Effect of wearable activity trackers on physical activity in children and adolescents: a systematic review and meta-analysis

Whitney W Au, Francesco Recchia, Daniel Y Fong, Stephen H S Wong, Derwin K C Chan, Catherine M Capio, Clare C W Yu, Sam W S Wong, Cindy H P Sit, Patrick Ip, Ya-Jun Chen, Walter R Thompson, Parco M Siu

Summary

Background Physical inactivity in children and adolescents has become a pressing public health concern. Wearable activity trackers can allow self-monitoring of physical activity behaviour and promote autonomous motivation for exercise. However, the effects of wearable trackers on physical activity in young populations remain uncertain.

Methods In this systematic review and meta-analysis, we searched PubMed, Embase, SPORTDiscus, and Web of Science for publications from database inception up to Aug 30, 2023, without restrictions on language. Studies were eligible if they were randomised controlled trials or clustered randomised controlled trials that examined the use of wearable activity trackers to promote physical activity, reduce sedentary behaviours, or promote overall health in participants with a mean age of 19 years or younger, with no restrictions on health condition or study settings. Studies were excluded if children or adolescents were not the primary intervention cohort, or wearable activity trackers were not worn on users' bodies to objectively track users' physical activity levels. Two independent reviewers (WWA and FR) assessed eligibility of studies and contacted authors of studies if more information was needed to assess eligibility. We also searched reference lists from relevant systematic reviews and meta-analyses. Systematic review software Covidence was used for study screening and data extraction. Study characteristics including study setting, participant characteristics, intervention characteristics, comparator, and outcome measurements were extracted from eligible studies. The two primary outcomes were objectively measured daily steps and moderate-to-vigorous physical activity. We used a random-effects model with Hartung–Knapp adjustments to calculate standardised mean differences. Between-study heterogeneity was examined using Higgins I^2 and Cochran Q statistic. Publication bias was assessed using Egger's regression test. This systematic review was registered with PROSPERO, CRD42023397248.

Findings We identified 9619 studies from our database research and 174 studies from searching relevant systematic reviews and meta-analyses, of which 105 were subjected to full text screening. We included 21 eligible studies, involving 3676 children and adolescents (1618 [44%] were female and 2058 [56%] were male, mean age was 13·7 years [SD 2·7]) in our systematic review and meta-analysis. Ten studies were included in the estimation of the effect of wearable activity trackers on objectively measured daily steps and 11 were included for objectively measured moderate-to-vigorous physical activity. Compared with controls, we found a significant increase in objectively measured daily steps (standardised mean difference 0·37 [95% CI 0·09 to 0·65; p=0·013]; Q 47·60 [p<0·0001]; I^2 72·7% [95% CI 53·4 to 84·0]), but not for moderate-to-vigorous physical activity (–0·08 [–0·18 to 0·02; p=0·11]; Q 10·26 [p=0·74]; I^2 0·0% [0·0 to 53·6]).

Interpretation Wearable activity trackers might increase daily steps in young cohorts of various health statuses, but not moderate-to-vigorous physical activity, highlighting the potential of wearable trackers for motivating physical activity in children and adolescents. More rigorously designed trials that minimise missing data are warranted to validate our positive findings on steps and to explore possible long-term effects.

Funding The Hong Kong University Grants Committee and Seed Fund for Basic Research of the University of Hong Kong.

Lancet Digit Health 2024; 6: e625–39

Published Online August 6, 2024
https://doi.org/10.1016/S2589-7500(24)00139-0

Division of Kinesiology, School of Public Health, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong Special Administrative Region, China (W W Au BBiomedSc, F Recchia MSc, Prof P M Siu PhD); School of Nursing, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong Special Administrative Region, China (D Y Fong PhD); Department of Sports Science and Physical Education, Faculty of Education, The Chinese University of Hong Kong, Hong Kong Special Administrative Region, China (Prof S H S Wong PhD, Prof C H P Sit PhD); Department of Early Childhood Education, Faculty of Education and Human Development, The Education University of Hong Kong, Hong Kong Special Administrative Region, China (D K C Chan PhD); Department of Physiotherapy, School of Nursing and Health Studies, The Hong Kong Metropolitan University, Hong Kong Special Administrative Region, China (C M Capio PhD); Department of Rehabilitation Sciences, Faculty of Health and Social Sciences, The Hong Kong Polytechnic University, Hong Kong Special Administrative Region, China (C C W Yu PhD); Physical Fitness Association of Hong Kong, China, Hong Kong Special Administrative Region, China (S W S Wong DPT); Department of Paediatrics and Adolescent Medicine, School of Clinical Medicine, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong Special Administrative Region, China (Prof P Ip MD); Department of Maternal and Child Health,

Introduction

Physical activity is important for overall health and wellbeing, including in young populations. According to WHO, children and adolescents aged 5–17 years should accumulate a minimum of 60 min of moderate-to-vigorous physical activity daily.[1] However, children and adolescents increasingly show high levels of physical inactivity, defined as physical activity not meeting the WHO recommended levels. Worldwide data from 1·6 million adolescent students (aged 11–17 years) in 2016 showed that less than a fifth met WHO recommended physical activity levels.[2] The COVID-19

School of Public Health, Sun Yat Sen University, Guangzhou, China (Prof Y-J Chen PhD); **College of Education and Human Development, Georgia State University, Atlanta, GA, USA** (Prof W R Thompson PhD)

Correspondence to: Prof Parco M Siu, Division of Kinesiology, School of Public Health, The University of Hong Kong, Hong Kong Special Administrative Region, China **pmsiu@hku.hk**

Research in context

Evidence before this study

The potential of technology-based interventions, particularly the use of wearable activity trackers, to promote healthy physical activity behaviours has been highlighted. We searched PubMed, from database inception to Feb 3, 2023, without language restrictions, for studies on the use of wearable activity trackers to motivate physical activity behaviour using the search strategy: ("wearable activity"[Title/Abstract] OR "wearable device*"[Title/Abstract] OR "wearable technology*"[Title/Abstract] OR "activity track*"[Title/Abstract] OR "fitness tracker*"[Title/Abstract] OR "commercial wearable*"[Title/Abstract] OR "fitbit"[Title/Abstract] OR "pedometer*"[Title/Abstract] OR "accelerometer"[Title/Abstract] OR "smart band*"[Title/Abstract] OR "wristband*"[Title/Abstract] OR "wearable electronic device*"[Title/Abstract]) AND ("physical activ*"[Title/Abstract] OR "MVPA"[Title/Abstract] OR "step*"[Title/Abstract] OR "daily step count*"[Title/Abstract] OR "steps per day"[Title/Abstract] OR "activity count*"[Title/Abstract] OR "energy expenditure"[Title/Abstract] OR "fitness"[Title/Abstract]). From this search, we found that most studies focused on the effects of wearable trackers on increasing physical activity in adults, and that systematic reviews showed inconclusive findings in children and adolescents. We identified only two meta-analytical studies that quantitatively synthesised available evidence on the effects of wearable activity trackers in children and adolescents, but one of them only focused on adiposity-related outcomes. Another meta-analysis investigated the effect of trackers on objectively measured physical activity and sedentary time in the healthy young population (mean age 5–18 years), where they found a moderate effect of wearable trackers on increasing daily total steps and a small effect on increasing moderate-to-vigorous physical activity, but an unfavourable effect on reducing sedentary behaviour. However, this meta-analysis had several limitations, including inclusion of a large proportion of non-randomised or non-controlled trials with high risk of bias, exclusion of clinical populations, limited rigorousness of data analysis method that might not account for between-individual variability, and the inclusion of control groups that might mask true intervention effects. To this end, we aimed to complete a meta-analysis that examined the effects of wearable activity trackers on physical activity in young participants (mean age ≤19 years) from both healthy and clinical populations, and synthesise data using rigorous data analyses from only studies with randomised controlled designs.

Added value of this study

To our knowledge, this is the first systematic review and meta-analysis that examined the effects of wearable activity trackers on physical activity in both healthy children and adolescents, as well as young people with suboptimal health. By synthesising data derived from randomised controlled trials and using stringent data analysis procedures, we found that wearable trackers seemed to have a positive effect on increasing daily steps in children and adolescents of various health statuses, but not on moderate-to-vigorous physical activity. Comprehensive sensitivity analyses that tested for robustness of findings confirmed the null effect found on moderate-to-vigorous physical activity, but also highlighted the importance of more rigorously designed trials that minimise missing data to confirm the positive effects on increasing step counts.

Implications of all the available evidence

Higher daily step count is associated with improved physical and mental health in young cohorts, and reduces risks of developing various non-communicable diseases and all-cause mortality, highlighting the potential of wearable activity trackers in improving the health of children and adolescents. More high-quality evidence is needed to confirm findings on steps and explore possible long-term effects, and future studies should also explore whether there might be differences in the effect of activity trackers on children and adolescents of different age, sex, or health statuses to facilitate more personalised and effective application of wearable activity trackers on physical activity promotion.

pandemic has been associated with a further decline in physical activity levels due to social isolation policies.[3] Physical inactivity has been found to further increase as children enter adolescence, with physical activity levels reducing at an average rate of 7% per year between the ages of 10 years and 19 years.[4] Physical inactivity can have serious consequences on the physical and mental health of young children that can extend into adulthood.[5] Due to its close association with non-communicable diseases, such as heart disease, type 2 diabetes, and cancers, physical inactivity has been estimated to contribute to approximately 10% of global mortality.[6,7] Physical inactivity is also associated with obesity,[8] and has been linked to the accelerating global prevalence of childhood obesity since the 1980s.[9] Excess adiposity in children is associated with an increased risk of mortality and cardiometabolic disease in later life.[10–12] Consequently, increasing physical activity is widely acknowledged as an effective tertiary treatment and preventive measure for obesity.[13] Increasing physical activity at a young age is particularly important to reduce the risk of developing obesity during prepubertal adiposity rebound[14] and during adolescence when physical activity levels typically decrease.[15] Intervening at a young age also holds great potential for eliciting behavioural changes to cultivate healthy lifestyle habits because behavioural development is more malleable at this age.[13]

