES	Logistic regression model	Adolescents with lower parental SES had higher odds of smoking, particularly among girls (Boys: OR: 1.31, 95% CI 0.73–2.35; Girls: OR: 4.08, 95% CI 1.13–14.69), compared to those from higher parental SES.	Higher parental education helps to reduce smoking behaviors in children and adolescents. However, this study underreports the smoking data and leads to inconclusive of findings.	6
14	Doku et al. (2010)	Cross-sectional	1,165	Ghana	13–18 years	Parental income and parental education	Logistic regression	Adolescents with low parental income had a higher smoking risk (OR: 2.2, 95% CI 0.9–5.3) than those from high parental SES. Likewise, those with lower parental education (illiterate) faced a higher smoking risk (OR: 3.0, 95% CI 1.3–7.3) compared to those with high parental education (tertiary).	Income plays a crucial role in adjusting the behaviors of individuals including children and adolescents. However, cause and effect cannot be emphasized as etiological conclusions.	7
15	Simetin et al. (2011)	Cross-sectional.	3,296	Croatia	11–15 years	SES	Binary logistic regression	Children and adolescents with high parental SES had a reduced smoking likelihood (Children: OR 0.4, 95% CI 0.1–1.2; Adolescents: OR 0.8, 95% CI 0.6–1.1) compared to those with low parental SES.	High social class and prestige help to adopt healthy behaviors and reduce the chances of smoking. Self-reporting bias and lack of causation limit conclusions on the high SES and smoking relationship.	6
16	Lazzeri et al. (2014)	Cross-sectional	3,291	Italy	11–15 years	Parental income	Logistic regression	Children and adolescents with high parental income had a reduced smoking likelihood (Children: OR 0.28, 95% CI 0.030–2.40; Adolescents: OR 0.92, 95% CI 0.50–1.67) compared to those with low parental income.	High SES contributes to reducing smoking behaviors in children and adolescents. However, this study also used the self-reported questionnaire, which may introduce inaccuracies that affect statistical connections.	6
17	Sweeting and Hunt (2015)	Cross-sectional	2,503	Scotland	13–15 years	SES	Logistic regression	Adolescents with low parental SES had higher odds of ever smoking and weekly smoking (OR ever smoke: 1.27, 95% CI 0.91–1.78; OR weekly smoke: 1.37, 95% CI 0.91–2.05) compared to those with high parental SES.	The pattern of smoking behaviors is based on parental SES background. However, methodological constraints affect the findings of this study.	6
18	Pförtner et al. (2015)	Cross-national survey	6,511	Belgium, Canada, England, Romania	15 years	SES	Pooled logistic regression models	Adolescents from low SES had a higher chance of smoking (OR: 1.44, OR 95%: CI 1.19–1.83) than those from medium and high SES.	The difference in smoking prevalence is determined by SES. Despite the statistical significance, this study has effect sizes that raise doubts about the significance of these findings.	8

compared to their counterparts; however, adolescents from Scotland, Wales, Norway, Finland, Denmark, Greece, Italy, Malta, Hungary, Russia, and Ukraine were only statistically significant. In summary, out of 18 studies, children (seven studies, or 38.88%) and adolescents (three studies, or 16.66%) from a high SES background had a higher chance of drinking alcohol than those from a low SES background, while six studies (33.33%) found a negative association between a high SES background and drinking alcohol in adolescents (Table 2).

3.4. Parental socioeconomic status and physical activity (PA)

3.4.1. Parental socioeconomic status and physical activity (PA) among children

We identified 15 studies (25, 48, 51, 53, 81, 89, 92, 94, 97, 98, 104, 105, 110, 113, 117) that examined the association between SES and PA. From a total of 15 studies, seven found a positive

TABLE 2 Studies examining the association between parental SES and alcohol consumption.

SN	Authors	Methodology description						Findings	Key strengths and limitations	Quality score
		Study design	Sample size (n)	Continent/ country	Age range	Measure	Method of analysis			
1	Moore and Littlecot (2015)	Cross-sectional	9,194	Wales	11–16 years	SES	The mixed-effects logistic regression model	Children and adolescents with high SES were found to be at a greater risk of drinking alcohol than those who were from low SES.	Families with higher SES backgrounds provide a suitable home environment for drinking alcohol. However, this cross-sectional study lacks to established causal association between the high SES and lower teenage smoking association.	8
2	Simetin et al. (2013)	Cross-sectional	1,601	Croatia	15 years	SES	Multi-level logistic regression	Adolescents from high SES had a higher chance of drunkenness (OR: 1.446; S.E.: 0.16) compared to those from low SES.	Predominantly, higher parental social status increases the probability of drinking alcohol in children and adolescents. However, adolescents' resilience to socioeconomic inequalities may affect the relationship between socioeconomic characteristics and risk behaviors.	8
3	Richter et al. (2009)	Cross-national	86,667	Europe (n = 26) North America (n = 2)	13–15 years	SES, parental occupation	Logistic regression	Low SES adolescents in most European regions had lower alcohol consumption rates, except in Spain and Latvia. Conversely, low SES North American adolescents, except in Canada, had higher alcohol consumption rates. Adolescents in Southern, Northern, and Western Europe with low parental occupation levels showed less alcohol consumption, except in Ireland and Wales. In contrast, adolescents from Central Europe, Eastern Europe, and North America (excluding Canada) with low parental occupation levels had a higher likelihood of alcohol consumption compared to high-occupation level counterparts.	Interestingly, low parental SES and low level of occupation level enhance the heavy alcohol drinking problem in adolescents. However, methodological constraints limit conclusive results.	8
4	Liu et al. (2013)	Cross-national	3,690	China and Finland	11–5 years	SES	Logistic regression	High SES children and adolescents were more likely to initiate alcohol use at an early age (Girls: OR 1.55; Boys: OR 1.92) compared to their counterparts.	HIGH-SES adolescents are more likely to consume alcohol under parental supervision. However, self-reporting questionnaires related to alcohol use may be biased due to social desirability.	8
5	Poulain et al. (2019)	Longitudinal	992	German	3–8 years	SES, maternal education, maternal occupation	Mixed-effect model	Children and adolescents with highly educated mothers (OR: 1.04, 95% CI 0.91–1.18) and mothers in high-occupational positions (OR: 1.01, 95% CI 0.83–1.23) were more likely to engage in alcohol consumption compared to those with lower maternal education and occupation levels.	The availability of alcohol at home for various reasons (i.e., cultural activities, and celebrations) increased the chance of drinking alcohol. However, this study may have limited representativeness across socioeconomic classes, potentially limiting its broader applicability.	9
6	Melotti et al. (2011)	Longitudinal	5,699	UK	13 years	Family income, maternal education, occupation	Multiple logistic regression models	Adolescents with illiterate mothers had higher odds of alcohol consumption (OR: 1.26, 95% CI 1.05–1.52) compared to those with literate mothers. Similarly, adolescents from lower social class backgrounds also had higher odds of alcohol consumption (OR: 1.22, 95% CI 0.88–1.71). Conversely, lower family income was associated with lower odds of alcohol consumption (OR: 0.87, 95% CI 0.68–1.11)	Lower literacy levels and awareness seem to be effective in increasing the consumption of alcohol in adolescents. However, the study exhibits significant gaps in data, potentially impacting the validity and reliability of the conclusions.	10

(Continued)

TABLE 2 (Continued)

SN	Authors	Methodology description						Findings	Key strengths and limitations	Quality score
		Study design	Sample size (n)	Continent/ country	Age range	Measure	Method of analysis			
7	Richter et al. (2006)	Cross-national	142,868	28 countries, including United State of America	11–15 years	SES	The multivariate logistic regression model	Low parental SES was associated with a reduced risk of drunkenness in children and adolescents across most European countries. However, boys from low parental occupation levels had a higher risk of drunkenness in several countries, while girls had a higher risk in most countries with low parental occupation, compared to their counterparts in high parental occupation.	There is a difference in accessing the resources. Indicating that alcohol is expensive, and lower-income families may prioritize basic needs over alcohol purchases. So, adolescents from low SES backgrounds are less likely to consume alcohol than those from high SES backgrounds. However, several methodological aspects limit the explanatory capacity of these results	8
8	Park and Hwang (2017)	Cross-sectional	72,435	South-Korea	13–18 years	SES	Multivariate logistic regression	Adolescents from low SES backgrounds had significantly lower alcohol consumption (OR: 0.809, 95% CI 0.782–0.869) compared to their counterparts.	The level of health literacy seems to decline in the consumption of alcohol in individuals. Thus, adolescents from low SES backgrounds had lower levels of health literacy and were more prone to consume alcohol compared with their counterparts. Nevertheless, there are certain methodological limitations in the study	8
9	Andersen et al. (2007)	Cross-sectional	1,302	Denmark	15 years	Parental social class	Multivariate logistic regression	Adolescents from high parental social class backgrounds were less likely to consume alcohol (Boys: OR: 0.53, 95% CI 0.28–1.01; Girls: OR: 0.55, 95% CI 0.27–1.13) compared to those from low parental social class.	Social prestige seems to be effective in decreasing the consumption of alcohol in adolescents. However, it did not provide a causal relationship between SES and drinking alcohol behavior.	8
10	Johansen et al. (2006)	Cross-sectional	3,458	Denmark	14–16 years	Maternal occupation	GEE logistic regression	Adolescents with unemployed mothers had a significantly reduced risk of weekly alcohol consumption (OR: 0.48, 95% CI 0.34–0.68) compared to their counterparts.	Being unemployed often means having limited financial resources. So, those who were from low SES backgrounds seemed to consume less alcohol compared with their counterparts. However, the study failed to establish a causal association between SES and drinking alcohol behavior.	6
11	Melotti et al. (2013)	Longitudinal	6,170	United Kingdom	11 years	Maternal education	Multivariable logistic regression	Children with mothers who had higher education were less likely to start drinking alcohol early (OR: 0.91, 95% CI 0.84–0.99) compared to their counterparts.	Educated individuals may have a better understanding of the potential negative consequences of alcohol consumption at a young age. Thus, those adolescents belonging to high parental education levels were found to have low alcohol consumption in their children. However, there might be a chance of reporting bias. So findings may be inconsistent.	10
12	Doku et al. (2012)	Cross-sectional	1,195	Ghana	12–18 years	SES	Logistic regression	Adolescents with low parental SES were found to have more drunkenness (OR: 2.3, 95% CI, 1.4–3.9) compared to those with high parental SES.	Adolescents have more free time and fewer constructive ways to spend it, potentially leading to alcohol use. However, data was collected using self-report measures and utilized a cross-sectional research design. So, it cannot establish a causal association and there might be a chance of biases in the findings.	7

(Continued)

TABLE 2 (Continued)

SN	Authors	Methodology description						Findings	Key strengths and limitations	Quality score
		Study design	Sample size (n)	Continent/ country	Age range	Measure	Method of analysis			
13	Simetin et al. (2011)	Cross-sectional.	3,296	Croatia	11–15 years	SES	Binary logistic regression	Children and adolescents with high parental SES were found to have a higher chance of drunkenness (OR: 1.1, 95% CI 0.7–1.7) compared to those with low parental SES.	Social opportunities and the availability of alcohol at home seem to increase the chance of drinking alcohol in children and adolescents. Self-reporting bias and lack of causation limit conclusions on the high SES and drinking alcohol.	8
14	Pedroni et al. (2021)	Cross-sectional	4,364	Belgium	10–14 years	SES	Pearson's chi-square tests and logistic regression	Children and adolescents from low parental SES were less likely to have consumed alcohol (Boys: OR 0.56, 95% CI 0.32–0.98; Girls: OR 0.71, 95% CI 0.40–1.23) compared to their high SES counterpart	Not all adolescents from low SES backgrounds will abstain from alcohol, and many factors, including personal choices, peer influences, and cultural contexts, can influence outcomes. However, the findings did not provide sufficient evidence to establish a causal relationship.	7
15	Lazzeri et al. (2014)	Cross-sectional	3,291	Italy	11–115 years	SES	Logistic regression	Children from households with high parental income had a higher likelihood of alcohol consumption (Children: OR 1.27, 95% CI 0.68–2.37) compared to those from low-income households. Conversely, adolescents with high parental income had a lower likelihood of alcohol consumption (Adolescents: OR 0.71, 95% CI 0.52–0.96) compared to their low-income counterparts.	High parental income often provides children with greater financial resources, allowing them to afford alcohol or attend social events where alcohol is readily available. However, the self-reported questionnaire in this study may contain biases that influence the conclusions.	6
16	Sweeting and Hunt (2015)	Cross-sectional	2,503	Scotland	13–15	SES	Logistic regression	Adolescents with low parental SES were significantly found higher chance of ever drinking alcohol (OR: 1.18,95% CI, 0.69–2.01) compared to those with high parental SES.	Maybe some lower-income communities may contribute to a higher acceptance of alcohol consumption, as a social norm or coping mechanism. However, these results were influenced by potential bias.	9
17	Pape et al. (2018)	Cross-sectional	12,966	Norway	14–17 years	Parental education	Poisson regression	Adolescents with low parental education were found to have a higher chance of drinking alcohol (RR: 1.42, 95% CI 1.24–1.62) compared to their counterparts.	Adolescents with low parental education may have fewer opportunities for extracurricular activities. This can lead to more idle time and an increased likelihood of experimenting with alcohol. However, the findings were influenced by the way of measuring the drinking alcohol leading to unusual results.	8
18	Andersen et al. (2008)	Longitudinal	729	Denmark	15 years	SES	Multivariate logistic regression model	Adolescents from low SES were more likely to drink alcohol (Boys: OR: 1.67, 95% CI, 0.76–3.65) and (Girls: OR: 1.30, 95% CI, 0.47–3.58) than those from high SES.	Adolescents from families with low SES face additional stressors related to financial instability or other challenges. So, adolescents may turn to alcohol as a way to cope with these stressors. However, methodological constraints might influence the results of the study.	10

association between high SES and PA in children (25, 48, 51, 98, 104, 110, 117); however, two reported a negative association between high SES and PA (53, 105). This negative association implies that those children from a high SES background had a lower chance of being physically active compared to their counterparts.

3.4.2. Parental socioeconomic status and physical activity (PA) among adolescents

Five studies found a positive association between high-SES and physical activity in adolescents (89, 92, 94, 97, 113). These findings implied that the adolescents from high parental SES backgrounds were more physically active compared to their counterparts, while one study found a negative association between high SES and PA (81). In summary, children from high-SES backgrounds in seven studies (46.66%) and adolescents in five studies (33.33%) had a higher chance of being more physically active than those from low-SES backgrounds (Table 3).

3.5. Parental socioeconomic status and fruits/vegetables

3.5.1. Parental socioeconomic status and fruits/ vegetables among children

Fourteen studies (48, 53, 79, 81, 82, 84, 89, 90, 95, 99, 106, 110, 111, 118) were identified that examined the association between SES and fruit and vegetable consumption. Ten of these studies found a positive link between high SES and children's consumption of fruits and vegetables (48, 53, 82, 84, 95, 99, 106, 110, 111, 118), which implies that children from a high SES background had a higher chance of consuming high amounts of fruits and vegetables compared to those from low SES backgrounds.

3.5.2. Parental socioeconomic status and fruits/ vegetables among adolescents

From 14 studies that examined the association between SES and the consumption of fruits and vegetables, four studies found a positive association between high SES and the consumption of fruit and vegetables in adolescents (79, 81, 89, 90). A study by Vereecken et al. (82) reported that adolescents from Europe (West, South, North, Central, East), North America, and Asia with low SES were less likely to consume fruits and vegetables than those from high-SES backgrounds. Adolescents from low-SES families in Western Europe, Northern Europe, Southern Europe, North-Eastern Europe (except Estonia, Hungary, Latvia, Russia, and Ukraine), North America, and Asia were less likely to consume vegetables than their counterparts. Overall, high SES was associated with greater rates of fruit and vegetable consumption among children (10 studies or 71.42%) and adolescents (4 studies or 28.57%) compared to low SES (see Table 4).

3.6. Parental socioeconomic status and dietary habits

3.6.1. Parental socioeconomic status and dietary habits among children

A total of 46 studies were included in this review study. Of these, 18 studies (25, 48, 79, 81, 82, 89, 90, 97, 99, 104–106, 111, 112, 114, 116–118) examined the association between SES and healthy diet habits in childhood and adolescence. Of a total of 18 studies, six studies revealed a positive association between high SES and healthy diet habits (e.g., animal products, nutritious food, balanced diet, breakfast) in children (25, 48, 104, 111, 116, 117). Consequently, another four studies reported a positive association between high SES and unhealthy diet (e.g., Biscuits, pastries, irregular breakfast, sweet foods, and soft drinks) (82, 89, 106, 114), while three studies found a negative association between high SES and low consumption of unhealthy dietary foods (99, 105, 118).

3.6.2. Parental socioeconomic status and dietary habits among adolescents

Out of 18 studies that examined the association between SES and dietary habits, five studies reported a positive association between high SES and consumption of healthy dietary food in adolescents (79, 81, 90, 97, 112), implying that adolescents with high parental SES had a higher probability of consuming a high proportion of dairy products, a regular breakfast, a healthy or nutritious diet, a balanced diet, and a low proportion of high-fat diet than those with low SES (see Table 5). In summary, six (33.33%) and five studies (27.77%) were positively associated with high SES and healthy dietary habits in childhood and adolescence, respectively.

3.7. Parental socioeconomic status and cannabis, marijuana, and illicit drug use by adolescents

In this literature review, we assessed three studies (47, 101, 103) out of 46 that examined the relationship between SES and cannabis use and illicit drugs. Of these, one study reported a negative association between high SES and cannabis use (47), while another found a negative relationship between high SES and marijuana consumption (101). Similarly, two other studies found a negative association between high SES and illicit drugs used by adolescents (101, 103). This indicates that adolescents with low SES were found to consume cannabis, marijuana, and illicit drugs more frequently than adolescents from high SES backgrounds. In summary, 66.66%, or two studies, reported a negative association between high SES and illicit drug used in adolescents (see Table 6).

