Review Article

DIGITAL HEALTH

DIGITAL HEALTH
Volume 9: 1–15

DOI: 10.1177/20552076231188213
journals.sagepub.com/home/dhj
Sage

Effectiveness of pedometer- and accelerometer-based interventions in improving physical activity and health-related outcomes among college students: A systematic review and meta-analysis

Sanying Peng[1,2], Ahmad Tajuddin Othman[2], Ahmad Zamri Khairani[2], Gao zeng[2], Zhou Xiaogang[2] and Yuan Fang[3]

Abstract

Background: Although the pedometer- and accelerometer-based interventions (PABI) have demonstrated efficacy in improving physical activity (PA) and health-related outcomes, the dearth of empirical evidence in college students warrants further investigation.

Objective: This systematic review and meta-analysis aim to examine the effects of PABI on improving PA and health-related outcomes among college students.

Methods: PubMed, Web of Science, Embase, Cochrane Library, and PsycINFO were searched for relevant literature from inception to 20 February 2022. Randomized controlled trials (RCTs) conducted among college students with PABI to increase objectively measured PA as the primary outcome were included in this study.

Results: A total of nine RCTs with 527 participants were included in this study. The combined results showed that PABI significantly improved PA (standardized mean difference = 0.41, 95% confidence interval (CI): 0.08, 0.74, $P = 0.016$) and significantly contributed to weight loss (mean differences (MD) = −1.56 kg, 95% CI: −2.40 kg, −0.73 kg, $P < 0.01$), and lower body mass index (MD = −0.33 kg/m^2, 95% CI: −0.66 kg/m^2, 0.00 kg/m^2, $P = 0.05$) compared to the control group, but no significant effects were observed on improvements of body fat (%) and exercise self-efficacy. Interventions in the group of step, general students, pedometer-based intervention, theory, and developed region were significantly more effective in subgroup analyses.

Conclusions: PABI was found to be effective in promoting PA and weight loss among college students. Future research is needed to further explore the long-term effects of PABI and the characteristics of multiple intervention models.

Keywords

Physical activity, pedometer, accelerometer, wearable activity trackers, college students, systematic review, meta-analysis

Submission date: 8 April 2023; Acceptance date: 28 June 2023

Introduction

Physical activity (PA) is widely recognized as a critical component of a healthy lifestyle for adults, as it not only serves to prevent non-communicable diseases and obesity but also exerts a positive impact on mental health by reducing symptoms of anxiety and depression.[1] Moreover, regardless of the intensity, PA has been shown to significantly

[1]Department of Physical Education, Hohai University, Nanjing, China
[2]School of Educational Studies, Universiti Sains Malaysia, Penang, Malaysia
[3]College of International Languages and Cultures, Hohai University, Nanjing, China

Corresponding author:
Ahmad Zamri Khairani, School of Educational Studies, Universiti Sains Malaysia, Penang, Malaysia.
Email: ahmadzamri@usm.my

reduce the risk of mortality in a dose-response manner.[2] Despite these well-established benefits, physical inactivity continues to afflict more than one-third of the global population,[3] with college students, who are often perceived as energetic, emerging as a particularly vulnerable group.[4] Indeed, a longitudinal investigation conducted by Owensw et al.[5] revealed that a staggering 81% of students who transfer from compulsory education to college fail to meet the recommended amount of PA. In line with this finding, a survey conducted by Pengpid et al.[6] across 23 counties demonstrated that more than 40% of college students are physically inactive, which can adversely affect their physical and mental well-being. Considering the severity of this issue, it is imperative to adopt and implement effective strategies to promote PA participation among college students.