Behavioural changes achieved through self-driven techniques, such as self-monitoring and goal setting, are important for increasing physical activity and making lifestyle changes.[9,16] While autonomous motivation is widely acknowledged to be important for promoting exercise behaviour,[17,18] a study in adolescents (aged 17–19 years) found that self-monitoring had the greatest mediating effect on autonomous motivation to subsequently increase physical activity.[19] Moreover, in a 2009 meta-regression analysis, self-monitoring was identified as the most effective behavioural change technique to promote physical activity and a healthy diet in 44747 adults.[20] Wearable activity trackers (eg, smartwatches, wristbands, pedometers, and accelerometers) are devices worn on a user's body that can allow self-monitoring of physical activity behaviour by tracking and providing feedback on the user's physical activity levels (eg, daily step count and time spent doing moderate-to-vigorous physical activity). The potential use of technology-based strategies, such as wearable activity trackers, has been highlighted as a potential way to deliver personalised health care and to promote adherence to a healthy lifestyle.[21] Although the benefits of wearable trackers on increasing physical activity have been well documented in healthy adults[22,23] and adults with diseases (eg, patients with rheumatic and musculoskeletal diseases[24] and cancer survivors[25]),[26] evidence in younger populations is scarce and the findings are inconclusive. Only a few systematic reviews have been conducted to evaluate the effects of activity trackers in children and adolescents. Böhm and colleagues[27] found that mHealth devices or wearable activity trackers had no effect on physical activity, whereas Ridgers and colleagues[28] and Creaser and colleagues[29] reported mixed results, although the effects on physical activity were generally positive. Notably, the meta-analysis by Casado-Robles and colleagues[30] concluded that wearable activity trackers were effective in increasing daily steps and moderate-to-vigorous physical activity in healthy children and adolescents. However, Casado-Robles and colleagues' study[30] had some considerable flaws and limitations. First, over half of the included studies were non-randomised or non-controlled trials. Studies with these designs are more prone to bias due to confounding and selection of study participants, as well as potential unbalanced prognostic factors between groups.[31] Moreover, studies identified to have a high risk of bias (60% and 80% of studies included for steps and moderate-to-vigorous physical activity outcomes, respectively) were not removed from their analyses as recommended, and no sensitivity analyses for risk of bias were conducted because of the substantially low proportion of studies classified as low risk.[31] Because of these methodological shortcomings, the overall certainty of the study's findings is questionable. Second, although effective interventions that can increase physical activity in young clinical populations (eg, individuals with obesity, type 1 diabetes, juvenile idiopathic arthritis, or with cancer) are particularly important to improve their health status and cardiorespiratory fitness,[32–35] clinical populations were excluded from Casado-Robles and colleagues' study,[30] restricting the generalisability of their findings to healthy young cohorts only. Third, the inconsistencies in data used for calculation of effect size (ie, data extracted for effect size calculation ranged from both pre-intervention and post-intervention data, mean change from pre-intervention to post-intervention, or post-intervention data only depending on study designs) might have resulted in between-individual variability being overlooked in estimates, which would have been better accommodated if only mean change was used to calculate standardised mean differences.[36] Finally, in an estimated 28% of the included randomised controlled trials or cluster-randomised controlled trials, control groups wore activity trackers that did not provide physical activity feedback (known as sealed activity trackers), such that true intervention effects might have been masked, as explained by the Hawthorne effect (ie, that awareness of being monitored could be sufficient to elicit physical activity increase).[37] This theory is supported by a pedometer study conducted in elementary students (age 7–11 years) in which the group that wore sealed trackers showed increases in physical activity most likely due to reactivity to wearing the pedometer.[38]

In this systematic review and meta-analysis, we aimed to comprehensively assess the effects of wearable activity trackers on physical activity in children and adolescents from both healthy and clinical populations. For the purpose of this review, a clinical population was defined as children or adolescents (mean age ≤19 years) with suboptimal health conditions diagnosed by a clinician or certified through validated medical or research instruments.

Methods

Search strategy and selection criteria

In this systematic review and meta-analysis, we searched PubMed, Embase, SPORTDiscus, and Web of Science for publications from database inception up to May 18, 2023, without any language restrictions. The search was repeated on Aug 30, 2023, to identify potential relevant new publications since the previous search. Search terms for each database are in the appendix (pp 2–3). Reference lists of relevant systematic reviews and meta-analyses identified from database search were also screened for potential eligible studies (appendix p 12). The title and abstracts of papers identified from the database search were screened by two investigators (WWA and FR), then papers agreed by both investigators to be included for full text review were sought for retrieval and assessed for eligibility. Authors of articles were contacted if more information was needed to assess study eligibility as agreed by both investigators during full text review. Any disagreements at any stages were resolved through discussion, with any persisting disagreements resolved by a third independent investigator (PMS). The systematic review software Covidence was used for study screening and data extraction.

See **Online** for appendix

For the **Covidence website** see https://www.covidence.org/

The inclusion criteria and search strategies were based on the population, intervention, comparison, outcomes, and study (PICOS) framework.[39] Studies were eligible for inclusion if they included children or adolescents, or both, with a mean age of 19 years or younger of any health condition, and if they involved interventions using wearable activity trackers to promote physical activity, reduce sedentary behaviour, or promote overall health, or a combination of these aims. The intervention could involve the use of only wearable activity trackers or could be delivered in combination with other behavioural components, including exercise programmes, health education sessions, goal setting, and reward schemes. Wearable activity trackers had to be worn on users' bodies and be able to track and provide objective estimations on users' physical activity levels. Eligible studies had to be randomised controlled trials or cluster-randomised controlled trials that had a control group that received no intervention or usual care, was waitlisted, or had no activity tracker as part of a multicomponent intervention. Additionally, eligible studies had to assess objectively or subjectively measured physical activity levels before the start and at the end of the intervention. No restrictions were placed on the study's setting because trackers can theoretically be worn on users' body everywhere and at all times.

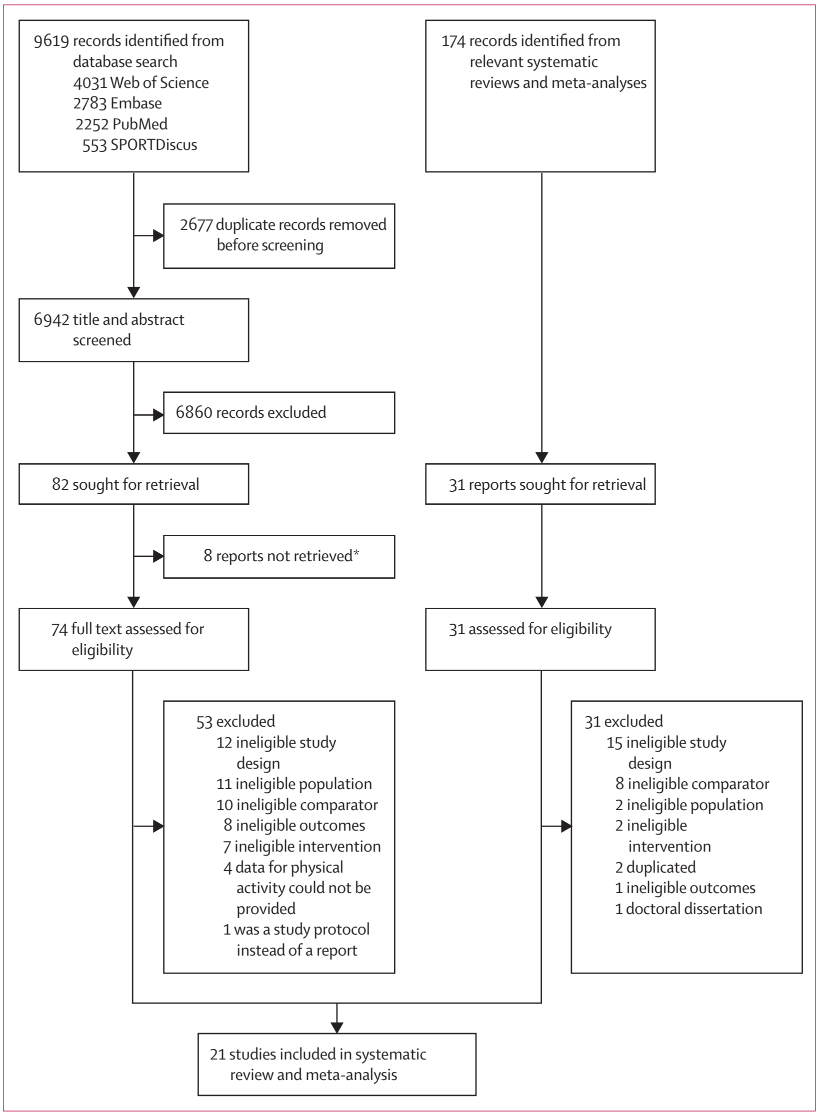

Figure 1: **PRISMA flowchart of study search and selection strategy**
*Unable to retrieve full text as these reports were conference abstracts without full text.

Studies were excluded if children or adolescents were not in the primary intervention cohort (ie, they did not wear trackers), trackers were used only as physical activity measurement tools, smartphone applications were used instead of wearable trackers for monitoring physical activity level, or both the intervention and comparator groups wore trackers (eg, control groups wore sealed pedometers without physical activity feedback). All eligible studies identified through our systematic review were included in the meta-analysis.

This systematic review and meta-analysis is registered at PROSPERO, CRD42023397248, and followed the PRISMA guidelines.[40] The protocol was amended to provide additional information on the primary and secondary outcomes reported in this Article.

Outcomes

The primary outcomes of interest were changes in the objectively measured physical activity outcomes of daily steps and moderate-to-vigorous physical activity. In addition to daily steps, which can represent physical activity, moderate-to-vigorous physical activity was chosen as a primary outcome because it is widely used as a physical activity parameter in WHO recommendations. Secondary outcomes were changes in objectively measured accelerometer counts per minute (CPM), light physical activity, and sedentary time, as well as subjectively measured moderate-to-vigorous physical activity. Long-term maintenance effects of the interventions (ie, at follow-up) were also examined if sufficient studies (ie, at least two studies) provided data on them.