4. Discussion

Our study produced evidence, mostly from cross-sectional and longitudinal studies, that consistently demonstrates a strong relationship between SES and health behaviors. SES plays a major and well-documented influence in the onset and progression of chronic diseases in children and adolescents. Lower-income children and adolescents may have less access to frequent check-ups, preventative care, and early disease identification, increasing their risk of acquiring chronic disorders. Furthermore, SES influences the availability and cost of healthy food. Low-income families may struggle to offer adequate diets, which can contribute to poor eating habits, obesity, and linked chronic illnesses such as type 2 diabetes (52, 119, 120). Childhood and adolescence are regarded as pivotal stages in the development of life foundations in the general population. Focusing on younger ages is important because health behaviors can be learned and consolidated during these ages, affecting an individual's health for the rest of their life. Therefore, this review study aims to examine the association between SES and health behaviors in children and adolescents.

The findings of this review demonstrate that children and adolescents from low SES backgrounds are more likely to engaged in unhealthy behaviors, such as smoking, alcohol consumption, physical inactivity, poor dietary choices, and drug use, when compared to their peers from higher SES backgrounds. These disparities in multiple health behaviors among children and adolescents may

TABLE 3 Studies examining the association between parental SES and physical activity (PA).

SN	Authors	Methodology description						Findings	Key strengths and limitations	Quality score
		Study design	Sample size (n)	Continent/ country	Age range	SES measure	Method of analysis			
1	Moore and Littlecott (2015)	Cross-sectional	9,194	Wales	11–16 years	SES	Mixed-effects logistic regression models	Adolescents from lower SES backgrounds exhibited a higher likelihood of engaging in physical activity (OR: 1.13, 95% CI 1.08, 1.18) compared to their peers from higher SES.	Lower SES backgrounds might have fewer opportunities for indoor entertainment or screen time due to limited access to electronic devices, television, or gaming consoles. However, inappropriate measures of the data and methodological constraints make inconclusive statements about the relationship between high SES and physical activity.	8
2	Hankonen et al. (2017)	Cross-sectional	659	Finland	16–19 years	SES	COM-B model	Adolescents with a lower SES were observed to face an elevated risk of physical inactivity in comparison to their counterparts with a higher SES.	Financial instability or housing insecurity can contribute to increased sedentary behaviors and decreased motivation for physical activity. However, the utilization of self-report measures to assess behavior, abilities, and environmental factors is susceptible to bias.	8
3	Richter et al. (2009a)	Cross-national survey	97,721	Europe (*n* = 30), Asia (*n* = 1), North America (*n* = 2)	13–15 years	SES	The multilevel logistic regression model	Adolescents with a lower SES demonstrated a significantly higher likelihood of engaging in physical activity when compared to their peers from higher SES backgrounds, with odds ratios of (OR: 1.34, 95% CI, 1.26–1.43) for boys and (OR: 1.57,95% CI, 1.45–1.71) for girls.	Lower SES backgrounds might be more likely to walk or bike to school or other destinations due to limited access to private transportation, thereby increasing their overall physical activity levels. However, the findings were influenced by the way physical activity is measured or reported leading to unusual results.	8
4	Yannakoulia et al. (2016)	Cross-sectional, National representative	11,717	Greece	3–18 years	SES	Classification–regression tree analysis (CART) model.	Children and adolescents from higher SES backgrounds tended to dedicate more time to sports activities, with children spending an average of 3.3 h (SD 1.9) compared to 2.7 h (SD 2.4) per week, and adolescents engaging for an average of 4.5 h (SD 3.2) versus 3.1 h (SD 3.0) per week for those from lower SES.	Higher SES communities may have better access to sports facilities, parks, and recreation programs, creating a supportive environment for sports participation. However, a low response rate might distort the findings	8
5	Poulain et al. (2019)	Longitudinal	2,492	German	3–18 years	SES	Mixed-effect model	Adolescents with mothers having higher SES had greater odds of being physically active (OR: 1.83, 95% CI: 1.45–2.31) than those with lower SES. Similarly, children with higher SES (OR: 1.42, 95% CI: 1.14–1.77) were more engaged in physical activities than those with lower SES.	Families may place a stronger emphasis on physical fitness and active lifestyles. However, this study may have limited representativeness across socioeconomic classes, potentially limiting its broader applicability.	9
6	Yang (2021)	Cross-sectional	1,040	South Korea	10–11 years	SES	Multiple linear regression model	Children from higher parental SES engaged in more weekly physical activity (β: 0.08, $p < 0.05$) than those from lower parental SES	Parenting role modeling may serve as positive role models for their children. However, this study limits the causal inferences.	8
7	Krist et al. (2017)	Cross-sectional	1,523	Germany	12–13 years	SES	A generalized linear mixed model with a logit	Children and adolescents from low parental SES had lower odds of physical activity (OR low: 0.90, 95% CI: 0.63–1.29) than those from high parental SES	Lack of role models may be fewer visible role models who prioritize and engage in physical activity. However, due to the structure of the questionnaire, the findings were overestimated.	8
8	Park and Hwang. (2017)	Cross-sectional	72,435	South-Korea	13 to 18 years	SES	Multivariate logistic regression	Adolescents with low parental SES had a higher risk of no physical activity (OR: 1.425, 95% CI: 1.336–1.521) than those with high parental SES	financial instability can contribute to increased sedentary behaviors and decreased motivation for physical activity. Nevertheless, there are certain methodological limitations in the study	8

(Continued)

TABLE 3 (Continued)

SN	Authors	Methodology description						Findings	Key strengths and limitations	Quality score
		Study design	Sample size (n)	Continent/ country	Age range	SES measure	Method of analysis			
9	Henriksen et al. (2016)	Cross-sectional	6,269	Denmark	11–15 years	Parental social class	Logistic regression	Children and adolescents from low parental social class face a higher risk of physical inactivity (OR: 2.10, 95% CI: 1.39–3.18) than those from high parental social class.	Time Constraints which can limit the time available for physical activities. However, this phenomenon is not conducive to casual interpretations.	6
10	de Buhr and Tannen (2020)	Cross-sectional	4,294	German	6–13 years	SES	Spearman's Rho correlations	Children from higher parental SES were more physically active (r: 0.079, 95% CI: 0.025–0.132) than those from lower parental SES.	Education and awareness seem to a protective factor and make them more physically active. However, interpreting adolescent PA patterns obtained from self-reports can be challenging due to the potential influence of social desirability bias.	8
11	Pavon et al. (2010)	Cross-sectional	3,259	Nine European countries (Sweden, Greece, Italy, Spain, Hungary, Belgium, France, Germany, and Austria)	12–17 years	SES	One-way analysis of covariance	Adolescents with high parental SES exhibited significantly better physical fitness ($p < 0.05$) than those with low parental SES.	Access to resources appears to have a positive impact on promoting physical activity. However, methodological issues might to a risk of inconclusive findings.	6
12	Falese et al. (2021)	Cross-sectional	10,510	Six European cities (Namur, Tampere, Hannover, Latina, Amersfoort, and Coimbra).	14–17 years	Parental income and parental education	The multilevel multivariable linear regression model	Adolescents with higher parental education levels were more likely to engage in more vigorous physical activity (OR: 2.7, 95% CI: 0.3–5.1), and those with higher parental income had increased physical activity (OR: 4.7, 95% CI: 2.8–6.6) compared to their counterparts.	Awareness and knowledge lead them to encourage themselves to be physically active. However, Self-reported measures of physical activity intensity may lead to either overestimation or underestimation	8
13	Simetin et al. (2011)	Cross-sectional	3,296	Croatia	11–15 years	SES	Binary logistic regression	Children and adolescents with high parental SES had greater odds of engaging in physical activity (OR children: 1.8, 95% CI: 1.3–2.5; OR adolescents: 1.3, 95% CI: 0.9–1.8) than those with low parental SES	Access to resources and facilities increases the likelihood of physical activity. However, self-reporting bias and lack of causation limit conclusions on the high SES and PA.	6
14	Al Sabbah et al. (2007)	Cross-sectional	8,885	Palestine	12–18 years	Maternal education	Logistic regression	Adolescents with high maternal education were more likely to engage in more physical activities (OR: 1.26, 95% CI: 1.09–1.46) than those with low maternal education.	Health literacy encourages them to promote physical activity for a healthy lifestyle. Nevertheless, self-reported measurements of physical activity might result in either an overestimation or underestimation.	6
15	Lazzeri et al. (2014)	Cross-sectional	3,291	Italy	11–15 years	Parental income	Logistic regression	Children and adolescents with high parental income were more likely to fall short of physical activity guidelines (OR children: 1.30, 95% CI: 0.48–3.55; OR adolescents: 5.0, 95% CI: 0.66–37.6) compared to those with low parental income	Access to digital devices and entertainment options that can potentially reduce physical activity levels. However, the finding may be influenced by measurement errors in physical activity data	6

be possibly due to low parental SES, which limits access to healthy food, physical activity, and health education. Lower parental SES also correlates with low health literacy, which may lead to a lack of awareness about the importance of healthy behaviors. These findings align with existing literature, highlighting the impact of economic constraints in low-SES households, hindering access to health-promoting resources. Limited financial resources often result in inadequate nutrition, reduced physical activity opportunities, and lower educational attainment, contributing to reduced health awareness (120–124). This knowledge and resource gap influences healthy behaviors in individuals, children, and adolescents. As a result, it is critical to emphasize the need for tailored interventions for disadvantaged children and adolescents.

In the context of SES and smoking behavior among children and adolescents, the results of this review study reported that children and adolescents with low parental SES backgrounds had heightened vulnerability to early exposure to smoking during childhood and early initiation of smoking during adolescence. This susceptibility may be attributed to a confluence of factors, including pervasive tobacco advertising, normalization of smoking within their social environments, easy access to cigarettes, limited social support for smoking cessation, heightened nicotine dependence, and the burden

TABLE 4 Studies examining the association between SES and fruits and vegetables consumption.

SN	Authors	Methodology description						Findings	Key strengths and limitations	Quality score
		Study design	Sample size (n)	Continent/ country	Age range	SES measure	Method of analysis			
1	Mikki et al. (2010)	Cross-sectional survey	2,952	Palestine	13–15 years	Parental education	The multivariate linear regression model	Adolescents with high parental education consumed fruits and vegetables more frequently (6.3 times per week) than those with low parental education.	Healthy eating habits are more prone in highly educated families which can influence their children's healthy dietary choices. One potential constraint of this study is the utilization of self-reported responses, which has the potential to impact both the validity and reliability of the findings.	8
2	Moore and Littlecott (2015)	Cross-sectional	9,194	Wales	11–16 years	SES	Mixed-effects logistic regression models	Children and adolescents with low SES had a lower likelihood (OR: 1.15, 95% CI: 1.10–1.20) of consuming fruits and vegetables compared to those from high SES.	Food insecurity can result in less frequent consumption of fruits and vegetables. However, this cross-sectional study lacks to established causal association between high SES and the consumption of fruits and vegetables.	8
3	Yannakoulia et al. (2016)	Cross-sectional, National representative	11,717	Greece	3–18 years	SES	Classification–regression tree analysis (CART) model	Children and adolescents from low SES consumed fewer fruits (31.2 and 25.3%, respectively) and vegetables (56.7 and 55.5%, respectively) than those from high SES.	Limited financial resources can make it difficult to afford fresh fruits and vegetables regularly. However, a low response rate might distort the findings	8
4	Richter et al. (2009a)	Cross-national survey	97,721	Europe (*n* = 30), Asia (*n* = 1), North America (*n* = 2)	13–15 years	SES	The multilevel logistic regression model	Adolescents with low SES had lower odds of consuming fruits and vegetables (OR boys: 0.61, 95% CI: 0.54–0.70; OR girls: 0.78, 95% CI: 0.73–0.84) than those with high SES.	Affordable food sources limit access to these nutritious options. However, self-reported adolescent behavioral patterns can make it difficult to estimate the inclusive results.	8
5	Richter et al. (2009)	Cross-national survey	86,667	Europe (*n* = 26) North America (*n* = 2)	11–15 years	SES	Logistic regression	Children and adolescents from various regions, including Southern, Northern, Western, Eastern, Central Europe, Northern America (USA and Canada), and Asia (Israel), had a lower likelihood of consuming vegetables if they were from low SES compared to high SES	SES disparities exist in many regions that can limit their ability to access and afford fresh vegetables. However, methodological constraints limit findings.	8
6	Svastisalee et al. (2012)	Cross-sectional	6,034	Denmark	11–15 years	Parental occupation	The multilevel logistic regression model	Children and adolescents from higher parental social class had a higher likelihood of consuming fruits (OR: 1.46, 95% CI: 1.24–1.71) and vegetables (OR: 1.86, 95% CI: 1.58–2.19) compared to those from lower social class	Higher social classes may be part of social circles that emphasize fruits and vegetables. Due to the nature of the data, this study is unable to draw a causality between SES and consumption of fruit and vegetables.	8
7	Vereecke et al. (2005)	Cross-national	114,558	28 European countries	11–15 years	SES, parental occupation	Multiple regression model	Children and adolescents from high parental SES had a higher likelihood of daily fruit consumption (OR: 1.530, 95% CI: 1.479–1.581) compared to those from low SES. Similarly, adolescents from high parental occupation levels had a higher likelihood of daily fruit consumption (OR: 1.186, 95% CI: 1.148–1.227) compared to their peers.	Healthy lifestyle prioritization contributes to daily fruit consumption. However, due to the poor classification of data measurement draws a poor conclusion.	6
8	Zaborskis et al. (2021)	Cross-national	192,755	42 countries including 40 countries from Europe, Canada, and Israel	11–15 years	SES	Logistic regression model and structural equation model	Adolescents with low parental SES were less likely to consume daily fruits (OR: 0.51; 95% CI: 0.49–0.53), vegetables (OR: 0.58; 95% CI: 0.56–0.60), and sweets (OR: 0.94; 95% CI: 0.90–0.97) than those with higher parental SES.	Access to affordable food and nutritional knowledge incorporated into diets. However, the findings are concerned with potential bias.	7
9	Voráčová et al. (2016)	Cross-sectional	10,831	Czech republic	11–15 years	SES	Logistic regression	Children and adolescents from higher parental SES backgrounds had higher odds of daily fruit (OR: 1.67, 95% CI: 1.34–2.08) and vegetable consumption (OR: 1.54, 95% CI: 1.22–2.00) compared to those from lower SES.	Food accessibility seems to increase the consumption of fruits and vegetables. However, eating habits as reported may have been influenced by social desirability	8

(Continued)

TABLE 4 (Continued)

SN	Authors	Methodology description						Findings	Key strengths and limitations	Quality score
		Study design	Sample size (n)	Continent/ country	Age range	SES measure	Method of analysis			
10	de Buhr and Tannen (2020)	Cross-sectional	4,294	German	6–13 years	SES	Spearman's Rho correlations	Children from higher parental SES consumed more vegetables and salad (r: 0.100, 95% CI: 0.047–0.153) and fruits (r: 0.086, 95% CI: 0.032–0.139) than those from lower SES.	Financial resources, nutritional knowledge, and healthy lifestyle prioritization contribute to increased consumption of healthy food. However, it does not explain whether SES influences dietary choices or if dietary choices influence SES	8
11	Johansen et al. (2006)	Cross-sectional	3,458	Denmark	14–16 years	Maternal occupation	GEE logistic regression	Adolescents with high maternal occupation significantly consumed more fruits and vegetables (OR: 1.65, 95% CI: 1.15–2.36) compared to their peers.	High-occupation may cultivate a health-conscious environment that encourages the consumption of fruits and vegetables. However, the study failed to establish a causal association between SES and healthy food behavior.	6
12	Nardone et al. (2020)	Cross-sectional	58,976	Italy	11–15 years	Parental income and parental education	Logistic regression	Children and adolescents with high parental education were more likely to consume fruits and vegetables (OR: 0.54, 95% CI: 0.48–0.61), as were those with high parental income (OR: 0.70, 95% CI: 0.64–0.77) compared to their counterparts with lower education and income.	Health-conscious behavior may prioritize providing nutritious foods. The poor study setting did not provide a valid conclusion.	6
13	Al Sabbah et al. (2007)	Cross-sectional	8,885	Palestine	12–18 years	Maternal education	Logistic regression	Adolescents with high maternal education were more likely to consume more fruits (OR: 1.35, 95% CI: 1.19–1.53) and vegetables (OR: 1.10, 95% CI: 0.98–1.24) compared to those with low maternal education.	Nutritional information associated with consuming fruits and vegetables. Nevertheless, self-reported measurements might result in either an overestimation or underestimation of the findings.	6
14	Zaborskis et al. (2012)	Cross-sectional	33,230	Lithuania	11–15 years	Parental income	Binary logistic regression	Adolescents with high parental income were more likely to consume fruits daily (OR: 2.15, 95% CI: 1.86–2.49) and vegetables (OR: 1.12, 95% CI: 0.97–1.28) compared to those with low parental income.	Families with higher incomes often have better access to fresh fruits and vegetables on a daily basis. However, it is hard to make causality inferences due to the study design.	8

of stressful life circumstances. These findings substantiate the existing body of literature, which consistently demonstrates an elevated prevalence of smoking within lower SES strata, often attributed to factors such as a paucity of robust social support networks and the presence of stress-inducing lifestyles. Furthermore, children from low SES backgrounds are approximately 6.6 times more likely to be exposed to secondhand smoke within their parental residences compared to their counterparts in high- SES households (125–127). This discrepancy underscores the urgent need for targeted interventions to mitigate the adverse consequences of smoking in vulnerable populations, particularly during the critical period of life.

On the other hand, alcohol consumption was significantly higher among adolescents with high SES. These findings align with those of previous research, reinforcing the robust association between SES and adolescent alcohol consumption. Specifically, adolescents from high parental SES backgrounds exhibit increased odds of alcohol use (OR = 1.4, 95% CI = 1.19–1.78) (128). Recent research by Torchyan et al. (129) further substantiates this phenomenon, indicating a heightened likelihood of weekly alcohol consumption (OR = 1.24, 95% CI = 1.16–1.32) among high-SES adolescents when compared to their counterparts (129). This persistent pattern has been confirmed in other studies, indicating that high-SES adolescents are more likely to consume alcohol under parental supervision than their counterparts, (130). This could be explained through social and cultural activities (business meetings, and, party celebrations), the availability of alcohol at home, and the availability of pocket money to purchase alcohol (131). This review underlines early alcohol initiation among children with high SES, which is often influenced by parental drinking behavior (132). Thus, parental discretion in alcohol consumption around children is pivotal in preventing negative alcohol-related behavior (133). Therefore, this study suggests that parents should take care while drinking alcohol in front of their children to prevent them from developing bad alcohol-related behavior.