Health behavior theories (HBT) serve as the most influential rationale for PA interventions.[7] Previous studies have demonstrated that interventions grounded in theories such as social cognitive theory (SCT), self-determination theory, self-efficacy theory, and the transtheoretical model yield more significant intervention effects in promoting PA compared to non-theoretical interventions.[8–11] Although a meta-analysis by McEwan et al.[12] has challenged this view and provided strong evidence to the contrary, extant research unanimously concurs that the specific content and interaction mechanisms of theory-based behavior change techniques (BCTs) are essential to effective PA interventions.[9,12,13] It can be ascertained that BCTs are pivotal avenues for the implementation of HBT. With the accelerated growth of information communication technology (ICT), numerous BCTs such as goal setting, self-feedback, planning, and behavior feedback have been applied in the fields of e-health and m-health to promote PA.[14] BCTs have long been regarded as the most direct and effective interventions to promote PA.[7] Self-monitoring and behavioral feedback are two prominent BCTs that are crucial contributors to the intervention of health behaviors by wearable devices and smartphones with built-in pedometers and accelerometers.[15] Pedometers and accelerometers automatically track PA through built-in chips and adopt algorithms to output parameters such as the number of step counts, energy expenditure, intervals, amount and intensity of PA, and even heart rate trajectories.[16,17]

Pedometers and accelerometers, two prevalent forms of electronic motion sensors utilized for measuring step count and velocity changes, are widely integrated into wearable devices such as fitness trackers, smartphones, and smartwatches.[18] The mechanisms inherent in pedometer- and accelerometer-based interventions (PABI) for PA stem from their motivational incentives with precise goal setting and dynamic feedback mechanisms that demonstrate activity monitoring data. In recent years, there has been a notable surge in scholarly attention within the scientific community toward the study of the effects of eHealth interventions, including PABI on PA and health-related indicators.[19] Numerous trials have been conducted to investigate the efficacy of PABI in promoting PA. However, the outcomes have yielded inconsistent findings. For example, some studies found significant effects of PABI in improving step counts,[20–22] moderate-to-vigorous intensity PA (MVPA),[23,24] and total PA (TPA)[25,26] across different participants, while Pope and Gao[27] and Mbada et al.[28] found no significant effects among college students.

Previous reviews have confirmed the effectiveness of PA interventions using PABI in promoting PA among adults by synthesizing results across multiple trials.[15,29–33] Several studies have revealed significant effects of PABI on weight loss,[30,34] body mass index (BMI),[35] and body fat (%).[35] However, despite various trials investigating the impact of PABI on improving self-efficacy,[36,37] few studies have combined the effect sizes of these interventions specially targeting exercise self-efficacy.

Among the extant reviews, the review conducted by Levis et al.[31] exclusively focused on qualitative examination, without delving into quantitative evidence exploration. Brickwood et al.[29] identified the effects of multivariate interventions associated with the activity tracker intervention; however, their study did not specifically focus on examining the effect size of PABI in isolation. A meta-analysis conducted by Tang et al.[32] pooled effect sizes using self-reported and objectively measured PA outcomes. The high heterogeneity resulting from this estimation method may weaken the interpretation strength of evidence. Another meta-analysis from He et al.[38] included several types of PA outcomes from the same study for pooling, and dilution of sample size and overly confounding combined effect sizes may have been a source of high heterogeneity in the study. Given this, more substantial evidence should be obtained by combining homogeneous PA outcomes measured quantitatively using objective measurement tools.

In addition, in reviewing the population of PABI-related studies that have increased in recent years, the populations of interest are children and adolescents,[38,39] older adults,[40,41] and clinical populations,[42,43] while few studies have focused on the college student. Due to their proficiency with ICT and the high prevalence of PAB devices, more research should be conducted to verify the effectiveness of PABI in promoting PA and other health indicators among college students and to make this intervention available on campus.

Therefore, the objectives of this review are twofold. The first objective is to evaluate the effectiveness and characteristics of PABI on PA and health-related outcomes among college students by pooling the effect sizes of high-quality trials. The second objective is to explore the sources of heterogeneity and to determine the effects of PABI favor which groups among college students in different contexts using subgroup analyses.

Materials and methods

This review was performed and presented in accordance with the Cochrane Handbook[44] and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[45] The protocol was registered on the PROSPERO (CRD42023407636).