Data analysis

Study characteristics including study setting (school-based, clinic-based, or daily life), participant characteristics (age, sex, and health status), intervention characteristics (duration, type of tracker, and strategies used in combination with tracker), comparator, and outcome measurements (physical activity parameter [eg, daily steps or moderate-to-vigorous physical activity], measurement tool, and follow-up period) were independently extracted by two investigators (WWA and FR). The data extracted by each investigator were then compared and verified, with potential disagreements being resolved by a third investigator (PMS). To calculate effect sizes, information regarding the sample size and mean (SD) of the outcome measure at baseline,

	Study design, country, setting	Participant characteristics				Intervention characteristics				Outcome		Follow-up
		Sample size (sex)	Health status	Population	Age range (mean age*), years	Duration	Tracker type	Tracker as major component or part of a multicomponent intervention	Comparator group	Objective	Subjective	
Baldursdottir et al (2017)[51]	Cluster RCT, Iceland, school	53 (31 [58%] female, 22 [42%] male)	Healthy	Adolescents (secondary school)	15–16 (not stated)	3 weeks	Pedometer (waist)	Major component: self-monitoring through self-record, reminders, goal setting by a third party	No intervention	Daily steps	..	NR
Corepal et al (2019)[52]	Cluster RCT, Ireland, school	224 (119 [53%] female, 105 [47%] male)	Healthy	Adolescents (after primary school)	12–14 (not stated)	22 weeks	Fitbit Zip† (pocket, bag, or clip)	Major component: goal setting by participant, reward, competition, reminders, social support, family or parental involvement, and StepSmart Challenge website (Fitbit data upload and track, competition leader board, motivational messages, and weekly challenges)	No intervention	Daily steps, moderate-to-vigorous physical activity, light physical activity, moderate physical activity, vigorous physical activity, and sedentary time	..	30 weeks
Devine et al (2020)[53]	RCT, USA, clinic	49 (24 [49%] female, 25 [51%] male)	Cancer survivors	Adolescents and young adults	13–25 (18·5)	12 weeks	Fitbit Charge or Alta† (wrist)	Multicomponent: goal setting by participant, social support, advice on goal setting, lifestyle and health education, FitSurvivor app (feedback on Fitbit activity data, goal setting, cancer-specific and general information, strength and high intensity workout videos or pictures, rewards, and accomplishment boards), and regular exercise sessions	Waiting list	Moderate-to-vigorous physical activity	Moderate-to-vigorous physical activity and sedentary time	3 months
Guagliano et al (2020)[54]	RCT, UK, daily life	52 (34 [65%] female, 18 [35%] male)	Healthy	Children	7–11 (9·3)	8 weeks	Pedometer (waist)	Major component—intervention 1: family involvement, lifestyle and health education; multicomponent—intervention 2: goal setting by participant, family involvement, lifestyle and health education, and FRESH website (step challenges selection and steps record tracking)	No intervention	Moderate-to-vigorous physical activity, and sedentary time	..	1 year
Horne et al (2009)[55]	Cluster RCT, UK, school	100 (50 [50%] female, 50 [50%] male)	Healthy	Children (primary school)	9–11 (10·0)	14 weeks	Pedometer (waist)	Major component: self-monitoring through self-record, reward, reminders, and goal setting by a third party	No intervention	Daily steps	..	NR
Jago et al (2006)[56]	Cluster RCT, USA, daily life	473 (0 female, 473 [100%] male)	Healthy	Children and adolescents (boy scouts)	10–14 (13·0)	9 weeks	Pedometer (not stated)	Multicomponent: goal setting by participant, reward, advice on goal setting, interactive website (goal setting, goal attainment reporting, problem solving, and physical activity knowledge games), and regular exercise sessions	Placebo	Moderate-to-vigorous physical activity, light physical activity, sedentary time, and accelerometer counts per min	..	6 months

(Table continues on next page)

	Study design, country, setting	Participant characteristics				Intervention characteristics				Outcome		Follow-up
		Sample size (sex)	Health status	Population	Age range (mean age*), years	Duration	Tracker type	Tracker as major component or part of a multicomponent intervention	Comparator group	Objective	Subjective	
(Continued from previous page)												
Knox et al (2019)[57]	RCT, UK, daily life	49 (22 [45%] female, 27 [55%] male)	Type 1 diabetes	Children (hospital patients)	9–12 (10·6)	6 months	PolarActive activity watch‡ (wrist)	Major component: goal setting by participant, lifestyle and health education, and STAK-D website (goal setting, activity tracking, goal feedback from researchers, problem solving, physical activity, dance routine, and platform for communication between peers, parents, or a health-care professional)	Usual care	Moderate-to-vigorous physical activity, and weekly steps	Physical activity score	NR
Lee et al (2012)[58]	RCT, Taiwan, school	94 (94 [100%] female, 0 male)	Healthy	Adolescents (secondary school)	16–20 (16·2)	12 weeks	Pedometer (pocket, bag or clip)	Multicomponent: goal setting by participant, reward, social support, goal setting by a third party, and advice on goal setting	No intervention	Daily steps	··	NR
Lubans et al (2009)[59]	Cluster RCT, Australia, school	124 (71 [57%] female, 53 [43%] male)§	Healthy	Adolescents (secondary school)	Not stated (14·1)	6 months	Pedometer (waist)	Multicomponent: self-monitoring through self-record, social support, family involvement, lifestyle and health education, and regular exercise sessions	Minimal intervention without activity tracker	Daily steps	··	NR
Lubans et al (2011)[60]	Cluster RCT, Australia, school	100 (0 female, 100 [100%] male)	Healthy	Adolescents (secondary school)	Not stated (14·3)	6 months	Pedometer (waist)	Multicomponent: goal setting by participant, self-monitoring through self-record, social support, lifestyle and health education, and regular exercise sessions	Waiting list	Daily steps	··	NR
Lubans et al (2012)[61]	Cluster RCT, Australia, school	357 (357 [100%] female, 0 male)	Healthy	Adolescents (secondary school)	12–14 (13·2)	12 months	Pedometer (not stated)	Multicomponent: goal setting by participant, self-monitoring through self-record, social support, family involvement, lifestyle and health education, regular exercise sessions	Waiting list	Moderate-to-vigorous physical activity and accelerometer counts per min	··	12 months
Mendoza et al (2017)[62]	RCT, USA, daily life	59 (35 [59%] female, 24 [41%] male)	Cancer survivors	Adolescents	14–18 (16·6)	10 weeks	Fitbit Flex† (wrist)	Major component: reminders, social support, goal setting by a third party, and mHealth app (Fitbit Flex physical activity metrics display and goal setting)	Usual care	Moderate-to-vigorous physical activity, light physical activity, and sedentary time	··	NR
Morris et al (2019)[63]	Cluster RCT, UK, school	83 (49 [59%] female, 34 [41%] male)	Healthy	Children (primary school)	10–11 (9·9)	6 weeks	Pedometer (waist)	Major component: self-monitoring through self-record, goal setting by a third party, and teacher-led regular exercise sessions	No intervention	Moderate-to-vigorous physical activity, light physical activity, and sedentary time	··	NR
Neto et al (2016)[64]	RCT, Brazil, daily life	19 (7 [37%] female, 12 [63%] male)	Obese	Children	8–10 (not stated)	12 weeks	Pedometer (waist)	Major component: self-monitoring through self-record, goal setting by a third party, and advice on goal setting	No intervention	Daily steps	··	NR

(Table continues on next page)

	Study design, country, setting	Participant characteristics				Intervention characteristics				Outcome		Follow-up
		Sample size (sex)	Health status	Population	Age range (mean age*), years	Duration	Tracker type	Tracker as major component or part of a multicomponent intervention	Comparator group	Objective	Subjective	
(Continued from previous page)												
Newton et al (2009)[65]	RCT, New Zealand, daily life	78 (42 [54%] female, 36 [46%] male)	Type 1 diabetes	Children and adolescents	11–18 (14·4)	12 weeks	Pedometer (not stated)	Major component: self-monitoring through self-record, reminders, and goal setting by a third party	Usual care	Daily steps	Moderate-to-vigorous physical activity	NR
Ruotsalainen et al (2015)[66]	RCT, Finland, school	30 (21 [70%] female, 9 [30%] male)	Overweight and obese	Adolescents	13–16 (14·8)	12 weeks	Polar Active physical activity monitor¶ (wrist)	Multicomponent: self-monitoring through self-record, social support, family involvement, goal setting by a third party, and lifestyle and health education (with tailored exercise programme suggestions)	No intervention	Moderate-to-vigorous physical activity, light physical activity, moderate physical activity, vigorous physical activity, and sedentary time	..	NR
Sharp et al (2016)[67]	RCT, Canada, daily life	184 (98 [53%] female, 86 [47%] male)	Healthy	Adolescents (university; first year)	≥17 (18·0)	12 weeks	Pedometer (waist)	Major component: self-monitoring through self-record, reminders, goal setting by a third party, advice on goal setting, and lifestyle and health education through email	No intervention	..	Light physical activity, moderate physical activity, and vigorous physical activity	NR
Slootmaker et al (2010)[68]	RCT, Netherlands, daily life	87 (55 [63%] female, 32 [37%] male)†	Healthy	Adolescents (secondary school)	Not stated (15·1)	12 weeks	PAM accelerometer‖ (waist)	Major component: goal setting by participant, self-monitoring through self-record, advice on goal setting, and PAM COACH website (physical activity data log, goal setting, problem solving, and individualised physical activity advice)	No intervention	..	Moderate-to-vigorous physical activity, light physical activity, moderate physical activity, vigorous physical activity, and sedentary time	5 months
Smith et al (2014)[69]	Cluster RCT, Australia, school	361 (0 female, 361 [100%] male)	Healthy	Adolescents (secondary school)	12–14 (12·7)	20 weeks	Pedometer	Multicomponent: goal setting by participant, self-monitoring through self-record, reminders, family involvement, smartphone app (daily step counts record, fitness challenge results tracking, resistance training skill peer assessment, goal setting, and personalised motivational messaging), regular exercise sessions with enhanced physical activity environment in school	Waiting list	Moderate-to-vigorous physical activity and accelerometer counts per min	..	10 months