In addition, our review study found that children and adolescents with high SES were more likely to be engaged in physical exercise. These findings are consistent with previous studies and led to the conclusion that parental SES (OR = 2.73, 95% CI = 2.18, 3.42) were significantly ($p < 0.05$) associated with participation in indoor and outdoor physical activities by children and adolescents (134, 135). If parents had a good family income, there would be a higher chance of availability of goods and material resources at home (136). This availability of materials would make it possible to be more engaged in physical activity rather than spending more time watching television or

TABLE 5 Studies examining the association between parental SES and diet habits.

SN	Authors	Methodology description						Findings	Key strengths and limitations	Quality score
		Study design	Sample size (n)	Continent/ country	Age range	SES measure	Method of analysis			
1	Mikki et al. (2010)	Cross-sectional survey	2,952	Palestine	13–15 years	Parental education	The multivariate linear regression model	Adolescents with higher parental education were more likely to have a healthier dietary pattern compared to those with lower parental education	Awareness of health risks associated with poor dietary choices. This awareness can motivate them to emphasize healthy eating in their households. One potential constraint of this study is the utilization of self-reported responses, which has the potential to impact both the validity and reliability of the findings.	8
2	Yannakoulia et al. (2016)	Cross-sectional, National representative	11,717	Greece	3–18 years	SES	Classification–regression tree analysis (CART) model	Children and adolescents from low SES backgrounds had lower consumption of dairy products and daily breakfast than those from high SES backgrounds. Similarly, low SES adolescents had lower consumption of dairy products and daily breakfast than their high SES peers.	Lower-educated parents may have less knowledge about the nutritional benefits. So, they may not prioritize healthy foods in their children's diets. However, self-reported adolescent behavioral patterns can make it difficult to estimate the inclusive results.	8
3	Richter et al. (2009a)	Cross-national survey	97,721	Europe (*n* = 30), Asia (*n* = 1), North America (*n* = 2)	13–15 years	SES	The multilevel logistic regression model	Adolescents with low SES had a reduced likelihood of consuming breakfast (OR boys: 0.75, 95% CI: 0.66–0.86; OR girls: 0.83, 95% CI: 0.75–0.93) compared to those with high SES	Economic constraints limit their access to a variety of nutritious breakfast options. However, the findings were influenced by the way physical activity is measured or reported leading to unusual results.	8
4	Poulain et al. (2019)	Longitudinal	1,223	German	3–18 years	SES	Mixed-effect models	Children (β: 0.05, 95% CI −0.03 to 0.13) and adolescents (β: 0.10, 95% CI: 0.01–0.18) in higher-SES were more likely to consume nutritious food compared to those in lower-SES families	Education and nutrition knowledge emphasize the importance of fruits, vegetables, and other healthy food items. However, this study may have limited representativeness across socioeconomic classes, potentially limiting its broader applicability.	9
5	Vereecke et al. (2005)	Cross-national	114,558	28 European countries	11–15 years	SES	Multiple regression model	Children and adolescents with high SES were more likely to consume a higher number of soft drinks (OR: 1.257, 95% CI: 1.211–1.305) compared to their peers.	Higher disposable may have greater purchasing power for non-essential items. Due to the poor classification of data measurement draws a poor conclusion.	6
6	Sinai et al. (2021)	Cross-sectional	3,902	Isreal	11–18 years	SES	Multiple regression model	Adolescents with higher SES had a higher consumption of plant-based foods, cereals, milk, and spreads (OR Plant-based food: 1.50, 95% CI: 1.23–1.82, OR Cereals and milk: 1.10, 95% CI: 0.91–1.33) compared to those with lower SES.	Access to resources and health consciousness make easier for people from high SES backgrounds to incorporate these foods into their diets. However, self-reported information could influence the results.	8
7	Yang (2021)	Longitudinal	1,040	South Korea	10–11 years	SES	Multiple linear regression model	Children from higher parental SES levels were more likely to consume healthy food (β = 0.07, *p* = 0.018) compared to their peers.	Parents prioritize healthy eating behaviors which are more likely to adopt similar habits to their children. However, this study limits the causal inferences	10
8	Esquius et al. (2021)	Cross-sectional	7,319	Spain	12–18 years	SES	Multilevel Poisson regression models	Adolescents with low SES were at a higher risk of skipping breakfast (PR boys: 1.28, 95% CI: 1.04–1.58; PR girls: 1.30, 95% CI: 1.12–1.52) compared to their peers	Time and routine constraints can make it difficult to prioritize breakfast. Self-reported adolescent diet patterns can be difficult to assess because of social desirability bias.	8
9	Park and Hwang (2017)	Cross-sectional	72,435	South-Korea	13–18 years	SES	Multivariate logistic regression	The odds of skipping breakfast were significantly higher (OR: 1.433, 95% CI: 1.347–1.523) for adolescents with low parental SES compared to those with high parental SES.	Food insecurity can result in irregular meal patterns, including breakfast-skipping. Nevertheless, there are certain methodological limitations in the study	8
10	Voráčová et al. (2016)	Cross-sectional	10,831	Czech Republic	11–15 years	SES	Logistic regression	Children and adolescents from higher parental SES backgrounds had lower odds of consuming sweets (OR: 0.79, 95% CI: 0.69–0.90) and soft drinks (OR: 0.41, 95% CI: 0.31–0.53) compared to their peers.	Parental monitoring can lead to healthier food choices for their children. However, eating habits as reported may have been influenced by social desirability bias.	8

(Continued)

TABLE 5 (Continued)

SN	Authors	Methodology description						Findings	Key strengths and limitations	Quality score
		Study design	Sample size (n)	Continent/ country	Age range	SES measure	Method of analysis			
11	Johansen et al. (2006)	Cross-sectional	3,458	Denmark	14–16 years	Maternal occupation	GEE logistic regression	Adolescents with unemployed mothers had significantly higher odds of irregular breakfast consumption (OR: 1.56, 95% CI: 1.06–2.29) compared to their peers.	Unemployment can lead to food insecurity in the household. In such cases, adolescents may skip meals, including breakfast. However, the study did not provide a clear pattern of how SES contributes to eating a healthy diet.	6
12	Morgan et al. (2021)	Longitudinal	176,094	Wales	11–16 years	SES	Multinomial logistic regression	Children and adolescents with low SES had a lower likelihood of daily sugar-sweet beverage consumption (RRR: 0.68, 95% CI: 0.66–0.70) and lower consumption of energy drinks (RRR: 0.67, 95% CI: 0.63–0.70) compared to those with high SES.	Low SES neighborhoods may have limited access to stores that offer soft drink beverage options. Methodological constraints affect the findings of this study.	8
13	Nardone et al. (2020)	Cross-sectional	58,976	Italy	11–15 years	Parental income and parental education	Logistic regression	Children and adolescents with higher parental education were less likely to skip breakfast (OR: 0.75, 95% CI: 0.67–0.84), as were those with higher parental income (OR: 0.84, 95% CI: 0.76–0.92).	Health consciousness can provide guidance on healthy eating habits, including breakfast. The poor study setting did not provide a valid conclusion.	6
14	Simetin et al. (2011)	Cross-sectional	3,296	Croatia	11–15 years	SES	Binary logistic regression	Children from high parental SES backgrounds had a higher likelihood of consuming regular breakfast (OR: 1.3, 95% CI: 1–1.8) compared to those from low parental SES.	Higher resources and knowledge emphasis on regular breakfast consumption. However, self-reporting bias and lack of causation limit conclusions on the high SES and consumption of diet.	6
15	Al Sabbah et al. (2007)	Cross-sectional	8,885	Palestine	12–18 years	Maternal education	Logistic regression	Adolescents with higher maternal education were more likely to consume sweets (OR: 1.15, 95% CI: 1.01–1.30) and soft drinks (OR: 1.28, 95% CI: 1.11–1.48) compared to those with low maternal education.	Consumption of sweets and soft drinks can be influenced by cultural and social norms. Nevertheless, self-reported measurements might result in either an overestimation or underestimation of the findings.	6
16	Lazzeri et al. (2014)	Cross-sectional	3,291	Italy	11–15 years	Parental income	Logistic regression	Children and adolescents with high parental income were more likely to have irregular breakfast consumption (OR children: 1.12, 95% CI: 0.60–2.09; OR adolescents: 1.80, 95% CI: 0.98–3.31) compared to those with low parental income.	Parents from high SES backgrounds may have demanding jobs or work long hours, which can affect the time allocated for breakfast preparation and consumption. However, the finding may be influenced by measurement errors.	6
17	Zaborskis et al. (2012)	Cross-sectional	33,230	Lithuania	11–15 years	Parental income	Binary logistic regression	Children and adolescents with high parental income were more likely to regularly consume sweets and chocolates, regularly drink soft drinks, and regularly consume biscuits and pastries (OR for sweets and chocolates: 1.48, 95% CI: 1.31–1.68; OR for soft drinks: 1.39, 95% CI: 1.21–1.60; OR for biscuits and pastries: 1.38, 95% CI: 1.17–1.63) compared to those with low parental income	Accessibility and parental time constraints can lead to an increase in the consumption of fast food including chocolates, soft drinks, biscuits, and pastries. However, it is hard to make causality inferences due to the study design.	8
18	Zaborskis et al. (2021)	Cross-national	192,755	42 countries including 40 countries from Europe, Canada, and Israel	11–15 years	SES	Logistic regression model and structural equation model	Children and adolescents from low parental SES were more likely to consume more soft drinks (OR: 1.25; 95% CI: 1.20, 1.30) than those from higher parental SES.	Soft drinks are often more affordable than healthier beverage options. However, the findings are concerned with potential bias.	7

being inactive (137). However, children and adolescents from lower parental SES backgrounds were found to participate less often in physical activity but were more often involved in sedentary behaviors. Previous studies have found that poor parental SES backgrounds were significantly associated with poor physical activity, high sedentary activity, and high screen time in children and adolescents (113, 138, 139). Moreover, there was ample evidence to suggest that more children and adolescents from deprived SES were more likely to spend more time inside the home due to a lack of a secure neighborhood, lack of green areas for sports and recreational activities, and the cost associated with physical activity (140, 141).

TABLE 6 Studies examining the association between SES and cannabis, and illicit drug use.

SN	Authors	Methodology description						Findings	Key strengths and limitations	Quality score
		Study design	Sample size (n)	Continent/ country	Age range	SES measure	Methodology			
1	Simetin et al. (2013)	Cross-sectional	1,601	Croatia	15 years	SES	Multi-level logistic regression	Adolescents from high SES backgrounds had a higher likelihood of cannabis consumption (OR: 1.49; SE: 0.22) compared to those from low SES.	High-SES adolescents have more disposable income, making cannabis and other drugs easier to afford. However, the association between socioeconomic factors and risk behaviors may be influenced by adolescents' relative resilience to socioeconomic inequalities	8
2	Doku et al. (2012)	Cross-sectional	1,195	Ghana	12–18 years	SES	Logistic regression	Adolescents from low parental SES were more likely to use marijuana (OR: 12.4, 95% CI: 3.7–41.0) and illicit drugs (OR: 15.9, 95% CI: 3.7–67.8) than those from high parental SES.	Economic pressures can increase teenage stress and anxiety. They may be more tempted to utilize drugs. However, data was collected using self-report measures and utilized a cross-sectional research design. So, it cannot establish a causal association and there might be a chance of biases in the findings.	7
3	Lee et al. (2018)	Longitudinal	3,395	USA	12–16 years	Parental education		Adolescents with lower parental education were more likely to use illicit drugs (β: 0.08, 95% CI: 0.004–0.158) compared to those with higher parental education	Inequality in information and peer pressure enhance illicit drug use. However, the findings were distorted due to the measurement bias.	9

In relation to SES and diet (e.g., dairy products, fruit, vegetables, breakfast, soft drinks, and high-fat diet), we found that higher SES was positively associated with the consumption of breakfast, dairy products, fruit, vegetables, and a balanced diet, but negatively associated with consumption of sugar, sugar items, high- fat diet, and soft drinks. The findings of this review study are consistent with those of other studies that show that parental SES has a strong influence on children's diet (142). These findings show that children and adolescents from high-SES families consume a healthy proportion of calories ($\beta = 1.86$, SE = 0.76) rather than high-energy foods (143). Children and adolescents from low-SES families may have few food options and may even face food insecurity and scarcity at home (144). Therefore, low parental SES may lead to low price food, high-fat diet, high- salt food, energy-dense food, and low intake of regular breakfast, dairy products, fruits, and vegetables during childhood and adolescence (144–147).

Moreover, in the context of SES and cannabis and illicit drug abuse in adolescents, there was a correlation between the consumption of cannabis and illicit drug abuse and low parental SES, poor schooling, unsafe neighborhoods, and stressful daily life events. Thus, it is important to consider how parental SES particularly affects an adolescent's health behaviors. This review study revealed that 66.66% of the adolescents had consumed illicit drugs. These conditions increase the risk of physical, psychological, social, and emotional competence in adolescents. These findings could help to provide information about how low parental SES affects children and adolescents, and thus motivate authorities to carry out preventative activities and appropriate rules, regulations, and policies to promote healthy lifestyles in children and adolescents (148). Overall, risky health behaviors were found to be a major concern, particularly in children and adolescents with low parental SES. These conditions may increase the risk of poor health and development in childhood and adolescence. Therefore, to control these issues, an appropriate strategy helps to protect and prevent risky health behaviors in children and adolescents and gives them equal rights, services, and facilities to fight against inequalities. Hence, this study indicated that parental SES play a significant role in developing social and emotional competence and positive health outcomes in children and adolescents. Therefore, authorities and government bodies should pay more attention to the health and health behaviors of every individual, including children and adolescents, and provide support to children and adolescents, especially those with low parental SES.

5. Strength and limitations

This study comprehensively examined the association between SES and health behaviors, including protecting and impairing health behaviors in children and adolescents across the world. Moreover, this study used multiple databases and followed a structural research process that provided transparent, unbiased, and reliable information on SES and health behaviors. In summary, this study's strengths lie in its comprehensive approach, use of multiple databases, adherence to a structured research process, and commitment to providing unbiased information. However, this study had certain limitations. The heterogeneity of the studies makes Meta-Analysis not possible. Another limitation is no risk of bias and no registration in "PROSPERO," was remedied by that two researchers have independently assessed each article, and that a Quality Score was provided (Supplementary Table S4) as well as a "PRISMA" approach (Supplementary Table S3).

6. Conclusion

The current study revealed a robust association between low parental SES and a myriad of unhealthy behaviors (high smoking behavior, low physical exercise, illicit drug use, low consumption of fruit and vegetables, and unhealthy diet) in children and adolescents. However, alcohol consumption was more common in adolescents with a high parental SES. Based on these significant findings, this study underscores the urgent need for an appropriate intervention program that caters to the unique needs of children and adolescents from low-SES families. By implementing measures such as free all-day schools with complementary meals, free after-school activities, and supervised homework sessions, we can bridge the gaps in opportunities, capabilities, and productivity, thereby fostering healthier and more promising futures for these individuals.

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

NG: conceptualization, data curation, methodology, software, formal analysis, and original drafting. GD: methodology, reviewing, editing, supervision, and validation. MR: reviewing, editing, supervision, and validation. RK: conceptualization, reviewing, editing, supervision, and validation. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1228632/full#supplementary-material

References

1. Kivimäki M, Batty GD, Pentti J, Shipley MJ, Sipilä PN, Nyberg ST, et al. Association between socioeconomic status and the development of mental and physical health conditions in adulthood: a multi-cohort study. *Lancet Public Health*. (2020) 5:e140–9. doi: 10.1016/S2468-2667(19)30248-8

2. Yusuf S, Joseph P, Rangarajan S, Islam S, Mente A, Hystad P, et al. Modifiable risk factors, cardiovascular disease, and mortality in 155 722 individuals from 21 high-income, middle-income, and low-income countries (PURE): a prospective cohort study. *Lancet*. (2020) 395:795–808. doi: 10.1016/S0140-6736(19)32008-2

3. Qin Z, Wang N, Ware RS, Sha Y, Xu F. Lifestyle-related behaviors and health-related quality of life among children and adolescents in China. *Health Qual Life Outcomes*. (2021) 19:8. doi: 10.1186/s12955-020-01657-w

4. Macsinga I, Nemeti I. The relation between explanatory style, locus of control and self-esteem in a sample of university students. *Procedia Soc Behav Sci*. (2012) 33:25–9. doi: 10.1016/j.sbspro.2012.01.076

5. Janowski K, Kurpas D, Kusz J, Mroczek B, Jedynak T. Health-related behavior, profile of health locus of control and acceptance of illness in patients suffering from chronic somatic diseases. *PLoS One*. (2013) 8:e63920. doi: 10.1371/journal.pone.0063920

6. Patterson RE, Haines PS, Popkin BM. Health lifestyle patterns of US adults. *Prev Med*. (1994) 23:453–60. doi: 10.1006/pmed.1994.1062

7. Hirdes JP, Forbes WF. The importance of social relationships, socioeconomic status and health practices with respect to mortality among healthy Ontario males. *J Clin Epidemiol*. (1992) 45:175–82. doi: 10.1016/0895-4356(92)90010-K

8. Wiley JA, Camacho TC. Life-style and future health: evidence from the Alameda County study. *Prev Med*. (1980) 9:1–21. doi: 10.1016/0091-7435(80)90056-0

9. McGinnis JM, Foege WH. Actual causes of death in the United States. *JAMA*. (1993) 270:2207. doi: 10.1001/jama.1993.03510180077038

10. Braveman P, Gottlieb L. The social determinants of health: it's time to consider the causes of the causes. *Public Health Rep*. (2014) 129:19–31. doi: 10.1177/00333549141291S2

11. Peacock A, Leung J, Larney S, Colledge S, Hickman M, Rehm J, et al. Global statistics on alcohol, tobacco and illicit drug use: 2017 status report. *Addiction*. (2018) 113:1905–26. doi: 10.1111/add.14234