Search strategy

A comprehensive literature search was conducted for randomized controlled trials (RCTs) employing PABI to improve PA and health-related outcomes without language limitation. The literature searched was sourced from five electronic databases, including PubMed, Cochrane, Embase, Web of Science, and PsycINFO. The search period is from the inception of the databases to 22 February 2022. The search strategy was developed based on the search strategies of the e-health-related literature combined with the specific focus of this study. Boolean logic operators were employed to pair medical subject terms with free words for an exhaustive search. The leading search terms were as follows: participants (college student, university student, and higher education student), intervention modality (wearable activity tracker, wearable device, fitness trackers, pedometer, and accelerometer), outcomes (PA, exercise, sedentary, weight loss, fat percentage, BMI, and exercise self-efficacy), and study design (RCTs). The Supplemental material provides details of the search strategies and search procedures for all databases.

Eligibility criteria

PICOS (i.e., participant, intervention, comparator, outcome, and study design) criteria based on the Cochrane Handbook[44] were conducted to include related literature.

Participant. College students residing on campus were included in this review. The inclusion criteria did not impose any restrictions based on age, gender, health status, nationality, or ethnicity. Studies were excluded if the study sample included university employees or if participants lived in a setting distant from the campus.

Intervention. This study incorporated interventions utilizing pedometer or accelerometer devices, including interventions facilitated through a smartphone application leveraging the capabilities of two built-in device chips. When multiple intervention modalities were available in the research and multiple groups were set up for comparison, the group with only a single PABI component was included as the intervention group. If the group in which a usual care and education intervention accompanied the PABI was observed, it was included.

Comparator. The comparators included in this study were the groups without any intervention, usual care, conventional education group, or waiting list control group.

Outcome. PA outcomes measured by objective measurement tools were taken as the primary outcome (including TPA, MVPA, and light PA reported as minutes, hours, energy expenditure, or steps per unit). The outcomes of body weight, BMI, and body fat (%) measured by electronic devices and exercise self-efficacy as one of the psychological determinants of PA measured by a self-report questionnaire were also included as secondary outcomes. Studies that did not include any PA outcomes but included other health-related outcomes were excluded.

Study design. Published RCTs were included in this review, including pilot RCTs and cluster RCTs, while cross-sectional studies, case studies, and quasi-experiments were excluded.

Study selection and data extraction

The records of the search were imported into Endnote 20 software (Thomson ISI Research Soft, Philadelphia, PA, USA), which was used to remove duplicate records automatically. The titles and abstracts of the identified studies were reviewed independently by two reviewers. After reaching an agreement on the inclusion of a study, the full text was obtained and reviewed by the same reviewer to extract relevant data. Any inconsistencies or uncertainties in the included studies were determined through discussion and consultation with a third reviewer. A pre-developed Microsoft Excel data collection form was used to collect data and classify the studies' characteristics. For each study, data information extracted included study characteristics (year of publication, authors, region of trial, sample size, and distribution), participant information (age, female ratio, and baseline status of PA), intervention details (supporting theory and duration), outcome, and study design (RCT or not, per-protocol (PP) or intention to treat (ITT)). When various forms of PA were recorded, to avoid possible statistical bias when different forms of the same outcome were used for the same study, only one PA outcome was selected as the data source for the meta-analysis, with a limited order of selection being TPA, MVPA, steps, light PA, and walks. Only one group that met the inclusion criteria was extracted when studies were included with multiple comparison groups. The means, standard deviations measured in all-time points, and sample size were extracted as continuous data for meta-analysis. When data were presented regarding standard errors, confidence intervals (CIs), and *P*-values, the transformation was performed using the recommended method of the Cochrane Handbook. Missing data were obtained by contacting the author of the original article.