(Table continues on next page)

Study	Study design, country, setting	Participant characteristics				Intervention characteristics				Outcome		Follow-up
		Sample size (sex)	Health status	Population	Age range (mean age*), years	Duration	Tracker type	Tracker as major component or part of a multicomponent intervention	Comparator group	Objective	Subjective	
(Continued from previous page)												
Suchert et al (2015)[70]	Cluster RCT, Germany, school	1020 (484 [47%] female, 536 [53%] male)	Healthy	Adolescents (secondary school)	12–17 (13·7)	12 weeks	Pedometer (waist)	Major component: reward, competition, and lifestyle and health education	No intervention	..	Moderate-to-vigorous physical activity	1 year
Thompson et al (2016)[71]	RCT, USA, daily life	80 (41 [51%] female, 39 [49%] male)	Healthy	Adolescents	14–17 (not stated)	12 weeks	Pedometer (waist)	Major component—intervention 1: no strategies; multicomponent—intervention 2: goal setting by participant, social support, and goal setting by a third party; multicomponent—intervention 3: goal setting by participant, motivational messages, social support, and goal setting by a third party	No intervention	Moderate-to-vigorous physical activity, and daily steps	..	NR

RCT=randomised controlled trial. NR=not reported. *For each study mean age of participants was averaged over all participants who participated in the study. †Manufacturer FitBit (country of manufacturer not provided). ‡PolarActive activity watch (Polar Electro, Leamington Spa, UK). §Outcomes in male and female participants were separately reported in the study. ¶Polar Active physical activity monitor (Polar Electro Kempele Oy, Kempele, Finland). ||PAM accelerometer (PAM, Doorwerth, Netherlands).

***Table:* Characteristics of the included studies**

post-intervention, and at follow-up (if applicable) were collected for each study. Authors were contacted if measured physical activity data were not reported, or if data were not in the correct format for calculating effect size. If the results were not presented as mean (SD), we used previously validated methods to convert them to the desired format.[36,41]

Risk of bias was assessed using the revised Cochrane risk-of-bias tool for randomised trials and revised Cochrane risk-of-bias tool for cluster-randomised trials, which classifies studies into three categories, which are low risk of bias, some concerns, or high risk of bias.[42] Two investigators (WWA and FR) independently assessed the risk of bias and disagreements were resolved via discussion, with any persisting disagreements resolved by a third investigator (PMS) when necessary. The certainty of the evidence was assessed using the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) approach for the two primary outcomes.[43] Details regarding risk of bias and GRADE assessments are listed in the appendix (pp 4–7).

The meta-analysis was performed using R (version 4.2.0), with the “meta”, “metafor”, and “dmetar” packages. A random-effects model with Hartung–Knapp adjustments was used to calculate the standardised mean differences using mean change from baseline to post-intervention timepoint (and change from post-intervention timepoint to follow-up for the maintenance effect), the SD at the post-intervention timepoint, and sample size. Positive effect sizes indicated a positive effect of the wearable activity tracker intervention on increasing physical activity or reducing sedentary behaviour.

Publication bias was assessed with Egger’s regression test ($p<0 \cdot 10$ indicates the presence of publication bias) and by visually examining the funnel plot symmetry.[44] Publication bias assessment was conducted on the two primary outcomes. Sensitivity analyses were done to assess differences in the pooled effect estimates when using a fixed-effect model, after removing studies with high risk of bias, and after removing potential outliers (studies for which the confidence interval for the outcome of interest did not overlap with the confidence interval of the pooled effect estimate).[45]

To examine heterogeneity not attributable to sampling error, between-study heterogeneity was examined using Higgins I^2 statistic[46] and Cochran Q statistic (for which a p value of $<0 \cdot 05$ indicates the presence of heterogeneity), with I^2 values (presented along with 95% CI) of 25%, 50%, and 75% representing low, moderate, and high heterogeneity, respectively.[46] For any observed substantial heterogeneity, the possible reasons for this were examined by subgroup analyses and meta-regressions. Subgroup analyses were conducted to explore the influence of study setting (school-based *vs* daily life), participants’ characteristics (age [≤13 years *vs* >13 years], sex [male *vs* female *vs* male and female], and health status

	Intervention group			Control group			Standardised mean difference (95% CI)	Weight
	Total	Mean change	SD	Total	Mean change	SD		
Neto et al (2016)[64]	10	3421·90	3581·70	9	522·20	5146·90	0·63 (–0·30 to 1·56)	4·4%
Corepal et al (2019)[52]	126	334·00	3202·62	64	1462·37	4497·99	–0·30 (–0·61 to –0·00)	9·2%
Knox et al (2019)[57]	9	315·86	822·14	21	20·00	579·71	0·44 (–0·35 to 1·23)	5·3%
Lee at al (2012)[58]	46	371·00	832·03	45	–108·00	554·19	0·67 (0·25 to 1·09)	8·2%
Lubans et al (2009a*)[59]	26	852·00	3375·00	17	–2077·00	3603·00	0·83 (0·19 to 1·47)	6·4%
Lubans et al (2009b*)[59]	24	1333·00	2314·00	35	–2430·00	2400·00	1·57 (0·97 to 2·17)	6·7%
Lubans et al (2011)[60]	50	–19·00	5264·00	47	–153·00	3451·00	0·03 (–0·37 to 0·43)	8·4%
Thompson et al (2016a†)[71]	36	284·00	2446·67	34	–75·00	2351·90	0·15 (–0·32 to 0·62)	7·8%
Thompson et al (2016b†)[71]	31	55·00	2316·47	34	–75·00	2351·90	0·06 (–0·43 to 0·54)	7·6%
Thompson et al (2016c†)[71]	37	318·00	2378·24	34	–75·00	2351·90	0·16 (–0·30 to 0·63)	7·8%
Newton et al (2009)[65]	38	–292·33	4695·70	40	–642·33	3385·97	0·09 (–0·36 to 0·53)	8·0%
Baldursdottir et al (2017)[51]	26	1255·84	2904·05	27	–992·09	2854·03	0·77 (0·21 to 1·33)	7·0%
Horne et al (2009a‡)[55]	23	2873·00	3288·00	23	480·00	4239·51	0·62 (0·03 to 1·21)	6·7%
Horne et al (2009b‡)[55]	15	1548·00	9744·43	28	1512·00	9175·47	0·00 (–0·62 to 0·63)	6·5%
Random effects model	**497**			**458**			**0·37 (0·09 to 0·65)**	**100·0%**

Heterogeneity: I^2=72·7% (95% CI 53·4 to 84·0), τ^2=0·1650, p<0·0001

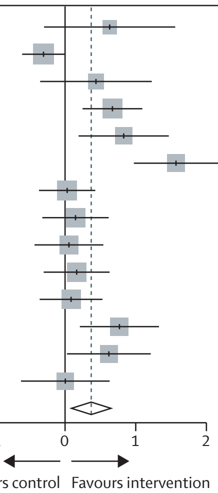

Figure 2: **Wearable activity tracker intervention effects on objectively measured steps at post-intervention timepoint**
*Lubans et al (2009a) and (2009b) indicate the cohorts of boys and girls, respectively. †Thompson et al (2016a), (2016b), and (2016c) indicate the cohorts of pedometer only, pedometer plus goal prompts, and the pedometer plus goal prompts plus motivational text groups, respectively. ‡Horne et al (2009a) and (2009b) indicate the cohorts of girls and boys, respectively.

[healthy *vs* clinical population]), as well as intervention characteristics (study duration [≤12 weeks *vs* >12 weeks], intervention components [activity tracker as the major component *vs* activity tracker as part of a multicomponent intervention], and intervention strategies used [extrinsic motivation *vs* social involvement *vs* referenceable advice *vs* education *vs* technology-based *vs* regular exercise session]) on the overall effect. A detailed description of how interventions were classified is in the appendix (p 13). Meta-regressions were done to explore whether the intervention effects were moderated by study duration and mean age of participants. All sensitivity and subgroup analyses were conducted a priori, per the study protocol. Because significant publication bias was detected for both primary outcomes, post-hoc trim-and-fill analyses were also conducted to account for publication bias.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

We identified 9619 records from four databases and 174 additional records were identified from searching the reference lists of relevant systematic reviews and meta-analyses. After abstract and title screening, 105 potential full texts were retrieved and assessed for eligibility. After full text screening, 21 studies involving 3676 children and adolescents (1618 [44%] were female and 2058 [56%] were male; mean age 13·7 years [SD 2·7]; 13 [62%] of 21 studies did not report race or ethnicity data, so these data were not summarised) were included in this systematic review and meta-analysis (figure 1). Four studies were excluded at full text review because the necessary physical activity data could not be extracted.[47–50] More details on studies excluded at full text screening are in the appendix (pp 8–12).