12. King DE, Mainous AG III, Carnemolla M, Everett CJ. Adherence to healthy lifestyle habits in US adults, 1988-2006. *Am J Med*. (2009) 122:528–34. doi: 10.1016/j.amjmed.2008.11.013

13. Guthold R, Stevens GA, Riley LM, Bull FC. Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1· 9 million participants. *Lancet Glob Health*. (2018) 6:e1077–86. doi: 10.1016/S2214-109X(18)30357-7

14. Falci CD. Self-esteem and mastery trajectories in high school by social class and gender. *Soc Sci Res*. (2011) 40:586–601. doi: 10.1016/j.ssresearch.2010.12.013

15. Twenge JM, Campbell WK. Self-esteem and socioeconomic status: a meta-analytic review. *Personal Soc Psychol Rev*. (2002) 6:59–71. doi: 10.1207/S15327957PSPR0601_3

16. Schwartz CE, Zhang J, Stucky BD, Michael W, Rapkin BD. Is the link between socioeconomic status and resilience mediated by reserve-building activities: mediation analysis of web-based cross-sectional data from chronic medical illness patient panels. *BMJ Open*. (2019) 9:e025602. doi: 10.1136/bmjopen-2018-025602

17. Zou R, Xu X, Hong X, Yuan J. Higher socioeconomic status predicts less risk of depression in adolescence: serial mediating roles of social support and optimism. *Front Psychol*. (2020) 11:1955. doi: 10.3389/fpsyg.2020.01955

18. Conger RD, Donnellan MB. An interactionist perspective on the socioeconomic context of human development. *Annu Rev Psychol*. (2007) 58:175–99. doi: 10.1146/annurev.psych.58.110405.085551

19. Quon EC, McGrath JJ. Subjective socioeconomic status and adolescent health: a meta-analysis. *Health Psychol*. (2014) 33:433–47. doi: 10.1037/a0033716

20. Pechey R, Monsivais P. Socioeconomic inequalities in the healthiness of food choices: exploring the contributions of food expenditures. *Prev Med*. (2016) 88:203–9. doi: 10.1016/j.ypmed.2016.04.012

21. Okamoto S. Parental socioeconomic status and adolescent health in Japan. *Sci Rep*. (2021) 11:12089. doi: 10.1038/s41598-021-91715-0

22. Chen Q, Kong Y, Gao W, Mo L. Effects of socioeconomic status, parent–child relationship, and learning motivation on reading ability. *Front Psychol*. (2018) 9:1297. doi: 10.3389/fpsyg.2018.01297

23. Charonis A, Kyriopoulos I-I, Spanakis M, Zavras D, Athanasakis K, Pavi E, et al. Subjective social status, social network and health disparities: empirical evidence from Greece. *Int J Equity Health*. (2017) 16:40. doi: 10.1186/s12939-017-0533-y

24. Belsky J, Bell B, Bradley RH, Stallard N, Stewart-Brown SL. Socioeconomic risk, parenting during the preschool years and child health age 6 years. *Eur J Pub Health*. (2007) 17:508. doi: 10.1093/eurpub/ckl261

25. Poulain T, Vogel M, Sobek C, Hilbert A, Körner A, Kiess W. Associations between socio-economic status and child health: findings of a large German cohort study. *Int J Env Res Public Health*. (2019) 16:677. doi: 10.3390/ijerph16050677

26. Hasan E. Inequalities in health care utilization for common illnesses among under five children in Bangladesh. *BMC Pediatr*. (2020) 20:192. doi: 10.1186/s12887-020-02109-6

27. Li J, Wang J, Li JY, Qian S, Jia RX, Wang YQ, et al. How do socioeconomic status relate to social relationships among adolescents: a school-based study in East China. *BMC Pediatr*. (2020) 20:271. doi: 10.1186/s12887-020-02175-w

28. Shaw BA, Agahi N, Krause N. Are changes in financial strain associated with changes in alcohol use and smoking among older adults? *J Stud Alcohol Drugs*. (2011) 72:917–25. doi: 10.15288/jsad.2011.72.917

29. Kipping RR, Smith M, Heron J, Hickman M, Campbell R. Multiple risk behaviour in adolescence and socio-economic status: findings from a UK birth cohort. *Eur J Pub Health*. (2015) 25:44–9. doi: 10.1093/eurpub/cku078

30. Umeda M, Oshio T, Fujii M. The impact of the experience of childhood poverty on adult health-risk behaviors in Japan: a mediation analysis. *Int J Env Res Public Health*. (2015) 14:145. doi: 10.1186/s12939-015-0278-4

31. Gong WJ, Fong DYT, Wang MP, Lam TH, Chung TWH, Ho SY. Increasing socioeconomic disparities in sedentary behaviors in Chinese children. *BMC Public Health*. (2019) 19:754. doi: 10.1186/s12889-019-7092-7

32. Assari S, Caldwell CH, Mincy R. Family socioeconomic status at birth and youth impulsivity at age 15; blacks' diminished return. *Children*. (2018) 5:58. doi: 10.3390/children5050058

33. Assari S, Smith J, Mistry R, Farokhnia M, Bazargan M. Substance use among economically disadvantaged African American older adults; objective and subjective socioeconomic status. *Int J Environ Res Public Health*. (2019) 16:1826. doi: 10.3390/ijerph16101826

34. Ben-Shlomo Y, Kuh D. A life course approach to chronic disease epidemiology: conceptual models, empirical challenges and interdisciplinary perspectives. *Int J Epidemiol*. (2002) 31:285–93. doi: 10.1093/ije/31.2.285

35. Due P, Krølner R, Rasmussen M, Andersen A, Trab Damsgaard M, Graham H, et al. Pathways and mechanisms in adolescence contribute to adult health inequalities. *Scand J Public Health*. (2011) 39:62. doi: 10.1177/14034948103959

36. United Nations International Children's Emergency Fund. The state of the world's children, growing well in a changing world children, food and nutrition. (2019). Available at: https://www.unicef.org/media/60806/file/SOWC-2019.pdf (Accessed November 15, 2021).

37. United Nation. Peace, dignity and equality on a healthy planet. (2019). Available at: https://www.un.org/en/global-issues/children (Accessed October 25, 2021).

38. Reiss F. Socioeconomic inequalities and mental health problems in children and adolescents: a systematic review. *Soc Sci Med*. (2013) 90:24–31. doi: 10.1016/j.socscimed.2013.04.026

39. Ross CE, Mirowsky J. The interaction of personal and parental education on health. *Soc Sci Med*. (2011) 72:591. doi: 10.1016/j.socscimed.2010.11.028

40. Simkiss D. Inequalities in children's health in the UK. *Paediatr Child Health*. (2014) 24:103.

41. Hahn RA, Truman BI. Education improves public health and promotes health equity. *Int J Health Serv*. (2015) 45:657–78. doi: 10.1177/002073141558598

42. Pearce A, Mason K, Fleming K, Taylor-Robinson D, Whitehead M. *Reducing inequities in health across the life-course: early years, childhood and adolescence*. WHO Regional Office for Europe: Denmark (2020).

43. Baker A, Bentley C, Carr D, Connolly AM, Heasman M, Johnson C, et al. *Reducing health inequalities: system, scale and sustainability*. London: Public Health England (2017).

44. World Health Organization. *Situation of child and adolescent health in Europe*. Copenhagen, Denmark: WHO Regional Office for Europe (2018).

45. Chen E, Matthews KA, Boyce WT. Socioeconomic differences in children's health: how and why do these relationships change with age? *Psychol Bull*. (2002) 128:295–329. doi: 10.1037/0033-2909.128.2.295

46. Hanson MD, Chen E. Socioeconomic status and health behaviors in adolescence: a review of the literature. *J Behav Med*. (2007) 30:263–85. doi: 10.1007/s10865-007-9098-3

47. Simetin IP, Kern J, Kuzman M, Pfortner TK. Inequalities in Croatian pupils' risk behaviors associated to socioeconomic environment at school and area level: a multilevel approach. *Soc Sci Med*. (2013) 98:154–61. doi: 10.1016/j.socscimed.2013.09.021

48. Yannakoulia M, Lykou A, Kastorini CM, Papasaranti ES, Petralias A, Veloudaki A, et al. Socio-economic and lifestyle parameters associated with diet quality of children and adolescents using classification and regression tree analysis: the DIATROFI study. *Public Health Nutr*. (2016) 19:339–47. doi: 10.1017/S136898001500110X

49. Liu Y, Wang M, Tynjälä J, Villberg J, Lv Y, Kannas L. Socioeconomic differences in adolescents' smoking: a comparison between Finland and Beijing, China. *BMC Public Health*. (2016) 16:805. doi: 10.1186/s12889-016-3476-0

50. Melotti R, Heron J, Hickman M, Macleod J, Araya R, Lewis G. Adolescent alcohol and tobacco use and early socioeconomic position: the ALSPAC birth cohort. *Pediatrics*. (2011) 127:e948–55. doi: 10.1542/peds.2009-3450

51. Krist L, Bürger C, Ströbele-Benschop N, Roll S, Lotz F, Rieckmann N, et al. Association of individual and neighbourhood socioeconomic status with physical activity and screen time in seventh-grade boys and girls in Berlin, Germany: a cross-sectional study. *BMJ Open*. (2017) 7:e017974. doi: 10.1136/bmjopen-2017-017974

52. Obita G, Alkhatib A. Disparities in the prevalence of childhood obesity-related comorbidities: a systematic review. *Front Public Health*. (2022) 10:923744. doi: 10.3389/fpubh.2022.923744

53. Moore GF, Littlecott HJ. School-and family-level socioeconomic status and health behaviors: multilevel analysis of a national survey in Wales, United Kingdom. *J Sch Health*. (2015) 85:267. doi: 10.1111/josh.12242

54. Haddad MR, Sarti FM. Sociodemographic determinants of health behaviors among Brazilian adolescents: trends in physical activity and food consumption, 2009–2015. *Appetite*. (2020) 144:104454. doi: 10.1016/j.appet.2019.104454

55. Currie C, Zanotti C, Morgan A, Currie D, De Looze M, Roberts C, et al. *Social determinants of health and well-being among young people. Health behaviour in school-aged children (HBSC) study: international report from the 2009/2010 survey. (Health Policy for Children and Adolescents)*. Copenhagen, Denmark: WHO Regional Office for Europe (2012).

56. Jackson CA, Henderson M, Frank JW, Haw SJ. An overview of prevention of multiple risk behaviour in adolescence and young adulthood. *J Public Health*. (2012) 34:i31–40. doi: 10.1093/pubmed/fdr113

57. McInnes MD, Moher D, Thombs BD, McGrath TA, Bossuyt PM, Clifford T, et al. Preferred reporting items for a systematic review and meta-analysis of diagnostic test accuracy studies: the PRISMA-DTA statement. *JAMA*. (2018) 319:388. doi: 10.1001/jama.2017.19163

58. Moher D, Liberati A, Tetzlaff J, Altman DGGroup* P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Ann Intern Med*. (2009) 151:264. doi: 10.7326/0003-4819-151-4-200908180-00135

59. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst Rev*. (2015) 4:1. doi: 10.1186/2046-4053-4-1

60. US Department of Health. *Pediatric expertise for advisory panels - guidance for industry and FDA staff*. Geretta Wood: US Department of Health and Human Services Food and Drug Administration, Center for Devices and Radiological Health (2003).

61. Johns Hopkins Medicine. The growing child: adolescent 13 to 18 years. Available at: https://www.hopkinsmedicine.org/health/wellness-and-prevention/the-growing-child-adolescent-13-to-18-years (Accessed November 22, 2021).

62. Munn Z, Aromataris E, Tufanaru C, Stern C, Porritt K, Farrow J, et al. The development of software to support multiple systematic review types: the Joanna Briggs institute system for the unified management, assessment and review of information (JBI SUMARI). *Int J Evid Based Healthc*. (2019) 17:36–43. doi: 10.1097/XEB.0000000000000152

63. Moola S, Munn Z, Tufanaru C, Aromataris E, Sears K, Sfetcu R. Chapter 7: Systematic reviews of etiology and risk In: E Aromataris and Z Munn, editors. *Joanna Briggs Institute Reviewer's Manual*: The Joanna Briggs Institute. (2017).

64. Munn Z, Moola S, Lisy K, Riitano D, Tufanaru C. Methodological guidance for systematic reviews of observational epidemiological studies reporting prevalence and cumulative incidence data. *JBI Evid. Implement*. (2015) 13:147–53. doi: 10.1097/XEB.0000000000000054

65. Piper C. System for the unified management, assessment, and review of information (SUMARI). *J Med Libr Assoc*. (2019) 107:634. doi: 10.5195/jmla.2019.790

66. Dijkshoorn AB, van Stralen HE, Sloots M, Schagen SB, Visser-Meily JM, Schepers VP. Prevalence of cognitive impairment and change in patients with breast cancer: a systematic review of longitudinal studies. *Psychooncol*. (2021) 30:635–48. doi: 10.1002/pon.5623

67. Hoy D, Brooks P, Woolf A, Blyth F, March L, Bain C, et al. Assessing risk of bias in prevalence studies: modification of an existing tool and evidence of interrater agreement. *J Clin Epidemiol*. (2012) 65:934. doi: 10.1016/j.jclinepi.2011.11.014

68. Johnston M, Johnston DW. Assessment and measurement issues. In *comprehensive clinical psychology*. M Johnston, DW Johnston, AS Bellack and M Hersen, Eds. Elsevier Science Publishers B.V. (2001) 113–135.

69. Arnett JJ. Emerging adulthood: a theory of development from the late teens through the twenties. *Am Psychol*. (2000) 55:469–80. doi: 10.1037/0003-066X.55.5.469

70. Konner M. *The evolution of childhood: relationships, emotion, mind*. Cambridge, MA: Harvard University Press (2011).

71. Armstrong KH, Ogg JA, Sundman-Wheat AN, St John Walsh A, Armstrong KH, Ogg JA, et al. *Early childhood development theories*. New York, NY: Springer (2014).

72. Woodhead M. Early childhood development: a question of rights. *Int J Early Child*. (2005) 37:79–98. doi: 10.1007/BF03168347

73. Arnett JJ. Adolescent storm and stress, reconsidered. *Am Psychol*. (1999) 54:317–26. doi: 10.1037/0003-066X.54.5.317

74. Adler NE, Epel ES, Castellazzo G, Ickovics JR. Relationship of subjective and objective social status with psychological and physiological functioning: preliminary data in healthy. *White Women Health Psychol*. (2000) 19:586–92. doi: 10.1037/0278-6133.19.6.586

75. Doshi T, Smalls BL, Williams JS, Wolfman TE, Egede LE. Socioeconomic status and cardiovascular risk control in adults with diabetes. *Am J Med Sci*. (2016) 352:36–44. doi: 10.1016/j.amjms.2016.03.020

76. Bradley RH, Corwyn RF. Socioeconomic status and child development. *Annu Rev Psychol*. (2002) 53:371–99. doi: 10.1146/annurev.psych.53.100901.135233

77. Howe LD, Galobardes B, Matijasevich A, Gordon D, Johnston D, Onwujekwe O, et al. Measuring socio-economic position for epidemiological studies in low-and middle-income countries: a methods of measurement in epidemiology paper. *Int J Epidemiol*. (2012) 41:871. doi: 10.1093/ije/dys037

78. Bhusal M, Gautam N, Lim A, Tongkumchum P. Factors associated with stillbirth among pregnant women in Nepal. *J Prev Med Public Health*. (2019) 52:154–60. doi: 10.3961/jpmph.18.270

79. Johansen A, Rasmussen S, Madsen M. Health behaviour among adolescents in Denmark: influence of school class and individual risk factors. *Scand J Public Health*. (2006) 34:32–40. doi: 10.1080/14034940510032

80. Piko BF, Fitzpatrick KM. Socioeconomic status, psychosocial health and health behaviours among Hungarian adolescents. *Eur J Pub Health*. (2007) 17:353–60. doi: 10.1093/eurpub/ckl257

81. Richter M, Erhart M, Vereecken CA, Zambon A, Boyce W, Gabhainn SN. The role of behavioural factors in explaining socio-economic differences in adolescent health: a multilevel study in 33 countries. *Soc Sci Med*. (2009) 69:396. doi: 10.1016/j.socscimed.2009.05.023

82. Vereecken CA, Inchley J, Subramanian SV, Hublet A, Maes L. The relative influence of individual and contextual socio-economic status on consumption of fruit and soft drinks among adolescents in Europe. *Eur J Pub Health*. (2005) 15:224–32. doi: 10.1093/eurpub/cki005

83. Richter M, Leppin A, Gabhainn SN. The relationship between parental socio-economic status and episodes of drunkenness among adolescents: findings from a cross-national survey. *BMC Public Health*. (2006) 6:289. doi: 10.1186/1471-2458-6-289

84. Richter M, Vereecken CA, Boyce W, Maes L, Gabhainn SN, Currie CE. Parental occupation, family affluence and adolescent health behaviour in 28 countries. *Int J Public Health*. (2009) 54:203. doi: 10.1007/s00038-009-8018-4

85. Andersen A, Holstein BE, Due P. School-related risk factors for drunkenness among adolescents: risk factors differ between socio-economic groups. *Eur J Pub Health*. (2007) 17:27–32. doi: 10.1093/eurpub/ckl071

86. Kislitsyna O, Stickley A, Gilmore A, McKee M. The social determinants of adolescent smoking in Russia in 2004. *Int J Public Health*. (2010) 55:619. doi: 10.1007/s00038-010-0196-6

87. Doku D, Koivusilta L, Rainio S, Rimpela A. Socioeconomic differences in smoking among Finnish adolescents from 1977 to 2007. *J Adolesc Health*. (2010) 47:479. doi: 10.1016/j.jadohealth.2010.03.012

88. Doku D, Koivusilta L, Raisamo S, Rimpela A. Do socioeconomic differences in tobacco use exist also in developing countries? A study of Ghanaian adolescents. *BMC Public Health*. (2010) 10:758. doi: 10.1186/1471-2458-10-758