Quality assessment

The Cochrane Collaboration Risk of Bias Tool[46] was conducted to assess the risk of bias (ROB) for all included studies. The tool assesses six different domains through seven items: (1) selection bias (random sequence generation and allocation sequence concealment), (2) performance bias (blinding of participants and personnel), (3) detection bias (blinding of outcome assessment), (4) attrition bias (incomplete outcome data), (5) reporting bias (selective reporting), and (6) other bias (e.g. the difference of baseline measurements and conflict of interest). Given that blinding of participants and blinding of outcome assessment were not possible when using technology devices to intervene in PA, this study assessed the risk of bias for a single study in combination with the other five domains. The risk of bias in each field was classified as low, unclear, and high. Each study was rated as low, unclear, and high according to a combined assessment of all domains. Studies were rated as low risk if the random generation process and allocation concealment were performed with no high-risk bias for other items. Studies were judged unclear if one or two domains were rated as "unclear." A study was ranked as high risk if it was assessed as high risk in any one of the selection bias items. If more than two of the five areas were rated as "unclear," the study was considered high risk. Revman 5.4 (The Cochrane Collaboration, The Nordic Cochrane Centre, Copenhagen, Denmark) was employed to assess ROB. Two reviewers evaluated the ROB of the included studies, and disagreements were determined by discussion or consulting the third reviewer.

Data analysis

This review employed the outcomes of various forms of PA and several indicators related to PA (including sedentary, weight, BMI, body fat (%), and exercise self-efficacy) following the PABI as the source of data for the statistical analysis. All data were calculated and analyzed using the statistical software STATA16 (Stata Corp, College Station, TX, USA). Effect sizes were combined only when outcome indicators were presented in three or more studies. Considering only two of the included literature included SB outcomes, effect sizes were not combined for this indicator.

Given the inconsistency of measurement units for the objectively measured PA outcome and the self-reported questionnaire measured exercise self-efficacy, standardized mean differences (SMD) with 95% CIs from a random effects model were used to combine effect sizes for these outcome indicators. The units for the body composition indicators (weight, BMI, and fat percentage) were consistent criteria, so the mean differences (MD) were used to combine effect sizes for the indicators of weight, BMI, and body fat (%). In addition, five subgroup analyses were conducted in this review to explore the differences and characteristics of pooled effect sizes across different contexts: subgroup analyses of five moderators undertaken in this review are presented as follows: (1) outcome (TPA, MVPA, and steps), (2) participant (inactive vs general) (inactive refers to participants did not reach the PA recommendations; generally refers to participants without any PA level limitation), (3) intervention (pedometer-based vs accelerometer-based), (4) theory (yes vs no) (yes: explicitly mentions the adopting of HBT as guidance for the interventions; no: no mention of theories as guidance for interventions), (5) region (developed vs developing).

Between-studies heterogeneity was assessed by the statistic I^2. When the statistic I^2 was 25%, 50%, and 75%, it is considered the boundary limit of low, moderate, and high heterogeneity, respectively.[47] Funnel plots with Egger's test were used to test for publication bias.[48] In addition, sensitivity analyses were also conducted to explore the stability of the pooled effect sizes in this study.

Results

Literature searching results

Five electronic databases were searched to identify 1388 records. After removing duplicate and confused records, the titles and abstracts of the remaining 972 were screened. Following 895 records being excluded, a total of 77 studies were eligible for full-text reading. A rigorous two-round full-text screening was conducted to identify nine studies for quantitative meta-analysis. Details of the whole literature screening procedure are shown in Figure 1.

Study characteristics

Five hundred and sixty-five participants from nine studies were included in this review.[21,22,25–28,49–51] In two studies,[28,51] only female participants were included, while in one study,[25] only male participant was included. The remaining six studies consisted of mixed-gender students. The mean age of the participants ranged from 16 to 30 years old. Seven studies[21,25,27,28,49–51] recruited participants who were inactive college students (i.e. did not meet the recommended amount of PA) and two[22,26] targeted general college students (no restrictions on previous PA levels). Seven studies[21,22,25–27,49,50] were conducted in developed countries and two in developing countries.[28,51] All included studies were published in English.