The characteristics of the 21 included studies are shown in the table. Among the studies, 11 were randomised controlled trials and ten were cluster randomised controlled trials. 16 studies included male and female participants,[51–55,57,59,62–68,70,71] three included only male participants,[56,60,69] and two included only female partcipants.[58,61] Five studies involved children,[54,55,57,63,64] 14 involved adolescents,[51–53,58–62,65–71] and two involved both children and adolescents.[56,65] 11 studies were conducted in a school setting,[51,52,55,57,59–61,63,66,69,70] one in a clinic setting,[53] and nine in daily life.[54,56,57,62,64,65,67,68,71] Six studies were conducted in clinical populations: two in cancer survivors,[53,62] two in participants with type 1 diabetes,[57,65] and two in overweight and obese populations.[64,66] The mean duration of intervention was 17·24 weeks (SD 11·90), ranging from 3 weeks[51] to 12 months.[61] All studies used pedometers, with the exception of three studies that used a Fitbit (Fitbit Zip,[52] Fitbit Charge or Alta,[53] and Fitbit Flex,[62] all manufactured by Fitbit [country of manufacturer not available]), and three studies that used accelerometers (PolarActive activity watch [Polar Electro, Leamington Spa, UK],[57] Polar Active physical activity monitor [Polar Electro Kempele Oy, Kempele, Finland],[66] and PAM accelerometer [PAM, Doorwerth, Netherlands][68]). Objective physical activity levels were measured in 15 studies,[51,52,54–66,69,71]

	Intervention group			Control group			Standardised mean difference (95% CI)	Weight
	Total	Mean change	SD	Total	Mean change	SD		
Morris et al (2019)[63]	52	0·31	2·15	31	0·13	2·70	0·08 (–0·37 to 0·52)	5·4%
Smith et al (2014)[69]	68	–4·30	4·12	89	–3·50	3·77	–0·20 (–0·52 to 0·11)	10·7%
Corepal et al (2019)[52]	126	–2·23	19·65	64	0·43	24·57	–0·12 (–0·43 to 0·18)	11·9%
Devine et al (2020)[53]	15	–8·27	30·25	22	–0·31	11·78	–0·37 (–1·03 to 0·29)	2·5%
Knox et al (2019)[57]	9	21·01	46·30	21	–5·65	34·83	0·67 (–0·13 to 1·48)	1·7%
Lubans et al (2012)[61]	121	–9·27	9·75	135	–5·20	18·88	–0·27 (–0·51 to –0·02)	17·7%
Ruotsalainen et al (2015)[66]	14	4·80	33·60	14	–0·30	18·00	0·18 (–0·56 to 0·93)	1·9%
Thompson et al (2016a*)[71]	36	1·26	21·05	34	–1·56	20·19	0·14 (–0·33 to 0·60)	4·9%
Thompson et al (2016b*)[71]	31	0·11	19·82	34	–1·56	20·19	0·08 (–0·40 to 0·57)	4·5%
Thompson et al (2016c*)[71]	37	1·72	20·50	34	–1·56	20·19	0·16 (–0·31 to 0·63)	4·9%
Guagliano et al (2020a†)[54]	18	–7·85	17·60	23	–7·62	15·59	–0·01 (–0·63 to 0·60)	2·8%
Guagliano et al (2020b†)[54]	15	–8·67	12·13	23	–7·62	15·59	–0·07 (–0·72 to 0·58)	2·5%
Mendoza et al (2017)[62]	29	4·40	30·50	30	5·00	33·60	–0·02 (–0·53 to 0·49)	4·1%
Jago et al (2006a‡)[56]	64	–1·80	17·60	55	–0·40	17·80	–0·08 (–0·44 to 0·28)	8·3%
Jago et al (2006b‡)[56]	103	0·20	17·25	130	1·70	18·24	–0·08 (–0·34 to 0·17)	16·1%
Random effects model	**738**			**739**			**–0·08 (–0·18 to 0·02)**	**100·0%**

Heterogeneity: I^2=0·0% (95% CI 0·0 to 53·6), τ^2=0, p=0·74

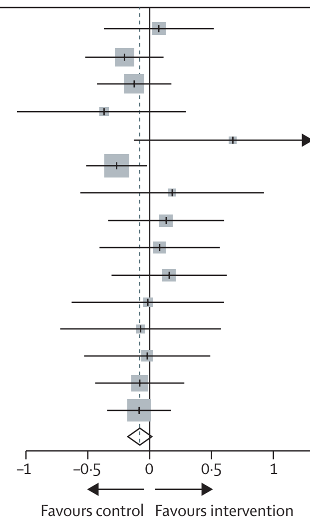

Figure 3: **Wearable activity tracker intervention effects on objectively measured moderate-to-vigorous physical activity at post-intervention timepoint**
*Thompson et al (2016a), (2016b), and (2016c) indicate the cohorts of pedometer only, pedometer plus goal prompts, and the pedometer plus goal prompts plus motivational text groups, respectively. †Guagliano et al (2020a) and (2000b) indicate the cohorts of pedometer only and the pedometer plus website groups, respectively. ‡Jago et al (2006a) and (2006b) indicate the cohorts of spring and fall batches, respectively.

whereas three studies measured self-reported (ie, subjective) physical activity,[67,68,70] and three measured both.[53,57,65] Eight studies assessed the maintenance effect of the interventions,[52–54,56,61,68–70] with a mean follow-up period of 35·1 weeks (SD 14·5). Valid objectively measured physical activity data were provided from a mean of 72% (SD 21) of participants across included studies, with a high of 90%[55] and a low of 25%.[57]

Ten studies (intervention groups n=497, control groups n=458; consisting of 14) were included to estimate the effect of wearable activity tracker interventions on objectively measured daily steps,[51,52,55,57–60,64,65,71] but only one study examined the effects at follow-up.[52] For one study, weekly steps were reported, which were converted to daily steps for the purposes of these analyses.[57] Wearable activity tracker interventions significantly improved objectively measured daily steps compared with control at the post-intervention timepoint (standardised mean difference 0·37 [95% CI 0·09–0·65; p=0·013]; Q 47·60 [p<0·0001]; I^2 72·7% [95% CI 53·4–84·0]; figure 2). Risk of bias assessments of the ten included studies classified five studies as having some concerns,[51,55,60,65,71] and five as having high risk of bias.[52,56,58,59,64]

11 studies (intervention groups n=738, control groups n=739) were included to estimate the effect of wearable activity trackers on objectively measured moderate-to-vigorous physical activity.[52–54,56,57,61–63,66,69,71] Wearable activity tracker interventions had no significant effect on objectively measured moderate-to-vigorous physical activity at the post-intervention timepoint (standardised mean difference –0·08 [95% CI –0·18 to 0·02; p=0·11]; Q 10·26 [p=0·74]; I^2 0% [95% CI 0·0 to 53·6]; figure 3). Only five studies (consisting of six intervention groups) assessed the maintenance effects at follow-up,[52–54,56,69] with a mean follow-up period of 31·1 weeks (SD 12·9). We found no significant effects on objectively measured moderate-to-vigorous physical activity at follow-up (standardised mean difference 0·17 [95% CI –0·05 to 0·38; p=0·10]; Q 7·08 [p=0·31]; I^2 15·2% [95% CI 0·0 to 59·0]; figure 4). Risk of bias assessment of the 11 included studies classified three studies as having low risk of bias,[54,61,69] four as having some concerns,[56,62,66,71] and four as having high risk of bias.[52,53,57,63]

For secondary outcomes, a total of three, four, five, and six studies were included to estimate the effects on objectively measured CPM,[56,61,69] objectively measured light physical activity,[52,56,63,66] subjectively measured moderate-to-vigorous physical activity,[53,65,66,68,70] and objectively measured sedentary time,[52,54,56,62,63,66] respectively. We found no significant effects on all secondary outcomes at both the post-intervention timepoint (appendix p 14) and at follow-up (appendix p 15).

All subgroup analyses for intervention effects on objectively measured steps and moderate-to-vigorous physical activity are shown in the appendix (pp 23–24). Meta-regression showed no significant moderation of participants' mean age (test of moderators [QM]=0·005 [p=0·94]; R^2=0·0%; test for residual heterogeneity [QE]=46·93 [p<0·0001]; I^2=74·0%) or study duration (QM=0·10 [p=0·75]; R^2=0·0%; QE=46·97 [p<0·0001]; I^2=73·7%) on objectively measured daily steps.

	Intervention group			Control group			Standardised mean difference (95% CI)	Weight
	Total	Mean change	SD	Total	Mean change	SD		
Smith et al (2014)[69]	46	4·10	3·39	71	3·30	3·37	0·24 (–0·14 to 0·61)	17·5%
Corepal et al (2019)[52]	126	0·87	22·50	64	–9·47	20·17	0·47 (0·17 to 0·78)	23·2%
Devine et al (2020)[53]	14	–3·21	18·21	22	–0·34	16·72	–0·16 (–0·83 to 0·51)	6·5%
Guagliano et al (2020a*)[54]	15	–5·33	17·34	22	–1·26	16·45	–0·24 (–0·90 to 0·42)	6·7%
Guagliano et al (2020b*)[54]	15	–2·51	13·57	22	–1·26	16·45	–0·08 (–0·74 to 0·58)	6·8%
Jago et al (2006a†)[56]	55	4·10	17·80	40	1·20	17·08	0·16 (–0·24 to 0·57)	15·2%
Jago et al (2006b†)[56]	75	3·10	16·45	108	1·40	17·67	0·10 (–0·20 to 0·39)	24·2%
Random effects model	**346**			**349**			**0·17 (–0·05 to 0·38)**	**100·0%**

Heterogeneity: I^2=15·2% (95% CI 0·0 to 59·0), τ^2=0·0122, p=0·31

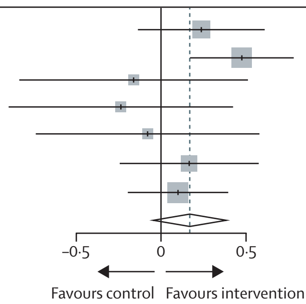

Figure 4: **Wearable activity tracker intervention effects on objectively measured moderate-to-vigorous physical activity at follow-up**
*Guagliano et al (2020a) and (2000b) indicate the cohorts of pedometer only and the pedometer plus website groups, respectively. †Jago et al (2006a) and (2006b) indicate the cohorts of spring and fall batches, respectively.

Sensitivity analyses for objectively measured steps showed similar effect sizes as the main analyses when using a fixed-effect model and after excluding two detected outliers (Corepal et al [2019][52] and Lubans et al [2009b];[59] appendix p 16). Because the effect size for girls in Lubans et al (2009b)[59] was detected as a statistical outlier, we conducted an additional sensitivity analysis in which we also excluded the cohort of boys (Lubans et al [2009a]),[59] and found that the effect size remained significant (appendix p 16). After removing five studies with high risk of bias, the effect size became non-significant (appendix p 17). Sensitivity analyses for objectively measured moderate-to-vigorous physical activity showed similar effect sizes as the main analysis when using a fixed-effect model and after removing studies with high risk of bias (appendix p 17); there were no outliers with the random-effect model for this outcome so no sensitivity analysis was conducted.