89. Al Sabbah H, Vereecken C, Kolsteren P, Abdeen Z, Maes L. Food habits and physical activity patterns among Palestinian adolescents: findings from the national study of Palestinian schoolchildren (HBSC-WBG2004). *Public Health Nutr*. (2007) 10:739–46. doi: 10.1017/S1368980007665501

90. Mikki N, Abdul-Rahim HF, Shi ZM, Holmboe-Ottesen G. Dietary habits of Palestinian adolescents and associated sociodemographic characteristics in Ramallah, Nablus and Hebron governorates. *Public Health Nutr*. (2010) 13:1419–29. doi: 10.1017/S1368980010000662

91. Andersen A, Holstein BE, Due P. Large-scale alcohol use and socioeconomic position of origin: longitudinal study from ages 15 to 19 years. *Scand J Public Health*. (2008) 36:326. doi: 10.1177/14034948070869

92. Pavon DJ, Ortega FP, Ruiz JR, Romero VE, Artero EG, Urdiales DM, et al. Socioeconomic status influences physical fitness in European adolescents independently of body fat and physical activity: the HELENA study. *Nutr Hosp*. (2010) 25:311. doi: 10.3305/nh.2010.25.2.4596

93. Moor I, Rathmann K, Lenzi M, Pförtner TK, Nagelhout GE, de Looze M, et al. Socioeconomic inequalities in adolescent smoking across 35 countries: a multilevel analysis of the role of family, school and peers. *Eur J Public Health*. (2015) 25:457–63. doi: 10.1093/eurpub/cku244

94. Hankonen N, Heino MT, Kujala E, Hynynen ST, Absetz P, Araújo-Soares V, et al. What explains the socioeconomic status gap in activity? Educational differences in determinants of physical activity and screentime. *BMC Public Health*. (2017) 17:144. doi: 10.1186/s12889-016-3880-5

95. Svastisalee CM, Holstein BE, Due P. Fruit and vegetable intake in adolescents: association with socioeconomic status and exposure to supermarkets and fast food outlets. *J Nutr Metab*. (2012) 2012:1–9. doi: 10.1155/2012/185484

96. Levin KA, Dundas R, Miller M, McCartney G. Socioeconomic and geographic inequalities in adolescent smoking: a multilevel cross-sectional study of 15 year olds in Scotland. *Soc Sci Med*. (2014) 107:162–70. doi: 10.1016/j.socscimed.2014.02.016

97. Park MH, Hwang EH. Effects of family affluence on the health behaviors of Korean adolescents. *Jpn J Nurs Sci*. (2017) 14:173. doi: 10.1111/jjns.12146

98. Henriksen PW, Rayce SB, Melkevik O, Due P, Holstein BE. Social background, bullying, and physical inactivity: national study of 11- to 15-year-olds. *Scand J Med Sci Sports*. (2016) 26:1249–55. doi: 10.1111/sms.12574

99. Voráčová J, Sigmund E, Sigmundová D, Kalman M. Family affluence and the eating habits of 11- to 15-year-old Czech adolescents: HBSC 2002 and 2014. *Int J Environ Res Public Health*. (2016) 13:1034. doi: 10.3390/ijerph13101034

100. Melotti R, Lewis G, Hickman M, Heron J, Araya R, Macleod J. Early life socio-economic position and later alcohol use: birth cohort study. *Addiction*. (2013) 108:516–25. doi: 10.1111/add.12018

101. Doku D, Koivusilta L, Rimpela A. Socioeconomic differences in alcohol and drug use among Ghanaian adolescents. *Addict Behav*. (2012) 37:357. doi: 10.1016/j.addbeh.2011.11.020

102. Liu Y, Wang M, Tynjala J, Villberg J, Lv Y, Kannas L. Socioeconomic inequalities in alcohol use of adolescents: the differences between China and Finland. *Int J Public Health*. (2013) 58:177–85. doi: 10.1007/s00038-012-0432-3

103. Lee JO, Cho J, Yoon Y, Bello MS, Khoddam R, Leventhal AM. Developmental pathways from parental socioeconomic status to adolescent substance use: alternative and complementary reinforcement. *J Youth Adolesc*. (2018) 47:334–48. doi: 10.1007/s10964-017-0790-5

104. Simetin IP, Kuzman M, Franelic IP, Pristas I, Benjak T, Dezeljin JD. Inequalities in Croatian pupils' unhealthy behaviours and health outcomes: role of school, peers and family affluence. *Eur J Pub Health*. (2011) 21:122–8. doi: 10.1093/eurpub/ckq002

105. Lazzeri G, Azzolini E, Pammolli A, Simi R, Meoni V, Giacchi MV. Factors associated with unhealthy behaviours and health outcomes: a cross-sectional study among tuscan adolescents (Italy). *Int J Equity Health*. (2014) 13:83. doi: 10.1186/s12939-014-0083-5

106. Zaborskis A, Lagunaite R, Busha R, Lubiene J. Trend in eating habits among Lithuanian school-aged children in context of social inequality: three cross-sectional surveys 2002, 2006 and 2010. *BMC Public Health*. (2012) 12:52. doi: 10.1186/1471-2458-12-52

107. Sweeting H, Hunt K. Adolescent socioeconomic and school-based social status, smoking, and drinking. *J Adolesc Health*. (2015) 57:37–45. doi: 10.1016/j.jadohealth.2015.03.020

108. Pape H, Rossow I, Andreas JB, Norstrom T. Social class and alcohol use by youth: different drinking behaviors, different associations? *J Stud Alcohol Drugs*. (2018) 79:132–6. doi: 10.15288/jsad.2018.79.132

109. Pförtner TK, Moor I, Rathmann K, Hublet A, Molcho M, Kunst AE, et al. The association between family affluence and smoking among 15-year-old adolescents in 33 European countries, Israel and Canada: the role of national wealth. *Addiction*. (2015) 110:162–73. doi: 10.1111/add.12741

110. de Buhr E, Tannen A. Parental health literacy and health knowledge, behaviours and outcomes in children: a cross-sectional survey. *BMC Public Health*. (2020) 20:1096. doi: 10.1186/s12889-020-08881-5

111. Nardone P, Pierannunzio D, Ciardullo S, Lazzeri G, Cappello N, Spinelli A, et al. Dietary habits among Italian adolescents and their relation to socio-demographic characteristics. *Ann Ist Super*. (2020) 56:504–13. doi: 10.4415/ANN_20_04_15

112. Esquius L, Aguilar-Martínez A, Bosque-Prous M, González-Casals H, Bach-Faig A, Colillas-Malet E, et al. Social inequalities in breakfast consumption among adolescents in Spain: the DESKcohort project. *Nutrients*. (2021) 13:2500. doi: 10.3390/nu13082500

113. Falese L, Federico B, Kunst AE, Perelman J, Richter M, Rimpela A, et al. The association between socioeconomic position and vigorous physical activity among adolescents: a cross-sectional study in six European cities. *BMC Public Health*. (2021) 21:866. doi: 10.1186/s12889-021-10791-z

114. Morgan K, Lowthian E, Hawkins J, Hallingberg B, Alhumud M, Roberts C, et al. Sugar-sweetened beverage consumption from 1998-2017: findings from the health behaviour in school-aged children/school health research network in Wales. *PLoS One*. (2021) 16:e0248847. doi: 10.1371/journal.pone.0248847

115. Pedroni C, Dujeu M, Lebacq T, Desnouck V, Holmberg E, Castetbon K. Alcohol consumption in early adolescence: associations with sociodemographic and psychosocial factors according to gender. *PLoS One*. (2021) 16:e0245597. doi: 10.1371/journal.pone.0245597

116. Sinai T, Axelrod R, Shimony T, Boaz M, Kaufman-Shriqui V. Dietary patterns among adolescents are associated with growth, socioeconomic features, and health-related behaviors. *Foods*. (2021) 10:3054. doi: 10.3390/foods10123054

117. Yang HM. Associations of socioeconomic status, parenting style, and grit with health behaviors in children using data from the panel study on Korean children (PSKC). *Child Health Nurs Res*. (2021) 27:309–16. doi: 10.4094/chnr.2021.27.4.309

118. Zaborskis A, Grincaitė M, Kavaliauskienė A, Tesler R. Family structure and affluence in adolescent eating behaviour: a cross-national study in forty-one countries. *Public Health Nutr*. (2021) 24:2521. doi: 10.1017/S1368980020003584

119. Lantz PM, House JS, Lepkowski JM, Williams DR, Mero RP, Chen J. Socioeconomic factors, health behaviors, and mortality: results from a nationally representative prospective study of US adults. *JAMA*. (1998) 279:1703. doi: 10.1001/jama.279.21.1703

120. McMaughan DJ, Oloruntoba O, Smith ML. Socioeconomic status and access to healthcare: interrelated drivers for healthy aging. *Front Public Health*. (2020) 8:231. doi: 10.3389/fpubh.2020.00231

121. Pampel FC, Krueger PM, Denney JT. Socioeconomic disparities in health behaviors. *Annu Rev Sociol*. (2010) 36:349–70. doi: 10.1146/annurev.soc.012809.102529

122. Fujiwara T, Isumi A, Ochi M. Pathway of the association between child poverty and low self-esteem: results from a population-based study of adolescents in Japan. *Front Psychol*. (2019) 10:937. doi: 10.3389/fpsyg.2019.00937

123. Svendsen MT, Bak CK, Sørensen K, Pelikan J, Riddersholm SJ, Skals RK, et al. Associations of health literacy with socioeconomic position, health risk behavior, and health status: a large national population-based survey among Danish adults. *BMC Public Health*. (2020) 20:565. doi: 10.1186/s12889-020-08498-8

124. Obita G, Alkhatib A. Effectiveness of lifestyle nutrition and physical activity interventions for childhood obesity and associated comorbidities among children from minority ethnic groups: a systematic review and meta-analysis. *Nutrients*. (2023) 15:2524. doi: 10.3390/nu15112524

125. Kuntz B, Lampert T. Social disparities in parental smoking and young children's exposure to secondhand smoke at home: a time-trend analysis of repeated cross-sectional data from the German KiGGS study between 2003-2006 and 2009-2012. *BMC Public Health*. (2016) 16:485. doi: 10.1186/s12889-016-3175-x

126. Tyas SL, Pederson LL. Psychosocial factors related to adolescent smoking: a critical review of the literature. *Tob Control*. (1998) 7:409–20. doi: 10.1136/tc.7.4.409

127. Hiscock R, Bauld L, Amos A, Fidler JA, Munafò M. Socioeconomic status and smoking: a review. *Ann N Y Acad Sci*. (2012) 1248:107–23. doi: 10.1111/j.1749-6632.2011.06202.x

128. Humensky JL. Are adolescents with high socioeconomic status more likely to engage in alcohol and illicit drug use in early adulthood? *Subst Abuse Treat Prev Policy*. (2010) 5:19. doi: 10.1186/1747-597X-5-19

129. Torchyan AA, Houkes I, Bosma H. Income inequality and socioeconomic disparities in alcohol use among eastern European adolescents: a multilevel analysis. *J Adolesc Health*. (2023) 73:347–51. doi: 10.1016/j.jadohealth.2023.03.001

130. Kuppens S, Moore SC, Gross V, Lowthian E, Siddaway AP. The enduring effects of parental alcohol, tobacco, and drug use on child well-being: a multilevel meta-analysis. *Dev Psychopathol*. (2020) 32:765. doi: 10.1017/S0954579419000749

131. Patrick ME, Wightman P, Schoeni RF, Schulenberg JE. Socioeconomic status and substance use among young adults: a comparison across constructs and drugs. *J Stud Alcohol Drugs*. (2012) 73:772. doi: 10.15288/jsad.2012.73.772

132. Donovan JE, Molina BS. Children's introduction to alcohol use: sips and tastes. *Clin Exp Res*. (2008) 32:108–19. doi: 10.1111/j.1530-0277.2007.00565.x

133. Skylstad V, Babirye JN, Kiguli J, Skar AMS, Kühl MJ, Nalugya JS, et al. Are we overlooking alcohol use by younger children? *BMJ Paediatr Open*. (2022) 6:e001242. doi: 10.1136/bmjpo-2021-001242

134. Wijtzes AI, Jansen W, Bouthoorn SH, Pot N, Hofman A, Jaddoe VW, et al. Social inequalities in young children's sports participation and outdoor play. *Int J Behav Nutr Phys Act*. (2014) 11:155. doi: 10.1186/s12966-014-0155-3

135. Gonzalo-Almorox E, Urbanos-Garrido RM. Decomposing socio-economic inequalities in leisure-time physical inactivity: the case of Spanish children. *Int J Equity Health*. (2016) 15:106. doi: 10.1186/s12939-016-0394-9

136. Story M, Neumark-Sztainer D, French S. Individual and environmental influences on adolescent eating behaviors. *J Am Diet Assoc*. (2002) 102:S40–51. doi: 10.1016/S0002-8223(02)90421-9

137. Federico B, Falese L, Capelli G. Socio-economic inequalities in physical activity practice among Italian children and adolescents: a cross-sectional study. *J Public Health*. (2009) 17:377–84. doi: 10.1007/s10389-009-0267-4

138. Lampinen EK, Eloranta AM, Haapala EA, Lindi V, Väistö J, Lintu N, et al. Physical activity, sedentary behaviour, and socioeconomic status among Finnish girls and boys aged 6–8 years. *Eur J Sport Sci*. (2017) 17:462. doi: 10.1080/17461391.2017.1294619

139. Musić Milanović S, Buoncristiano M, Križan H, Rathmes G, Williams J, Hyska J, et al. Socioeconomic disparities in physical activity, sedentary behavior and sleep patterns among 6-to 9-year-old children from 24 countries in the WHO European region. *Obes Rev*. (2021) 22:e13209. doi: 10.1111/obr.13209

140. Moore LV, Roux AVD, Evenson KR, McGinn AP, Brines SJ. Availability of recreational resources in minority and low socioeconomic status areas. *Am J Prev Med*. (2008) 34:16–22. doi: 10.1016/j.amepre.2007.09.021

141. Hoffimann E, Barros H, Ribeiro AI. Socioeconomic inequalities in green space quality and accessibility—evidence from a southern European city. *Int J Environ Res Public Health*. (2017) 14:916. doi: 10.3390/ijerph14080916

142. Agrawal S, Kim R, Gausman J, Sharma S, Sankar R, Joe W, et al. Socio-economic patterning of food consumption and dietary diversity among Indian children: evidence from NFHS-4. *Eur J Clin Nutr*. (2019) 73:1361–72. doi: 10.1038/s41430-019-0406-0

143. Leyva RPP, Mengelkoch S, Gassen J, Ellis BJ, Russell EM, Hill SE. Low socioeconomic status and eating in the absence of hunger in children aged 3–14. *Appetite*. (2020) 154:104755. doi: 10.1016/j.appet.2020.104755

144. Shinwell J, Defeyter MA. Food insecurity: a constant factor in the lives of low-income families in Scotland and England. *Front Public Health*. (2021) 9:588254. doi: 10.3389/fpubh.2021.588254

145. Attorp A, Scott JE, Yew AC, Rhodes RE, Barr SI, Naylor PJ. Associations between socioeconomic, parental and home environment factors and fruit and vegetable consumption of children in grades five and six in British Columbia, Canada. *BMC Public Health*. (2014) 14:150. doi: 10.1186/1471-2458-14-150

146. Zarnowiecki D, Ball K, Parletta N, Dollman J. Describing socioeconomic gradients in children's diets–does the socioeconomic indicator used matter? *Int J Behav Nutr Phys Act*. (2014) 11:44. doi: 10.1186/1479-5868-11-44

147. Vilela S, Oliveira A, Pinto E, Moreira P, Barros H, Lopes C. The influence of socioeconomic factors and family context on energy-dense food consumption among 2-year-old children. *Eur J Clin Nutr*. (2015) 69:47–54. doi: 10.1038/ejcn.2014.140

148. Janicijevic KM, Kocic SS, Radevic SR, Jovanovic MR, Radovanovic SM. Socioeconomic factors associated with psychoactive substance abuse by adolescents in Serbia. *Front Pharmacol*. (2017) 8:366. doi: 10.3389/fphar.2017.00366

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Influence of different caregiving styles on fundamental movement skills among children

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Purpose: This study investigated the influence of parenting and grandparenting caregiving styles on fundamental motor skills (FMS) of preschool children.

Method: A total of 1,326 preschool children (698 boys, 628 girls) aged 4–6 years were recruited from the kindergartens of Jinhua City, China. Locomotor skills (LM), ball skills (BS), and total fundamental movement skills (TS) of children were assessed by the Test of Gross Motor Development-3rd edition (TGMD-3).

Results: There were 978 children in parenting and 348 children in grandparenting caregiving styles. The LM, BS and TS scores of children were considerably ($p < 0.001$) increased with age (irrespective of sex or caregiving style). For the sex comparisons, BS scores of boys were significantly higher than girls ($p < 0.001$), while LM and TS scores were not different between boys and girls. For the caregiving style comparison, parenting is superior to grandparenting in developing of children's FMS. Parenting boys of 4-, 5-, and 6-years old showed better BS compared to age-matched parenting girls, whereas boys of 5-years old in grandparenting only showed better BS compared to same-age grandparenting girls ($p < 0.05$). Furthermore, parenting boys of 6-years reported higher LM ($p < 0.01$), BS ($p < 0.001$), and TS ($p < 0.001$) scores compared to grandparenting boys, but girls' FMS at all ages were not significantly different between the caregiving styles.

Conclusion: Parenting caregiving style is positively associated with proper development of FMS among children. Girl children with poor FMS in grandparenting may need a special care or intervention programs to promote their FMS.