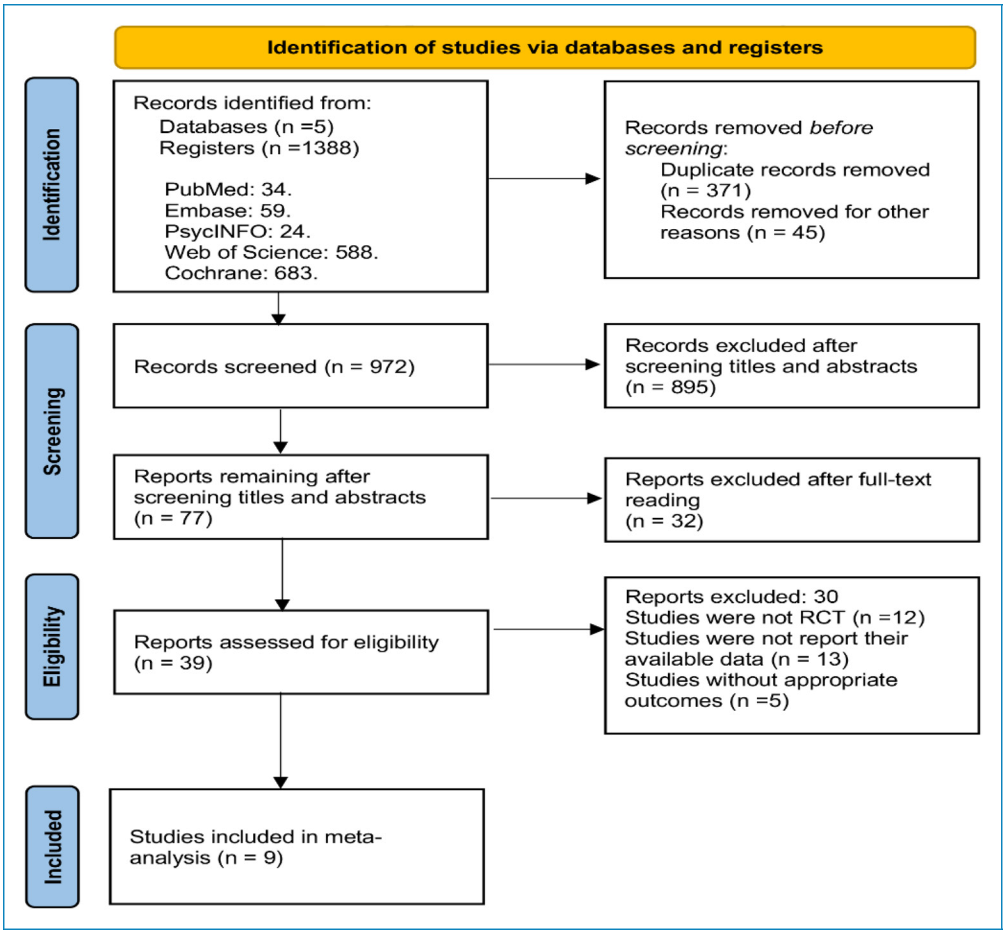

Figure 1. PRISMA flow chart of study selection.
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

Of the studies that used PABI as an intervention mode, five studies[21,22,26,28,51] utilized pedometer-based interventions where they measured PA as an indicator of steps per unit of time. The other four studies[25,27,49,50] utilized accelerometer-based interventions, and the outcomes measured were mainly TPA or MVPA, which were recorded and calculated based on individuals' activity time and energy expenditure. Intervention periods spanned from 1 week to one semester, with follow-up periods ranging from 8 weeks to 3 months. Most studies[21,26,27,49,51] (5/9) employed relevant HBT as the theoretical basis for the intervention, with SCT being used most frequently. All nine studies reported different outcomes of PA at post-intervention, and three studies[21,28,50] also reported PA outcomes at follow-up. In only two studies[27,49] the outcomes of sedentary behavior were reported. The outcomes of the PABI on other health-related indicators were reported as follows: five studies[22,25,27,28,49] for body weight, three studies[22,25,28] for BMI, four studies[22,25,27,49] for fat %, and five studies[21,26,27,49,51] for exercise self-efficacy.