Egger's regression test showed significant funnel plot asymmetry for both objectively measured steps (intercept –0·78 [SE=0·39]; p=0·018) and moderate-to-vigorous physical activity (intercept –0·36 [SE=0·10]; t=2·92; p=0·012; appendix p 18). To account for publication bias, trim-and-fill analyses were done, which led to a non-significant effect size for daily steps (standardised mean difference –0·01 [95% CI –0·35 to 0·33]; appendix p 19). However, because the reliability of trim-and-fill analysis could be undermined when between-study heterogeneity is high,[72–74] we did an additional trim-and-fill analysis for daily steps with the two detected outliers removed in response to the high heterogeneity observed,[45,72] which also resulted in a non-significant effect size (0·19 [–0·05 to 0·42]; appendix p 19). A similar result was observed for the trim-and-fill analysis after Lubans et al (2009a; boys)[59] was also removed along with the other two outliers (0·19 [–0·04 to 0·41]; appendix p 20). For objectively measured moderate-to-vigorous physical activity, the effect size remained similar to the main analysis after trim-and-fill analysis (–0·14 [–0·24 to –0·03]; appendix p 20).

Details regarding the risk of bias assessments of individual studies on each outcome are shown in the appendix (pp 21–22). For the GRADE assessment, the pooled effect size for objectively measured steps and moderate-to-vigorous physical activity were graded as having low and high certainty of evidence, respectively (appendix p 25).

Discussion

To our knowledge, this is the first systematic review and meta-analysis to examine the effects of wearable activity trackers on physical activity levels of children and adolescents of various health statuses. Compared with controls, wearable activity trackers showed a small significant effect on increasing objectively measured daily step counts right after the intervention, but not on objectively measured moderate-to-vigorous physical activity. We found no significant effects on secondary outcomes (objectively measured CPM, light physical activity and sedentary time, and subjectively measured moderate-to-vigorous physical activity) or on any outcome measured at follow-up.

Wearable activity trackers have been previously shown to increase daily steps in healthy and diseased adults,[22,24,25,37,75] the general population,[23] and healthy children and adolescents.[30] Although no consensus exists on the optimal number of daily steps for children and adolescents to stay healthy,[76] increasing daily steps has been associated with reduced all-cause mortality risk in adults.[77,78] While a prospective cohort study found that adults with higher step counts had reduced risk of cancer and cardiovascular disease,[79] benefits of increasing steps extends to mental health by lowering the risk of developing depression.[80] In children, increasing steps has been shown to be negatively associated with adiposity[81] and positively associated with physical fitness.[82] Given that both adiposity[10–12] and cardiorespiratory fitness[83,84] at an early age strongly influence the immediate and future health of children and adolescents, increasing daily steps is considered to be beneficial to the long-term wellbeing of young populations. Furthermore, increased step counts might also indicate an intention for behavioural change to adopt a healthier lifestyle with more physical activity. Despite the considerable heterogeneity found between studies incldued in our meta-analysis for the outcome of objectively measured daily steps, heterogeneity was substantially reduced after removal of two outliers in a sensitivity analysis (I^2 28%), while maintaining a similar effect size, indicating that the high heterogeneity detected might have been caused by two studies that did not have a strong influence on the effect size observed.[52,59] However, we could not fully examine the maintenance effect of increased daily steps, because only one study included a follow-up measurement. Future studies should incorporate follow-up assessments to explore the long-term efficacy of activity trackers on increasing daily steps in children and adolescents.

The use of wearable activity trackers did not substantially increase moderate-to-vigorous physical activity in our dataset of children and adolescents. These findings are inconsistent with the results reported by Casado-Robles et al (2022),[30] which found wearable activity trackers to have a small positive effect on moderate-to-vigorous physical activity. This discrepancy might be mainly attributed to our exclusion of non-randomised controlled trials that are more prone to overestimating intervention effects,[31] and our adoption of a more scientifically rigorous effect size computation methodology.[36] The null effect found on moderate-to-vigorous physical activity was robust, as confirmed by comprehensive sensitivity analyses. The absence of a significant effect on moderate-to-vigorous physical activity might be due to several reasons. First, pedometers were the predominant type of wearable tracker in the included studies (15 of 21 studies). Although accelerometers are widely acknowledged to have the characteristics of providing physical activity feedback that can be hard to recall and be quantified by children,[85] pedometers are often perceived to be a good motivator of physical activity,[86] because they can provide more simple, straightforward, and quantifiable feedback. Second, physical activity measurement trackers might not capture moderate-to-vigorous physical activity during high-intensity sport events because adolescents have been found to often take off activity trackers during their most active hours of the day (eg, sports training).[87] Third, the absence of standardised cutpoints for classifying physical activity intensity from accelerometer data could also limit the accuracy of moderate-to-vigorous physical activity data. Although various accelerometer cutpoints have been developed to classify physical activity intensity in children, they can vary greatly; for example, the cutpoints for classifying moderate-to-vigorous physical activity from Freedson et al (2005)[88] and Puyau et al (2002)[89] are at least 2220 CPM and at least 3200 CPM, respectively. However, no consensus has been reached on cutpoints for younger populations.[90] Among the included studies on moderate-to-vigorous physical activity, six studies used the cutpoint from Evenson et al (2008),[91] one from Puyau et al (2002),[89] one from Freedson et al (2005),[88] and one from Chandler et al (2016),[92] and furthermore, Ruotsalainen et al (2016)[66] classified intensities using metabolic equivalent of task (known as MET) values, and Knox et al (2019)[57] did not specify the cutpoint used. Given the large differences between cutpoints, the effect size pooled from these studies needs to be interpreted with caution. Moreover, although standardisation of optimal accelerometer cutpoints for classifying physical activity intensities in young populations is important to strengthen the rigorousness of physical activity studies, only two studies we identified examined both step counts and moderate-to-vigorous physical activity simultaneously.[57,71] Thus, more research is needed to substantiate the differential effects found on these two physical activity parameters, and whether trackers that give simple step count feedback might be more effective in motivating physical activity in young populations than relatively more abstract physical activity intensity-based feedback (eg, moderate-to-vigorous physical activity).

Non-adherence and non-compliance to activity tracker use was also a common limitation observed in almost all studies we included in this systematic review and meta-analysis, with reduced engagement with the tracker over time being one of the major challenges of wearable tracker interventions.[93] Low adherence to wearing the tracker would not only affect intervention fidelity, but also affect measurement of physical activity and reduce data available for analysis. Such missing data in our study sample largely reduced the sample size and statistical power to detect intervention effects. Indeed, feeling uncomfortable or embarrassed to wear trackers, or finding them to be unfashionable, are potential reasons for poor adherence.[61] Studies also reported that participants tended to remove their trackers when engaging in structured sports to prevent physical discomfort, hurting others during contact sports, and damaging the device.[87] Thus, targeting causes of non-adherence and improving compliance to tracker interventions are crucial to augment the effect of activity trackers in young populations and ensure adequate physical activity data are available for analysis.[61]

Our study had some limitations. First, although only randomised controlled trials and cluster randomised controlled trials were included in the systematic review and meta-analysis, many of these studies were classified as having some concerns or high risk of bias in the risk of bias assessment, which was largely attributed to missing physical activity data due to low compliance. Second, we attempted to account for between-study variability with stringent subgroup and sensitivity analyses; however, the small sample size in each group restricted the interpretation of our findings. To foster more personalised and effective wearable tracker application to promote physical activity in children and adolescents of different characteristics, more rigorously designed studies are warranted to explore whether effectiveness of trackers might differ by sex, age, or health status. We also could not fully discern the individual effect of wearable activity trackers because they were often incorporated with other minor behavioural strategies (eg, goal setting, feedback, and step diaries). This limitation was also highlighted in a similar review conducted in adults[37] and by an Editorial published in *The Lancet Digital Health*.[21] In our view, the integration of other minor behavioural strategies in interventions is not a substantial issue because the use of wearable activity trackers in real life is likely to be accompanied by additional minor lifestyle adjustments (eg, feedback received on the app associated with the wearable tracker and advice-seeking from health-care professionals to set appropriate physical activity targets).[94] Therefore, examining the effects of trackers with these complementary strategies might be meaningful to replicate real-life conditions. Nevertheless, more studies are needed to compare the effects of interventions incorporating physical activity trackers as their main component with multicomponent interventions involving trackers in addition to exercise sessions or behavioural change strategies. Finally, publication bias and studies with high risk of bias might have restricted the certainty of the evidence for objectively measured daily steps, as shown by the change in effect size after trim-and-fill analyses and the sensitivity analysis in which we removed studies with high risk of bias. However, trim-and-fill analyses are more prone to underestimating positive effects when between-study heterogeneity is high,[73] thus the true intervention effect might have been underestimated even though we attempted to account for publication bias. Studies with more robust designs are needed with a focus on better adherence to wearable trackers to validate our findings on objectively measured daily steps, and to explore whether the effects differ with specific participant or intervention characteristics.

Our findings demonstrate that wearable activity tracker interventions might increase daily step counts, but not moderate-to-vigorous physical activity, in healthy children and adolescents and those with suboptimal health, showing the potential of wearable trackers to motivate physical activity and improve health in young populations. Comprehensive tests confirmed the robustness of the null effect on moderate-to-vigorous physical activity, although more rigorously designed studies that minimise missing data are warranted to confirm the positive findings on steps and explore possible long-term effects.

Contributors
WWA and PMS formulated the research question, conceived the study, drafted and revised the initial version of the manuscript, and are responsible for the decision to submit the manuscript for publication. WWA and FR formulated the inclusion and exclusion criteria, designed search terms, screened the records, performed data extraction and statistical analysis, and assessed risk of bias and certainty of evidence. WWA and FR also directly assessed and verified all the underlying data reported in the manuscripts and performed the statistical analyses with guidance from DYF. All the authors interpreted the data, revised the manuscript, and approved the final version of the manuscript, and had full access to all the data in the study.