KEYWORDS

preschoolers, motor skills, parenting, grandparenting, ball skills, physical activity

1 Introduction

Fundamental movement or motor skills (FMS) are defined as basic learning movement patterns in preschool children. Preschool age is a crucial period for developing and practicing of FMS that are essential for more complex physical and sporting activities (1). The items in FMS, including locomotor skills, object control, and stability skills, are positively correlated with many aspects of children's health (2). Children with poor FMS are often fail to attain specific motor skills, which induce physical inactivity that lead to anxiety and depression (3–5). It is further showed that elementary school children with poor FMS had learning disabilities and cognitive impairments (6, 7). On the other hand, children with higher levels sof FMS competence reported to have better cognitive function and academic performance (7, 8). This scenario emphasizes that preschool age or early childhood is a critical period for FMS learning as well as teaching (1). FMS strongly mediates specific motor skills of children at an early age, and its impact may persist until reaching adolescence or even a lifetime (9). During early childhood, several domains, such as biological factors (sex, age, and bodyweight), socio-economic status, cultural background and caregiving styles, are involved in proper development of FMS (10, 11). Among these domains, caregiving style or parenting is one of the important factors that could influence FMS development, and this phenomenon is yet to be disclosed in preschool children.

Previous studies have shown that family environment, particularly parenting, or caregiving style is involved in improving of physical activity, academic performance and motor skills among children (8, 11, 12). Since FMS cannot occurs naturally (13), caregivers' role is inevitable for proper learning of motor skills in the early stage of childhood. Very recently, high parental participation has been shown to improve FMS proficiency in children of 2–7 years old (14). In a family system, parenting and/or grandparenting is common in several countries, and grandparenting has been increased worldwide in the recent decades (15). About 80% of adults aged 65 years and older are grandparents in the USA, where grandparenting is becoming more intense (16). Most of grandparents are involved in almost every aspect of the daily care and support of their grandchildren in the USA (17). Reliance on grandparents for caring of children is also prevalent in Australia (18), Canada (19), England (20), and many other countries (21). In the Confucian culture, taking care of grandchildren is more common among Chinese grandparents (22). In addition, young parents in China tend to move to cities due to modernization or employment, which results in leaving of their preschool children with grandparents (23). Data from the China Health and Retirement Longitudinal Study (CHARLS) revealed that about 53% of grandparents in China are providing care for their grandchildren, aged under 16 years (24).

According to the social-ecological model and theoretical frameworks, parenting (by parents or grandparents) plays a fundamental role in shaping their children's behavior and personality (25, 26). Parenting is broadly conceptualized into two dimensions, including autonomy-supportive and controlling styles (25, 27). Autonomy-supportive parenting is characterized by empathy for children and respect for their perspectives, while controlling parenting (psychological or behavioral controlling) ignores child's opinions, needs and feelings (28, 29). Autonomy-supportive parenting is associated with positive outcomes (less depression, higher wellbeing, and self-efficacy), whereas controlling parenting is associated with negative outcomes (social incompetence, anxiety, and depression) among children (25, 28–30). Autonomy-supportive parenting was said to be associated with improved child wellbeing and family cohesion in German families during COVID-19 pandemic (31). Not only children, but also toddlers benefited from the autonomy-supportive parenting, as toddlers' rule internalization was positively correlated with authoritative parenting practice (32). Furthermore, parents' autonomous motivation with positive emotions was directly associated with students' positive emotions and self-efficacy for doing homework (33). Based on the above two dimensions, parenting is further classified into four types, namely authoritarian, authoritative, permissive, and uninvolved types (27, 34, 35). Among these, authoritative parenting type is a balanced one, in which parent develops a close, nurturing relationship with their children, and children are confident, responsible, and able to self-regulate as they grown (35). Irrespective of parenting type, caregivers, either parents or grandparents play a vital role in supporting and promoting the motor development in children from an early age (14, 36). Previous studies identified the differences in FMS proficiency between boys and girls, which might be due to their behavioral habits, biological or social factors (37, 38). A meta-analysis showed that age of children (3–6 years) is correlated with gender specific differences in object control skills (38), but parenting role is unanswered in their analysis. Therefore, it is important to assess the FMS proficiency in boys and girls separately from their early childhood, in both parenting and grandparenting caregiving styles. Identifying of a child, who do not masterly perform his/her FMS, is important for designing of appropriate interventions based on their age, sex, and caregiving style.

Although parenting and grandparenting is advantageous on various outcomes of children, the child caring values and benefits of caregiving styles are contradictory between parents and grandparents (39). The outcomes (social, educational, physical, and health) of preschool children are reported to be equivocal with parenting and grandparenting. For example, a study showed that parental involvement can decrease behavioral problems of children and improve their social skills (40). Luby et al. (41) stated that maternal support in early childhood is a predictive of larger hippocampal volumes among children at school age. In contrast, some studies showed negative effects of grandparenting on children's creativity (42) and bodyweight (overweight) (43), and beneficial effects on infants' (9 months) communication and personal-social development (44). Nonetheless, the influence of grandparenting on children's FMS is remaining unexplained. As grandparenting is continuously increasing in China (23, 24), there is a need of studying children's motor skill development, and it is important to unveil whether grandparenting caregiving style could affect preschool children's FMS.

In this study, we aimed to monitor the FMS development in kindergarten children (aged 4–6 year), and compare the influence of parenting and grandparenting caregiving styles on FMS competence. We then examined the age-specific and sex-specific changes in FMS competence among children with both caregiving styles. Since authoritative parenting is favor to promote several outcomes in children (40, 41), we hypothesized that authoritative parenting might be beneficial to develop FMS proficiency, and this development might be associated with age or sex of children.

2 Materials and methods

2.1 Recruitment strategy and participants

This cross-sectional study was conducted in Jinhua, a city with ∼1 M population in Zhejiang Province of Eastern China. A total of 1,343 healthy children (4, 5, and 6 years old) from two large-scale kindergartens (affiliated to Zhejiang Normal University and Jinhua Polytechnic) were recruited by a random cluster sampling method.

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The study was conducted from March to June 2021. During the study period, 17 children were dropped due to incomplete assessment scores, resulting 1,326 children as the final sample size. The basic characteristics of children, including age, height, weight, body mass index (BMI) and sex were recorded at their respective kindergartens. There were a total of 698 boys and 628 girls. The caregiving style of each child either parenting or grandparenting was recorded with the help of their teacher or caregiver. Other variables, like family economy status and sex of caregivers were not analyzed. Children in a family with a combination of caregivers (parents and grandparents) were not enrolled, and the ideal parenting type in this study was "authoritative."

The details of this study were provided with the Chinese version of the written informed consent form and also explained verbally to the directors of the kindergarten, teachers, parents, or grandparents, and students before their voluntary participation. The study design and all assessment procedures were reviewed and approved by the Institutional Ethical Committee of Zhejiang Normal University, and the approval number is ZSDR2019013.

2.2 Assessment of basic characteristics of children

The basic characteristics, including bodyweight (kg) and height (m) of children were measured using a weight and height scale to the nearest 0.1 kg and 0.1 cm, respectively. Then BMI was calculated using the weight and height of children at respective ages [weight (kg)/height (m)^2]. These assessments were performed in the empty hall of each kindergarten during the school hours. Meanwhile, demographic data (age and gender) of children provided by their teachers were recorded for the analysis. Caregivers provided the caregiving details of their children. Based on the caregiving type, we categorized the children into two groups namely, grandparenting and parenting. In "grandparenting caregiving style" grandparents are the main caregivers, while in "parenting caregiving style" parents are the main caregivers. The main caregiver means the person, who looks after the child's daily activities at least from 6 months prior to the study. Taking care of children by relatives, guardians or babysitters were excluded from our study.

2.3 Assessment of motor skills of children

In this study, FMS performance of all age groups of children was assessed using the scale, Test of Gross Motor Development, 3rd edition [TGMD-3, (45)]. The TGMD-3 includes two skill categories: six locomotor skills (i.e., running, galloping, sliding, skipping, horizontal jumping, and hopping) and seven ball skills (i.e., overhand throwing, underhand throwing, two-hand catching, one-hand stationary dribbling, forehand striking of the self-bounced ball, two hands striking a stationary ball, and kicking a stationary ball). For the test evaluation, each skill was categorized into 3–5 components, and each component was scored as either 1 (present) or 0 (absent). There were 46 points for locomotor skills (LM) and 54 points for ball skills (BS), with a full score of 100. The children's FMS competence test was conducted in the indoor gymnasium of each kindergarten after obtaining permission from the administrators. Two motor skill subset scores (LM and BS) were computed from the sum of raw scores from each subset, and the total fundamental movement skills score (TS) was the sum of LM and BS.

The TGMD-3 scale used in this study is a valid and reliable assessment tool for measuring the Chinese kindergarten children's FMS performances, and reported to have good test-retest reliability and internal consistency (46, 47). A total of 14 professionals, including two sport science researchers, two psychologists and 10 testers (postgraduates) were involved in the test assessments. The administration of TGMD-3 for the assessment required roughly ∼20 min for each child. Two independent testers simultaneously observed each child's performance. The correlation coefficient between the testers was used to ensure the consistency for different rater scores when scoring the same subject and the results proved that the inter-rater reliability was good. All assessments were conducted in accordance with the TGMD-3 recommendations (48, 49). Required equipment was prepared prior to the assessment date. On the day of assessment, all procedures were verbally explained, and accurate demonstration was given on scoring of each skill. Each child completed one practice, and then performed two formal trials. The scores of two formal trials were recorded and used for the analyses.

2.4 Statistical analysis

Obtained data were analyzed using the IBM SPSS Statistics (Version 22.0, IBM Corporation, New York, USA). Descriptive statistics for participant characteristics were displayed as Means ± SD or n (%). For the purpose of analysis, children were grouped on the basis of sex (two groups), caregiving styles (two groups), and age (three groups). For the age comparisons, all children were arbitrarily categorized into three age groups, including 4, 5, and 6 years. One-way ANOVA was performed (separately) among the FMS scores and caregiving styles, age, and sex to explore the influence of each of these three variables. In order to examine any significant difference across caregiving styles according to age groups and sex classes, across age groups according to caregiving styles and sex, and across sex classes according to caregiving styles and age groups, one-way ANOVA was subsequently performed. The results of the one-way ANOVA displayed through the F-values and level of significance was set at $p < 0.05$.

3 Results

3.1 Characteristics of children

In this study, a total of 1,326 kindergarten children aged 4, 5, and 6 years with parenting and grandparenting caregiving styles were participated. There were 522 boys and 456 girls in parenting, and 176 boys and 172 girls in grandparenting caregiving style. The average height of boys and girls in parenting and grandparenting caregiving styles was not different (Table 1). Similarly, the weight and BMI of children was not differing either with parenting or grandparenting at respective ages. We noticed an increased height

TABLE 1 Basic characteristics of the preschool children.

	Parenting	Grandparenting	Total
Number of children	978 (73.8%)	348 (26.2%)	1,326 (100%)
Boys	522 (74.8%)	176 (25.2%)	698 (100%)
Girls	456 (72.6%)	172 (27.4%)	628 (100%)
Age (y)			
4	115 (69.3%)	51 (30.7%)	166 (100%)
5	330 (68.3%)	153 (31.7%)	483 (100%)
6	533 (78.7%)	144 (21.3%)	677 (100%)
Height (m)			
Boys	1.18 ± 0.08	1.17 ± 0.08	1.18 ± 0.08
Girls	1.19 ± 0.07	1.18 ± 0.07	1.19 ± 0.07
Age (y)			
4	1.06 ± 0.07	1.08 ± 0.05	1.07 ± 0.07
5	1.16 ± 0.05	1.17 ± 0.05	1.16 ± 0.05
6	1.22 ± 0.08	1.23 ± 0.05	1.23 ± 0.05
Weight (kg)			
Boys	20.64 ± 3.80	20.17 ± 3.19	20.52 ± 3.66
Girls	20.57 ± 3.58	20.46 ± 3.31	20.54 ± 3.51
Age (y)			
4	17.16 ± 2.31	17.54 ± 1.62	17.27 ± 2.12
5	19.44 ± 2.03	19.53 ± 1.87	19.47 ± 1.98
6	22.07 ± 3.98	22.13 ± 3.77	22.08 ± 3.94
BMI (kg/m^2)			
Boys	14.70 ± 1.46	14.57±1.46	14.66±1.46
Girls	14.54 ± 1.62	14.53 ± 1.45	14.54 ± 1.57
Age (y)			
4	15.24 ± 1.18	15.13 ± 1.02	15.21 ± 1.13
5	14.41 ± 1.28	14.28 ± 1.29	14.37 ± 1.28
6	14.62 ± 1.54	14.62 ± 1.67	14.62 ± 1.70

y, years; m, meter; kg, kilogram; BMI, body mass index; kg/m^2, kilogram/meter^2. Values expressed in numbers, percentage and mean ± standard deviation.

and weight of children by age in both caregiving styles; however, we did not notice such a trend in BMI (Table 1).

3.2 Differences in FMS scores among children by age, sex, and caregiving styles

The scores of locomotor skills, ball skills, and total fundamental movement skills of children were presented in Table 2. We found that LM, BS, and TS scores of children were progressively increased with age ($p < 0.001$). For the gender comparison, the scores of LM and TS were not significantly different between boys and girls, whereas the BS scores were significantly higher in boys compared with girls ($p < 0.001$). For caregiving styles, children with parenting

TABLE 2 Changes in FMS scores among children by age, gender, and caregiving styles.

FMS	Age (y, M ± SD)			F (d.f. = 2)	Sex (M ± SD)		F (d.f. = 1)	Caregiving styles (M ± SD)		F (d.f. = 1)
	4	5	6		Boys	Girls		Parenting	Grandparenting	
LM	20.65 ± 7.10	25.53 ± 7.96	31.04 ± 6.08	189.64***	27.58 ± 7.90	27.87 ± 7.84	0.44	28.10 ± 7.83	26.65 ± 7.90	8.68**
BS	15.52 ± 6.15	20.59 ± 6.66	28.16 ± 7.24	308.00***	24.60 ± 8.66	22.91 ± 7.90	13.69***	24.57 ± 8.55	21.66 ± 7.34	31.85***
TS	36.17 ± 11.55	46.12 ± 12.88	59.20 ± 11.36	328.11***	52.18 ± 14.93	50.78 ± 14.22	3.05	52.66 ± 14.73	48.31 ± 13.78	23.13***

LM, locomotor skills score; BS, ball skills score; TS, total fundamental movement skills score; d.f., degrees of freedom; The scores were significant at $^{**}p < 0.01$ and $^{***}p < 0.001$ in each factor (age, sex, and caregiving style).

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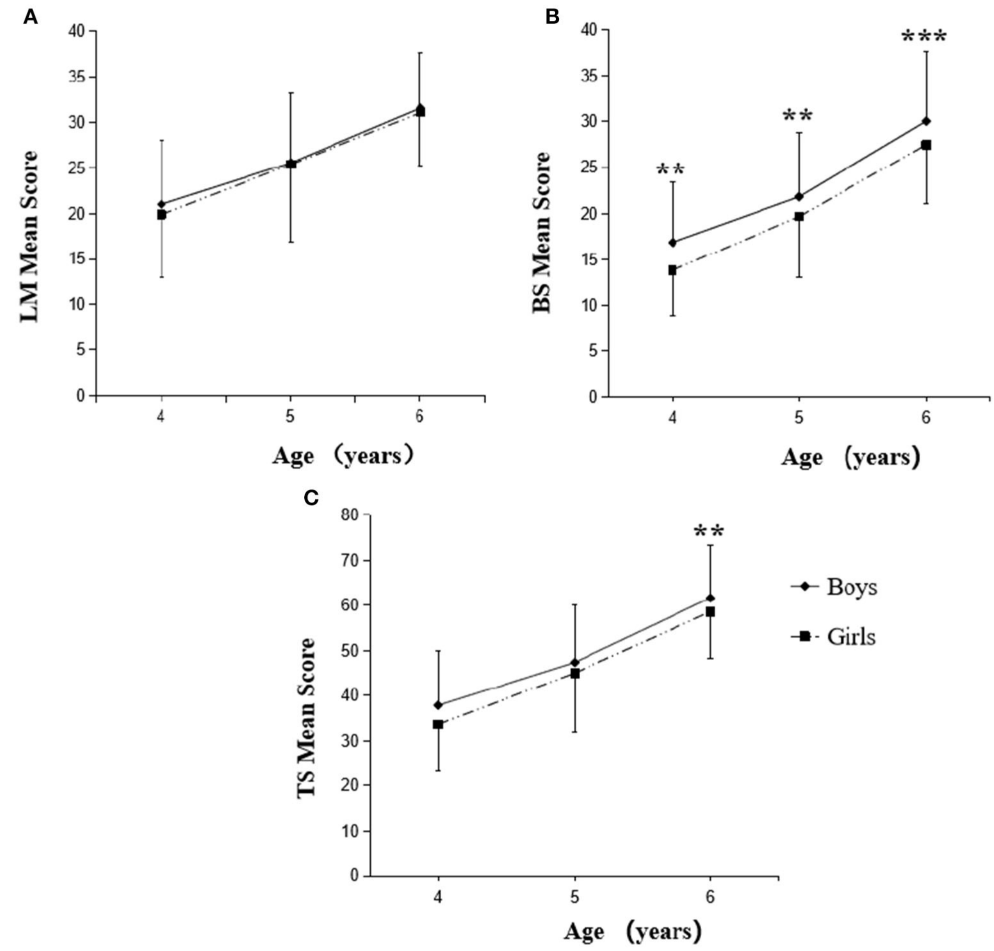

FIGURE 1
Changes in FMS scores of boys and girls with parenting caregiving style. LM, locomotor skills **(A)**; BS, ball skills **(B)**; TS, total fundamental movement skills **(C)**. The scores are significant (** $P < 0.01$, *** $P < 0.001$) between boys and girls at respective age.

showed superior FMS scores (LM, BS, and TS) than that of children with grandparenting caregiving style (Table 2).

3.3 Changes in FMS scores of boys and girls with different caregiving styles

The FMS performance scores of boys and girls with parenting caregiving style are shown in Figure 1. We noticed that the progressive increase of LM scores with age was not significantly different between boys and girls in parenting (Figure 1A). However, the BS scores of boys at each age (4, 5, and 6 years) in parenting were significantly higher than that of girls at respective ages (Figure 1B). Nevertheless, boys at the age of 6 years only showed the higher total FMS scores ($p < 0.01$) than girls at the same age (Figure 1C). In grandparenting caregiving style, the progressive increase of LM and TS scores with age was not significantly different between boys and girls (Figures 2A, C). Five-year-old boys in grandparenting only showed the higher BS scores ($p < 0.05$) compared to girls at the same age, which is different from the boys in parenting (Figure 2B).

3.4 Parenting caregiving style promotes FMS in boys, not in girls

Figures 3, 4 showed the influence of caregiving styles on development of FMS among children of 4–6 years old. Initially, we found that there was no significant difference between two caregiving styles on LM, BS, and TS scores of boys at the age of 4- and 5-year. However, boys at the age of 6-year in authoritative parenting reported significantly higher LM ($p < 0.01$), BS ($p < 0.001$), and TS ($p < 0.001$) scores compared with that of same age of boys in grandparenting (Figure 3). It is worth to note that the FMS scores of girls (LM, BS, and TS) were not specifically influenced by either parenting or grandparenting caregiving style (Figure 4).

4 Discussion

To the best of our knowledge, this is the first study to explore whether caregiving style (parenting and grandparenting) could influence the fundamental motor skills of preschool age children. We studied the changes in FMS among children (4–6 years) from Zhejiang province of China, and the changes were compared

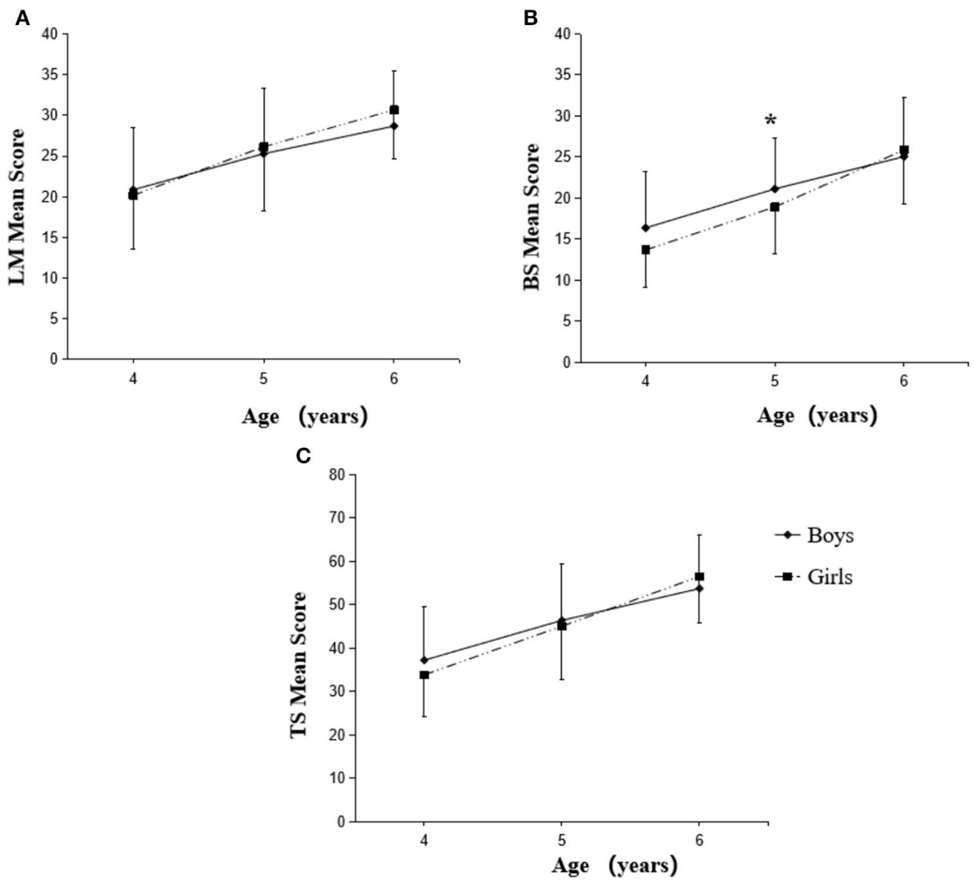

FIGURE 2
Changes in FMS scores of boys and girls with grandparenting caregiving style. LM, locomotor skills **(A)**; BS, ball skills **(B)**; TS, total fundamental movement skills **(C)**. The scores are significant (*$P < 0.05$) between boys and girls at respective age.

with their age, sex, and caregiving styles. Our findings showed that caregiving styles influence preschool children's FMS, and this influence is associated with age (4–6 years) and sex of children. Parenting caregiving style significantly improved FMS of boys at 6-year, while FMS of girls (all ages) remained unchanged with parenting and grandparenting caregiving styles. To be specific, the ball skills of boys at all ages (4-, 5-, and 6-year) were better than girls of respective ages with parenting caregiving style. Our findings revealed that authoritative parenting type is important to promote various motor skills of preschool children. However, the influence of parental sex, and the role of other parenting types (authoritative, permissive, and uninvolved) on children's FMS competence is yet to be elucidated.

4.1 Age-specific response of FMS

Increasing age is the most consistent key variable of all subsets of FMS among children (50). In our study, the scores of FMS of children aged 4–6 years were significantly improved with age. Our results are consistent with previous findings of Bolger et al. (51), who reported increased locomotor and object-control skills in Irish children aged 5–10 years. The early stage of children (3–7 years) is a critical period for proper development of FMS (1), and improvement of FMS after this age may not be efficient as early stages (52). The possible explanation is that children have different physical development characteristics in different stages of growth. During this period, children have more opportunities to engage in several physical activities for daily needs and thereby learn more motor skills. Therefore, the motor proficiency of children constantly increases with age, which then leads to a gradual increase in both locomotor skills and ball skills naturally (51). From our findings, it is interesting to note that the improvement of ball skills of girls with age was comparatively lower than that of the improvement of ball skills of boys with age.

4.2 Sex-specific response of FMS

Exploring of sex-specific responses of FMS among children with parenting and grandparenting is an important perspective to understand whether caregiving style affects FMS differently in boys and girls. In this context, we found that boys scored higher than girls in BS but not in LM and TS. We then identified that

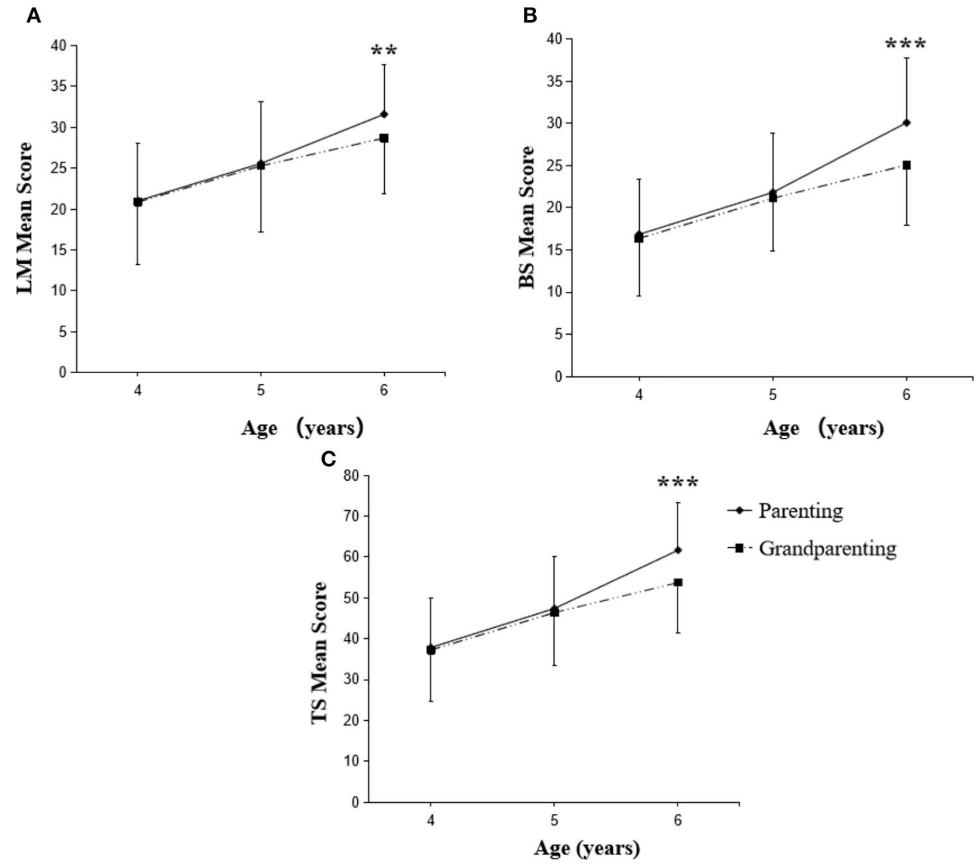

FIGURE 3
Changes in FMS scores of boys with parenting and grandparenting caregiving styles. LM, locomotor skills **(A)**; BS, ball skills **(B)**; TS, total fundamental movement skills **(C)**. The scores are significant (**$P < 0.01$, ***$P < 0.001$) between parenting and grandparenting children at respective age.

boys of all ages (4-, 5-, and 6-year), particularly in parenting caregiving style, possess better ball skills than girls. Similar to our findings, a study from Australia reported that the boys had better object-control skills than the girls (53). Other studies from the USA (54) and Brazil (55) also reported superior scores of BS and LM in boys than that of in girls. In contrast, some studies reported specific motor skills of girls are better than boys. For instance, the jumping skills of Belgian girls are superior than boys (56), and the fundamental skill performance of girls from Hong Kong was better than boys (57). The difference in FMS subsets between boys and girls might be linked with various factors. Gender differences among children in learning of FMS depend on their family, elder siblings, peers, and teachers through socialization and imitation, and consequently participate in particular activities that fit these gender norms (38). A study on children from the deprived areas of England stated that cultural background, ethnicity, and other factors are critically involved in gender-specific differences in learning of motor skills (58). The better ball skills of boys in our study explained that boys may spend more time than girls in practicing of object-control related activities, like ball games, and thereby develop their ball skills. In addition to the above said factors, we found caregiving style is also a considerable factor for the sex-specific differences in various motor skills among preschool children.

4.3 FMS and caregiving styles

According to Clark (59), it is a common misconception that children's FMS develop naturally as they grow-up. It is also said that providing of well-equipped physical activity facility may not improve FMS in children, instead being engaged, accompanying person, or supporting sibling may contribute for appropriate development of FMS (1, 60). Goodway et al. (1) also pointed out that FMS proficiency does not occur naturally with growth and development of children, but it requires structured teaching, practice, and consolidation. Although social-environmental variables influence the FMS, parental and family-related variables (61) or older siblings (62) of children are strongly involved in proper development of FMS. For the first time, we demonstrated the influential role of caregiving style among Chinese children in developing of motor skills. Our findings showed that boys in parenting at the age of 6-year performed better LM, BS, and TS scores than the same age of boys in grandparenting. Interestingly, caregiving style had no effect on the development of FMS proficiency among girls.

There are several reasons to explain the differences in children's FMS scores between parenting and grandparenting caregiving styles. The selected parenting type in this study was authoritative, in which parents maintain a positive and warmth relationship with

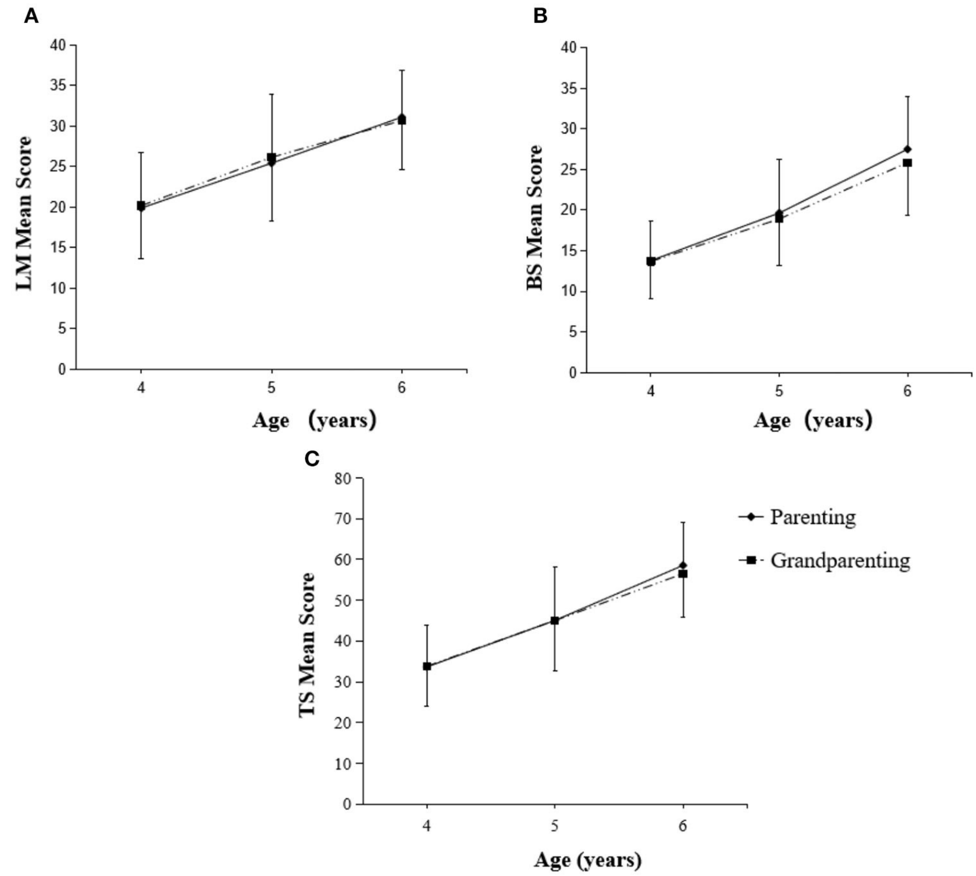

FIGURE 4
Changes in FMS scores of girls with parenting and grandparenting caregiving styles. LM, locomotor skills **(A)**; BS, ball skills **(B)**; TS, total fundamental movement skills **(C)**.

their child, and child tend to gain confidence, self-efficacy, and positive emotions (25, 35). Therefore, we assume that authoritative parents may entertain or actively interact with their kids in several ways, which could promote various motor skills. In contrast, grandparents may not vigorously interact with grandchildren during playtime (due to aging or physical fitness issues), which could result lower motor competence in children. Previous studies have shown that grandparenting had a negative effects on children's emotions, academic performance and other social behaviors (63, 64). A recent study from China reported that children grown-up in grandparents-headed families had lower creativity than those from families living without grandparents (42). This study further explained that the resources provided by parents are quite different from the resources provided by grandparents, which can influence creativity in children (42). Children with lower creativity or poor academic performance tend to be physically inactive, and displayed lower gross motor skills (65). Besides, childhood obesity among children aged 8–10 year in China is said to be associated with grandparenting caregiving style (66). Although the bodyweight of Chinese children (4–6 years) in our study was not significantly altered with caregiving style, other studies reported an association between obesity and poor motor skills in children. A systematic review identified an inverse association between motor competence and bodyweight status of children and adolescents (67). Increased fat mass is not only detrimental to motor competence performance (68) but also impede movement patterns of object projection skills that inherently demand high segmental velocities (69). Our findings further explained that authoritative parents may have some innovative approaches to help children to grasp new motor skills. Nevertheless, the influence of other parenting types, like authoritative, permissive, and uninvolved on motor skills of children (4–6 years) is yet to be investigated.

Due to the rapid migration of young parents from rural to urban areas in China (for better career or business opportunities), taking care of their child is a major concern in many families (23, 70). As a result, primary care of preschool children by grandparents is increasing in China (21, 23, 24).Grandparenting is associated with poor academic performance, poor creativity (63, 64) and lower physical activity among grandchildren (65). Less physical exercise and outdoor activities among children subsequently decrease physical fitness, weakened immunity, and even cause obesity (10). Previous studies have shown a strong positive correlation between children's FMS and physical activity (71–73). On the other hand, there is an erroneous perception among grandparents or elder community that academic activities are more important than physical activities or outdoor programs for children. It is therefore essential to understand the preschool children's motor competence, especially, who are taking care by grandparents. Furthermore, it is also imperative to study the motor skills of children from rural areas, where high percentage of grandparenting can be seen. Parenting without providing autonomous support may also lead to poor motor competence in children. Therefore, young parents particularly in uninvolved type, should prioritize their child's needs and feelings, and monitor their emotional and sedentary behaviors. Importantly, parents should avoid excessive screen time or social media usage, and need to engage with their child and praise their accomplishments. Additional activities like, taking children to parks, providing construction toys, weekend outdoor programs, and active co-participation in physical activities by caregivers could promote children's self-esteem and motor skills. Taken together, our findings emphasize that families and kindergarten schools need to pay attention and work collectively to provide children with more opportunities for physical activities.

4.4 Limitations

Preschool children participated in this study are Chinese, and our findings can be generalized to children in the Chinese society, where most caregivers are biological parents. Further studies are necessary to demonstrate the influence of similar caregiving styles on FMS of children from Western countries. The differences between biological parenting and non-biological parenting on motor skills can be studied in future to emphasize the importance of biological parenting. Our findings primarily addressed the influence of caregiving styles on children's FMS, however, the influence of other variables, including parental sex and household income on motor competence of children needs to be investigated. Furthermore, parenting type in this study was authoritative, and the influence of other parenting types, such as authoritative, permissive, and uninvolved on children's FMS is also need to be demonstrated. Finally, children in this study were from one caregiving style (parents or grandparents), and the effect of combination of two caregiving styles (both parents and grandparents) on children's FMS is also yet to be elucidated.

4.5 Practical implications

Poor motor competence observed in girl preschoolers with grandparenting implies that some practical interventions are necessary to promote their motor skills. Based on our findings, it is encouraged to practice positive parenting, particularly authoritative type to build a strong bonding between child and parent and to promote FMS proficiency. Furthermore, young parents should strive to balance their career and family, ensuring that they offer adequate care, facilities and support for their children.

5 Conclusion

Parenting caregiving style is strongly associated with proper development of FMS competence among kindergarten children. Improved FMS proficiency in children helps to enhance cognitive skills, academic performance, health-related outcomes and physical fitness. Therefore, parenting is highly encouraged for preschoolers, especially for girls, who reported poor motor skills with grandparenting caregiving style.