Declaration of interests
We declare no competing interests.

Data sharing
Extracted data used in this study will be made available on request to the corresponding author. Unpublished data from various researchers will only be shared with their respective permission.

Acknowledgments
This study was supported by Research Impact Fund of Research Grants Council of the Hong Kong University Grants Committee (project number R7024-20) and Seed Fund for Basic Research of the University of Hong Kong. Publication was made possible in part by support from the HKU Libraries Open Access Author Fund sponsored by the HKU Libraries. We thank all contacted authors for providing information and data for this meta-analysis.

Editorial note: The Lancet Group takes a neutral position with respect to territorial claims in institutional affiliations.

References
1 Bull FC, Al-Ansari SS, Biddle S, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br J Sports Med* 2020; **54:** 1451–62.
2 Guthold R, Stevens GA, Riley LM, Bull FC. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants. *Lancet Child Adolesc Health* 2020; **4:** 23–35.
3 Peçanha T, Goessler KF, Roschel H, Gualano B. Social isolation during the COVID-19 pandemic can increase physical inactivity and the global burden of cardiovascular disease. *Am J Physiol Heart Circ Physiol* 2020; **318:** H1441–46.
4 Dumith SC, Gigante DP, Domingues MR, Kohl HW 3rd. Physical activity change during adolescence: a systematic review and a pooled analysis. *Int J Epidemiol* 2011; **40:** 685–98.
5 Beauchamp MR, Puterman E, Lubans DR. Physical inactivity and mental health in late adolescence. *JAMA Psychiatry* 2018; **75:** 543–44.
6 Kohl HW 3rd, Craig CL, Lambert EV, et al. The pandemic of physical inactivity: global action for public health. *Lancet* 2012; **380:** 294–305.
7 Lee I-M, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet* 2012; **380:** 219–29.
8 Tremblay MS, Willms JD. Is the Canadian childhood obesity epidemic related to physical inactivity? *Int J Obes Relat Metab Disord* 2003; **27:** 1100–05.
9 Han JC, Lawlor DA, Kimm SY. Childhood obesity. *Lancet* 2010; **375:** 1737–48.
10 Bao W, Srinivasan SR, Valdez R, Greenlund KJ, Wattigney WA, Berenson GS. Longitudinal changes in cardiovascular risk from childhood to young adulthood in offspring of parents with coronary artery disease: the Bogalusa Heart Study. *JAMA* 1997; **278:** 1749–54.
11 Mossberg H-O. 40-year follow-up of overweight children. *Lancet* 1989; **334:** 491–93.
12 Pinhas-Hamiel O, Dolan LM, Daniels SR, Standiford D, Khoury PR, Zeitler P. Increased incidence of non-insulin-dependent diabetes mellitus among adolescents. *J Pediatr* 1996; **128:** 608–15.
13 Steinbeck KS. The importance of physical activity in the prevention of overweight and obesity in childhood: a review and an opinion. *Obes Rev* 2001; **2:** 117–30.
14 Cole T. Children grow and horses race: is the adiposity rebound a critical period for later obesity? *BMC Pediatr* 2004; **4:** 6.

15 Kimm SY, Glynn NW, Kriska AM, et al. Decline in physical activity in black girls and white girls during adolescence. *N Engl J Med* 2002; **347:** 709–15.

16 McLachlan S, Chan D, Keatley D, Hagger M. Social psychological theories and models. In: Tod D, Lavallee, eds. The psychology of strength and conditioning. London: Routledge, 2013: 38–63.

17 Teixeira PJ, Carraça EV, Markland D, Silva MN, Ryan RM. Exercise, physical activity, and self-determination theory: a systematic review. *Int J Behav Nutr Phys Act* 2012; **9:** 78.

18 Chan DKC, Lee ASY, Tang TCW, et al. Young children's motivations and social cognitions toward swimming: testing direct and moderation effects of sport competence in two large-scale studies. *J Sports Sci* 2023; **41:** 859–73.

19 Nurmi J, Hagger MS, Haukkala A, Araújo-Soares V, Hankonen N. Relations between autonomous motivation and leisure-time physical activity participation: the mediating role of self-regulation techniques. *J Sport Exerc Psychol* 2016; **38:** 128–37.

20 Michie S, Abraham C, Whittington C, McAteer J, Gupta S. Effective techniques in healthy eating and physical activity interventions: a meta-regression. *Health Psychol* 2009; **28:** 690–701.

21 The Lancet Digital Health. Wearable technology and lifestyle management: the fight against obesity and diabetes. *Lancet Digit Health* 2019; **1:** e243.

22 Brickwood K-J, Watson G, O'Brien J, Williams AD. Consumer-based wearable activity trackers increase physical activity participation: systematic review and meta-analysis. *JMIR Mhealth Uhealth* 2019; **7:** e11819.

23 Ferguson T, Olds T, Curtis R, et al. Effectiveness of wearable activity trackers to increase physical activity and improve health: a systematic review of systematic reviews and meta-analyses. *Lancet Digit Health* 2022; **4:** e615–26.

24 Davergne T, Pallot A, Dechartres A, Fautrel B, Gossec L. Use of wearable activity trackers to improve physical activity behavior in patients with rheumatic and musculoskeletal diseases: a systematic review and meta-analysis. *Arthritis Care Res (Hoboken)* 2019; **71:** 758–67.

25 Singh B, Zopf EM, Howden EJ. Effect and feasibility of wearable physical activity trackers and pedometers for increasing physical activity and improving health outcomes in cancer survivors: a systematic review and meta-analysis. *J Sport Health Sci* 2022; **11:** 184–93.

26 Larsen RT, Wagner V, Korfitsen CB, et al. Effectiveness of physical activity monitors in adults: systematic review and meta-analysis. *BMJ* 2022; **376:** e068047.

27 Böhm B, Karwiese SD, Böhm H, Oberhoffer R. Effects of mobile health including wearable activity trackers to increase physical activity outcomes among healthy children and adolescents: systematic review. *JMIR Mhealth Uhealth* 2019; **7:** e8298.

28 Ridgers ND, McNarry MA, Mackintosh KA. Feasibility and effectiveness of using wearable activity trackers in youth: a systematic review. *JMIR Mhealth Uhealth* 2016; **4:** e129.

29 Creaser AV, Clemes SA, Costa S, et al. The acceptability, feasibility, and effectiveness of wearable activity trackers for increasing physical activity in children and adolescents: a systematic review. *Int J Environ Res Public Health* 2021; **18:** 6211.

30 Casado-Robles C, Viciana J, Guijarro-Romero S, Mayorga-Vega D. Effects of consumer-wearable activity tracker-based programs on objectively measured daily physical activity and sedentary behavior among school-aged children: a systematic review and meta-analysis. *Sports Med Open* 2022; **8:** 18.

31 Reeves BC, Deeks JJ, Higgins JP, Wells GA. Including non-randomized studies. In: Higgins PT, Green S, eds. Cochrane handbook for systematic reviews of interventions: Cochrane book series. Wiley, 2008: 389–432.

32 Maggio ABR, Hofer MF, Martin XE, Marchand LM, Beghetti M, Farpour-Lambert NJ. Reduced physical activity level and cardiorespiratory fitness in children with chronic diseases. *Eur J Pediatr* 2010; **169:** 1187–93.

33 Trost SG, Kerr LM, Ward DS, Pate RR. Physical activity and determinants of physical activity in obese and non-obese children. *Int J Obes Relat Metab Disord* 2001; **25:** 822–29.

34 Valerio G, Spagnuolo MI, Lombardi F, Spadaro R, Siano M, Franzese A. Physical activity and sports participation in children and adolescents with type 1 diabetes mellitus. *Nutr Metab Cardiovasc Dis* 2007; **17:** 376–82.

35 Winter C, Müller C, Hoffmann C, Boos J, Rosenbaum D. Physical activity and childhood cancer. *Pediatr Blood Cancer* 2010; **54:** 501–10.

36 Higgins JP, Thomas J, Chandler J, et al. Cochrane handbook for systematic reviews of interventions, 2nd edn. Oxford and Hoboken, NJ: John Wiley & Sons, 2019.

37 Bravata DM, Smith-Spangler C, Sundaram V, et al. Using pedometers to increase physical activity and improve health: a systematic review. *JAMA* 2007; **298:** 2296–304.

38 Butcher Z, Fairclough S, Stratton G, Richardson D. The effect of feedback and information on children's pedometer step counts at school. *Pediatr Exerc Sci* 2007; **19:** 29–38.

39 Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *Ann Intern Med* 2009; **151:** W65–94.

40 Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Int J Surg* 2021; **88:** 105906.

41 Wan X, Wang W, Liu J, Tong T. Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. *BMC Med Res Methodol* 2014; **14:** 135.

42 Sterne JA, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ* 2019; **366:** I4898.

43 Guyatt G, Oxman AD, Akl EA, et al. GRADE guidelines: 1. Introduction—GRADE evidence profiles and summary of findings tables. *J Clin Epidemiol* 2011; **64:** 383–94.

44 Egger M, Smith GD, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ* 1997; **315:** 629–34.

45 Viechtbauer W, Cheung MWL. Outlier and influence diagnostics for meta-analysis. *Res Synth Methods* 2010; **1:** 112–25.

46 Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ* 2003; **327:** 557–60.

47 LeCheminant JD, Smith JD, Covington NK, Hardin-Renschen T, Heden T. Pedometer use in university freshmen: a randomized controlled pilot study. *Am J Health Behav* 2011; **35:** 777–84.

48 Ridgers ND, Timperio A, Ball K, et al. Effect of commercial wearables and digital behaviour change resources on the physical activity of adolescents attending schools in socio-economically disadvantaged areas: the RAW-PA cluster-randomised controlled trial. *Int J Behav Nutr Phys Act* 2021; **18:** 52.