Data availability statement

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

Ethics statement

The studies involving humans were approved by Institutional Ethical Committee of Zhejiang Normal University (ZSDR2019013). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

JH, SZ, and WY: data collection. JH and SZ: data analysis and original draft preparation. YZ, HZ, and LL: data interpretation and validation. WY, MK, and QC: supervision, project administration, review, and editing and finalize the manuscript. WY: funding acquisition. All authors have read and approved the final version of the manuscript.

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Conflict of interest

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

References

1. Goodway JD, Ozmun JC, Gallahue DL. *Understanding Motor Development: Infants, Children, Adolescents, Adults*. Burlington, MA: Jones & Bartlett Learning (2019).

2. Behan S, Belton S, Peers C, O'connor NE, Issartel J. Exploring the relationships between fundamental movement skills and health related fitness components in children. *Eur J Sport Sci.* (2022) 22:171–81. doi: 10.1080/17461391.2020.1847201

3. Dale LP, Vanderloo L, Moore S, Faulkner G. Physical activity and depression, anxiety, and self-esteem in children and youth: an umbrella systematic review. *Ment Health Phys Activ*. (2019) 16:66–79. doi: 10.1016/j.mhpa.2018.12.001

4. Lai SK, Costigan SA, Morgan PJ, Lubans DR, Stodden DF, Salmon J, et al. Do school-based interventions focusing on physical activity, fitness, or fundamental movement skill competency produce a sustained impact in these outcomes in children and adolescents? A systematic review of follow-up studies. *Sports Med*. (2014) 44:67–79. doi: 10.1007/s40279-013-0099-9

5. Piek JP, Barrett NC, Smith LM, Rigoli D, Gasson N. Do motor skills in infancy and early childhood predict anxious and depressive symptomatology at school age? *Hum Mov Sci*. (2010) 29:777–86. doi: 10.1016/j.humov.2010.03.006

6. Nourbakhsh P. Perceptual-motor abilities and their relationships with academic performance of fifth grade pupils in comparison with Oseretsky scale. *Kinesiology*. (2006) 38:40–8.

7. O'Hagan AD, Behan S, Peers C, Belton S, O'Connor N, Issartel J. Do our movement skills impact our cognitive skills? Exploring the relationship between cognitive function and fundamental movement skills in primary school children. *J Sci Med Sport*. (2022) 25:871–7. doi: 10.1016/j.jsams.2022.08.001

8. de Waal E. Fundamental movement skills and academic performance of 5-to 6-year-old preschoolers. *Early Childh Educ J*. (2019) 47:455–64. doi: 10.1007/s10643-019-00936-6

9. Kokstejn J, Musalek M, Wolanski P, Murawska-Cialowicz E, Stastny P. Fundamental motor skills mediate the relationship between physical fitness and soccer-specific motor skills in young soccer players. *Front Physiol*. (2019) 10:596. doi: 10.3389/fphys.2019.00596

10. Hardy LL, Reinten-Reynolds T, Espinel P, Zask A, Okely AD. Prevalence and correlates of low fundamental movement skill competency in children. *Pediatrics*. (2012) 130:e390-8. doi: 10.1542/peds.2012-0345

11. Roeber BJ, Tober CL, Bolt DM, Pollak SD. Gross motor development in children adopted from orphanage settings. *Dev Med Child Neurol*. (2012) 54:527–31. doi: 10.1111/j.1469-8749.2012.04257.x

12. Eyre ELJ, Adeyemi LJ, Cook K, Noon M, Tallis J, Duncan M. Barriers and facilitators to physical activity and FMS in children living in deprived areas in the UK: qualitative study. *Int J Environ Res Publ Health*. (2022) 19:1717. doi: 10.3390/ijerph19031717

13. Clark JE. On the problem of motor skill development. *J Phys Educ Recreat Dance*. (2007) 78:39–44. doi: 10.1080/07303084.2007.10598023

14. Flynn RJ, Pringle A, Roscoe CMP. Direct parent engagement to improve fundamental movement skills in children: a systematic review. *Children*. (2023) 10:1247. doi: 10.3390/children10071247

15. Choi M, Sprang G, Eslinger JG. Grandparents raising grandchildren: a synthetic review and theoretical model for interventions. *Fam Commun Health*. (2016) 39:120–8. doi: 10.1097/FCH.0000000000000097

16. Livingston G, Parker K. *Since the Start of the Great Recession, More Children Raised by Grandparents*. Pew Research Center's Social & Demographic Trends Project (2010).

17. Meyer MH, Kandic A. Grandparenting in the United States. *Innov Aging*. (2017) 1:igx023. doi: 10.1093/geroni/igx023

18. Hamilton M, Suthersan B. Gendered moral rationalities in later life: grandparents balancing paid work and care of grandchildren in Australia. *Ageing Soc*. (2020) 41:1651–72. doi: 10.1017/S0144686X19001855

19. Fuller-Thomson E. Canadian first nations grandparents raising grandchildren: a portrait in resilience. *Int J Aging Hum Dev*. (2005) 60:331–42. doi: 10.2190/LCR8-FJNM-F73L-58G3

20. Farrow C. A comparison between the feeding practices of parents and grandparents. *Eat Behav*. (2014) 15:339–42. doi: 10.1016/j.eatbeh.2014.04.006

21. Dolbin-MacNab ML, Yancura LA. International perspectives on grandparents raising grandchildren: contextual considerations for advancing global discourse. *Int J Aging Hum Dev*. (2018) 86:3–33. doi: 10.1177/0091415016689565

22. Chen F, Liu G. The health implications of grandparents caring for grandchildren in China. *J Gerontol Ser B*. (2012) 67:99–112. doi: 10.1093/geronb/gbr132

23. Yi Z, Wang Z. Dynamics of family and elderly living arrangements in China: new lessons learned from the 2000 census. *China Rev*. (2003) 2:95–119. Available online at: http://www.jstor.org/stable/23461906

24. Wu P. The impacts of caring for grandchildren on physical and mental health of middle and old-aged persons: an empirical study based in CHARLS data. *China Rural Survey*. (2018) 4:117–31.

25. Kuppens S, Ceulemans E. Parenting styles: a closer look at a well-known concept. *J Child Fam Stud*. (2019) 28:168–81. doi: 10.1007/s10826-018-1242-x

26. Li X, Liu Y. Parent-grandparent coparenting relationship, maternal parenting self-efficacy, and young children's social competence in Chinese urban families. *J Child Fam Stud*. (2019) 28:1145–53. doi: 10.1007/s10826-019-01346-3

27. Baumrind D. Current patterns of parental authority. *Dev Psychol*. (1971) 4:1–103. doi: 10.1037/h0030372

28. Katz I, Lemish D, Cohen R, Arden A. When parents are inconsistent: parenting style and adolescents' involvement in cyberbullying. *J Adolesc*. (2019) 74:1–12. doi: 10.1016/j.adolescence.2019.04.006

29. Young R, Tully M. Autonomy vs. control: associations among parental mediation, perceived parenting styles, and U. S. adolescents' risky online experiences. *Cyberpsychology*. (2022) 16:5. doi: 10.5817/CP2022-2-5

30. Froiland JM. Parental autonomy support and student learning goals: a preliminary examination of an intrinsic motivation intervention. *Child Youth Care Forum*. (2010) 40:135–49. doi: 10.1007/s10566-010-9126-2

31. Neubauer AB, Schmidt A, Kramer AC, Schmiedek F. A little autonomy support goes a long way: daily autonomy-supportive parenting, child well-being, parental need fulfillment, and change in child, family, and parent adjustment across the adaptation to the COVID-19 pandemic. *Child Dev*. (2021) 92:1679–97. doi: 10.1111/cdev.13515

32. Andreadakis E, Joussemet M, Mageau GA. How to support toddlers' autonomy: socialization practices reported by parents. *Early Educ Dev*. (2019) 30:297–314. doi: 10.1080/10409289.2018.1548811

33. Moè A, Katz I. Brief research report: parents' homework emotions favor students' homework emotions through self-efficacy. *J Exp Educ*. (2018) 86:597–609. doi: 10.1080/00220973.2017.1409180

34. Arafat SMY, Akter H, Islam MA, Shah MMA, Kabir R. Parenting: types, effects and cultural variation. *Asian J Pediatr Res*. (2020) 3:32–6. doi: 10.9734/ajpr/2020/v3i330130

35. Sanvictores TMD. *Types of Parenting Styles and Effects on Children: 2022*. Treasure Island, FL: StatPearls Publishing (2023).

36. Pedersen MRL, Hansen AF. Interventions by caregivers to promote motor development in young children, the caregivers' attitudes and benefits hereof: a scoping review. *Int J Environ Res Publ Health*. (2022) 19:11543. doi: 10.3390/ijerph191811543

37. Lee SK. Sex as an important biological variable in biomedical research. *BMB Rep*. (2018) 51:167–73. doi: 10.5483/BMBRep.2018.51.4.034

38. Zheng Y, Ye W, Korivi M, Liu Y, Hong F. Gender differences in fundamental motor skills proficiency in children aged 3-6 years: a systematic review and meta-analysis. *Int J Environ Res Publ Health*. (2022) 19:8318. doi: 10.3390/ijerph19148318

39. Goh ECL. Raising the precious single child in urban China-an intergenerational joint mission between parents and grandparents. *J Intergener Relationsh*. (2006) 4:6–28. doi: 10.1300/J194v04n03_02

40. El Nokali NE, Bachman HJ, Votruba-Drzal E. Parent involvement and children's academic and social development in elementary school. *Child Dev*. (2010) 81:988–1005. doi: 10.1111/j.1467-8624.2010.01447.x

41. Luby JL, Barch DM, Belden A, Gaffrey MS, Tillman R, Babb C, et al. Maternal support in early childhood predicts larger hippocampal volumes at school age. *Proc Natl Acad Sci USA*. (2012) 109:2854–9. doi: 10.1073/pnas.1118003109

42. Pang W, Lu Y, Long H, Wang Q, Lin L. Three-generational families: are they beneficial to Chinese children's creativity? *Think Skills Creativ*. (2020) 35:100623. doi: 10.1016/j.tsc.2019.100623

43. Li Q, Liang F, Liang W, Zhang J, Niu M, Han Y. The influence of different caregivers on infant growth and development in China. *Front Pediatr*. (2017) 5:243. doi: 10.3389/fped.2017.00243

44. Cruise S, O'Reilly D. The influence of parents, older siblings, and non-parental care on infant development at nine months of age. *Infant Behav Dev*. (2014) 37:546–55. doi: 10.1016/j.infbeh.2014.06.005

45. Ulrich DA. The test of gross motor development-3 (TGMD-3): administration, scoring, and international norms. *Spor Bilimleri Dergisi*. (2013) 24:27–33.

46. Diao Y, Dong C, Li J. The establishment of norm of gross motor development test in Shanghai. *China Sport Sci Technol*. (2018) 54:98–104. doi: 10.16470/j.csst.201802013

47. Wang H, Chen Y, Liu J, Sun H, Gao W. A follow-up study of motor skill development and its determinants in preschool children from middle-income family. *Biomed Res Int*. (2020) 2020:6639341. doi: 10.1155/2020/6639341

48. Ulrich D. *Test of Gross Motor Development (TGMD-3)*, 3rd Edn. Ann Arbor, MI: University of Michigan (2016).

49. Webster EK, Ulrich DA. Evaluation of the psychometric properties of the test of gross motor development—third edition. *J Motor Learn Dev*. (2017) 5:45–58. doi: 10.1123/jmld.2016-0003

50. Barnett LM, Lai SK, Veldman SLC, Hardy LL, Cliff DP, Morgan PJ, et al. Correlates of gross motor competence in children and adolescents: a systematic review and meta-analysis. *Sports Med*. (2016) 46:1663–88. doi: 10.1007/s40279-016-0495-z

51. Bolger LE, Bolger LA, O' Neill C, Coughlan E, O'Brien W, Lacey S, et al. Age and sex differences in fundamental movement skills among a cohort of Irish school children. *J Motor Learn Dev*. (2018) 6:81–100. doi: 10.1123/jmld.2017-0003

52. Bardid F, Huyben F, Lenoir M, Seghers J, De Martelaer K, Goodway JD, et al. Assessing fundamental motor skills in Belgian children aged 3–8 years highlights differences to US reference sample. *Acta Paediatr*. (2016) 105:e281–90. doi: 10.1111/apa.13380

53. Okely AD, Booth ML, Chey T. Relationships between body composition and fundamental movement skills among children and adolescents. *Res Q Exerc Sport*. (2004) 75:238–47. doi: 10.1080/02701367.2004.10609157

54. Robinson LE. The relationship between perceived physical competence and fundamental motor skills in preschool children. *Child*. (2011) 37:589–96. doi: 10.1111/j.1365-2214.2010.01187.x

55. Spessato BC, Gabbard C, Valentini N, Rudisill M. Gender differences in Brazilian children's fundamental movement skill performance. *Early Child Dev Care*. (2013) 183:916–23. doi: 10.1080/03004430.2012.689761

56. Vandaele B, Cools W, de Decker S, de Martelaer K. Mastery of fundamental movement skills among 6-year-old Flemish pre-school children. *Eur Phys Educ Rev*. (2011) 17:3–17. doi: 10.1177/1356336X11402268

57. Pang AW, Fong DT. Fundamental motor skill proficiency of Hong Kong children aged 6-9 years. *Res Sports Med*. (2009) 17:125–44. doi: 10.1080/15438620902897516

58. Adeyemi-Walker LJ, Duncan M, Tallis J, Eyre E. Fundamental motor skills of children in deprived areas of England: a focus on age, gender and ethnicity. *Children*. (2018) 5:110. doi: 10.3390/children5080110

59. Clark JE. From the beginning: a developmental perspective on movement and mobility. *Quest*. (2005) 57:37–45. doi: 10.1080/00336297.2005.10491841

60. Haywood KM, Getchell N. *Life Span Motor Development*. Champaign, IL: Human Kinetics Publishers (2021).

61. Iivonen S, Sääkslahti AK. Preschool children's fundamental motor skills: a review of significant determinants. *Early Child Dev Care*. (2013) 184:1107–26. doi: 10.1080/03004430.2013.837897

62. Krombholz H. Physical performance in relation to age, sex, birth order, social class, and sports activities of preschool children. *Percept Motor Skills*. (2006) 102:477–84. doi: 10.2466/pms.102.2.477-484

63. Edwards O, Ray S. An attachment and school satisfaction framework for helping children raised by grandparents. *School Psychol Q*. (2008) 23:125–38. doi: 10.1037/1045-3830.23.1.125

64. Edwards OW. Teachers' perceptions of the emotional and behavioral functioning of children raised by grandparents. *Psychol Schools*. (2006) 43:565–72. doi: 10.1002/pits.20170

65. Piya-amornphan N, Santiworakul A, Cetthakrikul S, Srirug P. Physical activity and creativity of children and youths. *BMC Pediatr*. (2020) 20:118. doi: 10.1186/s12887-020-2017-2

66. Li B, Adab P, Cheng KK. The role of grandparents in childhood obesity in China - evidence from a mixed methods study. *Int J Behav Nutr Phys Activ*. (2015) 12:91. doi: 10.1186/s12966-015-0251-z

67. Cattuzzo MT, Dos Santos Henrique R, Re AH, de Oliveira IS, Melo BM, de Sousa Moura M, et al. Motor competence and health related physical fitness in youth: a systematic review. *J Sci Med Sport*. (2016) 19:123–9. doi: 10.1016/j.jsams.2014.12.004

68. Lopes VP, Maia JAR, Rodrigues LP, Malina R. Motor coordination, physical activity and fitness as predictors of longitudinal change in adiposity during childhood. *Eur J Sport Sci*. (2012) 12:384–91. doi: 10.1080/17461391.2011.566368

69. D'Hondt E, Deforche B, De Bourdeaudhuij I, Lenoir M. Relationship between motor skill and body mass index in 5- to 10-year-old children. *Adapt Phys Activ Q*. (2009) 26:21–37. doi: 10.1123/apaq.26.1.21

70. Qi X. Floating grandparents: rethinking family obligation and intergenerational support. *Int Sociol*. (2018) 33:761–77. doi: 10.1177/0268580918792777

71. Engel AC, Broderick CR, van Doorn N, Hardy LL, Parmenter BJ. Exploring the relationship between fundamental motor skill interventions and physical activity levels in children: a systematic review and meta-analysis. *Sports Med*. (2018) 48:1845–57. doi: 10.1007/s40279-018-0923-3

72. Figueroa R, An R. Motor skill competence and physical activity in preschoolers: a review. *Matern Child Health J*. (2017) 21:136–46. doi: 10.1007/s10995-016-2102-1

73. Holfelder B, Schott N. Relationship of fundamental movement skills and physical activity in children and adolescents: a systematic review. *Psychol Sport Exerc*. (2014) 15:382–91. doi: 10.1016/j.psychsport.2014.03.005

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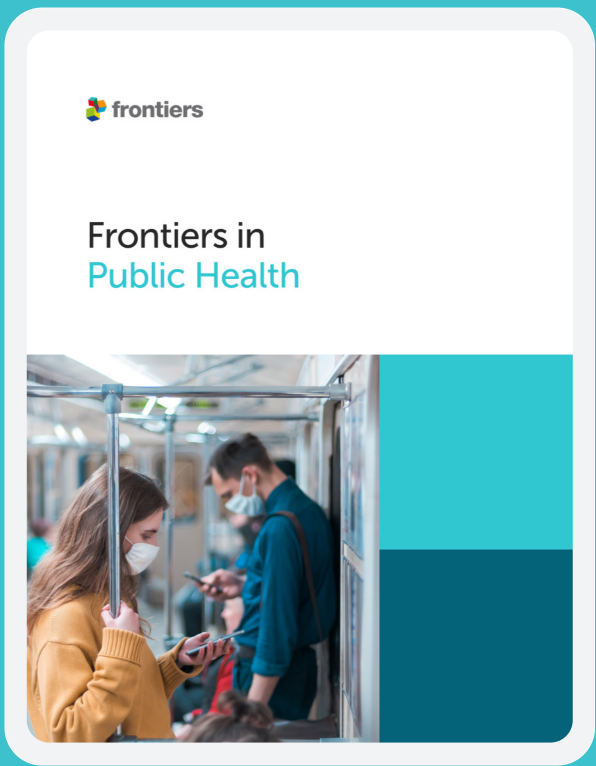

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