49 Verswijveren SJJM, Abbott G, Lai SK, et al. Mediators of effects on physical activity and sedentary time in an activity tracker and behavior change intervention for adolescents: secondary analysis of a cluster randomized controlled trial. *JMIR Mhealth Uhealth* 2022; **10:** e35261.

50 Vann LH, Stanford FC, Durkin MW, Hanna A, Knight LM, Stallworth JR. "Moving and losing": a pilot study incorporating physical activity to decrease obesity in the pediatric population. *J S C Med Assoc* 2013; **109:** 116–20.

51 Baldursdottir B, Taehtinen RE, Sigfusdottir ID, Krettek A, Valdimarsdottir HB. Impact of a physical activity intervention on adolescents' subjective sleep quality: a pilot study. *Glob Health Promot* 2017; **24:** 14–22.

52 Corepal R, Best P, O'Neill R, et al. A feasibility study of 'The StepSmart Challenge' to promote physical activity in adolescents. *Pilot Feasibility Stud* 2019; **5:** 132.

53 Devine KA, Viola A, Levonyan-Radloff K, et al. Feasibility of FitSurvivor: a technology-enhanced group-based fitness intervention for adolescent and young adult survivors of childhood cancer. *Pediatr Blood Cancer* 2020; **67:** e28530.

54 Guagliano JM, Armitage SM, Brown HE, et al. A whole family-based physical activity promotion intervention: findings from the families reporting every step to health (FRESH) pilot randomised controlled trial. *Int J Behav Nutr Phys Act* 2020; **17:** 120.

55 Horne PJ, Hardman CA, Lowe CF, Rowlands AV. Increasing children's physical activity: a peer modelling, rewards and pedometer-based intervention. *Eur J Clin Nutr* 2009; **63:** 191–98.

56 Jago R, Baranowski T, Baranowski JC, et al. Fit for Life Boy Scout badge: outcome evaluation of a troop and internet intervention. *Prev Med* 2006; **42:** 181–87.

57 Knox E, Glazebrook C, Randell T, et al. SKIP (supporting kids with diabetes in physical activity): feasibility of a randomised controlled trial of a digital intervention for 9–12 year olds with type 1 diabetes mellitus. *BMC Public Health* 2019; **19:** 371.

58 Lee LL, Kuo YC, Fanaw D, Perng SJ, Juang IF. The effect of an intervention combining self-efficacy theory and pedometers on promoting physical activity among adolescents. *J Clin Nurs* 2012; **21:** 914–22.

59 Lubans DR, Morgan PJ, Callister R, Collins CE. Effects of integrating pedometers, parental materials, and e-mail support within an extracurricular school sport intervention. *J Adolesc Health* 2009; **44:** 176–83.

60 Lubans DR, Morgan PJ, Aguiar EJ, Callister R. Randomized controlled trial of the Physical Activity Leaders (PALs) program for adolescent boys from disadvantaged secondary schools. *Prev Med* 2011; **52:** 239–46.

61 Lubans DR, Morgan PJ, Okely AD, et al. Preventing obesity among adolescent girls: one-year outcomes of the nutrition and enjoyable activity for teen girls (NEAT Girls) cluster randomized controlled trial. *Arch Pediatr Adolesc Med* 2012; **166:** 821–27.

62 Mendoza JA, Baker KS, Moreno MA, et al. A Fitbit and Facebook mHealth intervention for promoting physical activity among adolescent and young adult childhood cancer survivors: a pilot study. *Pediatr Blood Cancer* 2017; **64:** e26660.

63 Morris JL, Daly-Smith A, Defeyter MA, et al. A pedometer-based physically active learning intervention: the importance of using preintervention physical activity categories to assess effectiveness. *Pediatr Exerc Sci* 2019; **31:** 356–62.

64 Neto AS, Correa RC, de Farias JP, et al. Effects of an intervention with pedometer on metabolic risk in obese children. *Rev Bras Med Esporte* 2016; **22:** 476–79 (in Portuguese).

65 Newton KH, Wiltshire EJ, Elley CR. Pedometers and text messaging to increase physical activity: randomized controlled trial of adolescents with type 1 diabetes. *Diabetes Care* 2009; **32:** 813–15.

66 Ruotsalainen H, Kyngäs H, Tammelin T, Heikkinen H, Kääriäinen M. Effectiveness of Facebook-delivered lifestyle counselling and physical activity self-monitoring on physical activity and body mass index in overweight and obese adolescents: a randomized controlled trial. *Nurs Res Pract* 2015; **2015:** 159205.

67 Sharp P, Caperchione C. The effects of a pedometer-based intervention on first-year university students: a randomized control trial. *J Am Coll Health* 2016; **64:** 630–38.

68 Slootmaker SM, Chinapaw MJM, Seidell JC, van Mechelen W, Schuit AJ. Accelerometers and Internet for physical activity promotion in youth? Feasibility and effectiveness of a minimal intervention [ISRCTN93896459]. *Prev Med* 2010; **51:** 31–36.

69 Smith JJ, Morgan PJ, Plotnikoff RC, et al. Smart-phone obesity prevention trial for adolescent boys in low-income communities: the ATLAS RCT. *Pediatrics* 2014; **134:** e723–31.

70 Suchert V, Isensee B, Sargent J, Weisser B, Hanewinkel R. Prospective effects of pedometer use and class competitions on physical activity in youth: a cluster-randomized controlled trial. *Prev Med* 2015; **81:** 399–404.

71 Thompson D, Cantu D, Ramirez B, et al. Texting to increase adolescent physical activity: feasibility assessment. *Am J Health Behav* 2016; **40:** 472–83.

72 Harrer M, Cuijpers P, Furukawa T, Ebert D. Doing meta-analysis with R: a hands-on guide. New York, NY: Chapman and Hall/CRC, 2021.

73 Peters JL, Sutton AJ, Jones DR, Abrams KR, Rushton L. Performance of the trim and fill method in the presence of publication bias and between-study heterogeneity. *Stat Med* 2007; **26:** 4544–62.

74 Terrin N, Schmid CH, Lau J, Olkin I. Adjusting for publication bias in the presence of heterogeneity. *Stat Med* 2003; **22:** 2113–26.

75 Wong SH, Tan ZYA, Cheng LJ, Lau ST. Wearable technology-delivered lifestyle intervention amongst adults with overweight and obese: a systematic review and meta-regression. *Int J Nurs Stud* 2022; **127:** 104163.

76 Brusseau TA, Tudor-Locke C, Kulinna PH. Are children meeting any of the suggested daily step recommendations? *Biomed Hum Kinet* 2013; **5:** 11–16.

77 Saint-Maurice PF, Troiano RP, Bassett DR Jr, et al. Association of daily step count and step intensity with mortality among US adults. *JAMA* 2020; **323:** 1151–60.

78 Hansen BH, Dalene KE, Ekelund U, et al. Step by step: association of device-measured daily steps with all-cause mortality—a prospective cohort study. *Scand J Med Sci Sports* 2020; **30:** 1705–11.

79 del Pozo Cruz B, Ahmadi MN, Lee I-M, Stamatakis E. Prospective associations of daily step counts and intensity with cancer and cardiovascular disease incidence and mortality and all-cause mortality. *JAMA Intern Med* 2022; **182:** 1139–48.

80 Hussenoeder FS, Conrad I, Pabst A, et al. Physical activity and mental health: the connection between step count and depression, anxiety and quality of sleep. *Psychol Health Med* 2023; **28:** 2419–29.

81 Jiménez-Pavón D, Kelly J, Reilly JJ. Associations between objectively measured habitual physical activity and adiposity in children and adolescents: systematic review. *Int J Pediatr Obes* 2010; **5:** 3–18.

82 Fang C, Zhang J, Zhou T, et al. Associations between daily step counts and physical fitness in preschool children. *J Clin Med* 2020; **9:** 163.

83 Ortega FB, Ruiz JR, Castillo MJ, Sjöström M. Physical fitness in childhood and adolescence: a powerful marker of health. *Int J Obes (Lond)* 2008; **32:** 1–11.

84 Ruiz R, Gesell SB, Buchowski MS, Lambert W, Barkin SL. The relationship between Hispanic parents and their preschool-aged children's physical activity. *Pediatrics* 2011; **127:** 888–95.

85 Riddoch CJ, Mattocks C, Deere K, et al. Objective measurement of levels and patterns of physical activity. *Arch Dis Child* 2007; **92:** 963–69.

86 Tudor-Locke C, Lutes L. Why do pedometers work? A reflection upon the factors related to successfully increasing physical activity. *Sports Medicine* 2009; **39:** 981–93.

87 Audrey S, Bell S, Hughes R, Campbell R. Adolescent perspectives on wearing accelerometers to measure physical activity in population-based trials. *Eur J Public Health* 2013; **23:** 475–80.

88 Freedson P, Pober D, Janz KF. Calibration of accelerometer output for children. *Med Sci Sports Exerc* 2005; **37** (suppl 11)**:** S523–30.

89 Puyau MR, Adolph AL, Vohra FA, Butte NF. Validation and calibration of physical activity monitors in children. *Obes Res* 2002; **10:** 150–57.

90 Trost SG. State of the art reviews: measurement of physical activity in children and adolescents. *Am J Lifestyle Med* 2007; **1:** 299–314.

91 Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. *J Sports Sci* 2008; **26:** 1557–65.

92 Chandler JL, Brazendale K, Beets MW, Mealing BA. Classification of physical activity intensities using a wrist-worn accelerometer in 8–12-year-old children. *Pediatr Obes* 2016; **11:** 120–27.

93 Cajita MI, Kline CE, Burke LE, Bigini EG, Imes CC. Feasible but not yet efficacious: a scoping review of wearable activity monitors in interventions targeting physical activity, sedentary behavior, and sleep. *Curr Epidemiol Rep* 2020; **7:** 25–38.

94 Lyons EJ, Lewis ZH, Mayrsohn BG, Rowland JL. Behavior change techniques implemented in electronic lifestyle activity monitors: a systematic content analysis. *J Med Internet Res* 2014; **16:** e192.