The characteristics of the studies are presented in Table 1.

Quality assessment of included studies

A summary of each risk bias assessment item is presented in Figure 2, while the accumulated assessment of each study on each item is shown in Figure 3. Of the random sequence generation item, only one study, which did not adopt a random sampling method, was judged to be at high risk, and only that study was unclear in its presentation of the process for allocation concealment. Given the nature of the technology intervention, the employment of blinding on performance bias and detection bias was not clearly articulated in all but one study[21] that explicitly adopted blinding methods. All studies were rated as low risk in attrition bias and reporting bias. Of the other bias item, one study[50] was judged to be high risk due to the small sample size ($n = 22$), while another study was judged to be high risk due to potential conflicts of interest

Table 1. Studies characteristics.

Study	Participant characteristic	Study design	Intervention mode	Theory	Duration (follow-up)	Outcome and measurement
Pope (2020)	*N* = 44 (IG = 22, CG = 22) Age: 21.6 Female ratio = 72.72% Inactive; USA	Pilot RCT; ITT	MapMyFitness (a smartphone app based on ActiGraph GT3X and accelerometers)	SCT	10 weeks	1. PA: MVPA from ActiGraph GT3X 2. Weight: segmental body composition monitor 3. Fat%: segmental body composition monitor 4. Self-efficacy: nine-item questionnaire
Al-Nawaiseh (2022)	*N* = 114 (IG = 56, CG = 58) Age: 21.12 (2) Female ratio = 80.70% General; USA	RCT; PP	Smartphone apps based on pacer pedometer		12 weeks	1. PA (step counts/ week)
Pope (2019)	*N* = 38 (IG = 19, CG = 19) Age: 21.5 (3.4) Female ratio = 26.31% Inactive; USA	Pilot RCT; ITT	Facebook (social media) + Polar M400 ActiGraph link accelerometers + Polar M400	SCT/ SDT	12 weeks	1. PA: MVPA from Polar M400 2. Weight: Tanita BC-558 IRONMAN® scale 3. Fat%: Tanita BC-558 IRONMAN® scale 4. Self-efficacy: six-item questionnaire
Maselli (2019)	*N* = 22 (IG = 11, CG = 11) Age: 22 (2) Female ratio = 60.60% Inactive; Italy	RCT	Accelerometer ActiGraph-GT3X		12 weeks (3 months)	1. PA: MVPA from ActiGraph-GT3X
Miragall (2017)	*N* = 48 (IG = 22, CG = 26) Age: 22.18 (3.71) Female ratio = 85.50% Inactive; Spain	RCT; PP	Internet + pedometers (Fitbit One)	TTM	3 weeks (3 months)	1. PA: Steps from pedometer 2. Self-efficacy: five-item questionnaire
Mbada (2018)	*N* = 50 (IG = 25, CG = 25) Age: 21.95 (1.28) Female ratio =	RCT; PP	Short message through mobile phone based on pedometer (model JS-206B)		4 weeks (8 weeks)	1. PA: Steps from pedometer 2. Weight: Weighing scale 3. BMI: Stadiometer and weighing scale

(continued)

Table 1. Continued.

Study	Participant characteristic	Study design	Intervention mode	Theory	Duration (follow-up)	Outcome and measurement
	100% Inactive; Nigeria					
Shin (2017)	$N=64$ (IG = 32, CG = 32) Age: 27.8 Female ratio = 0 Inactive; South Korea	Pilot RCT; PP	The Fit Meter accelerometer + smartphone Apps + financial incentive AT		12 weeks	1. PA: TPA from accelerometer 2. Weight: InBody 520 3. Fat%: InBody 520
Lee (2012)	$N=94$ (IG = 46, CG = 48) Age: 16–20 Female ratio = 100% Inactive; Taiwan	RCT; PP	Based on electronic pedometer	SET	12 weeks	1. PA: Steps from pedometer 2. Self-efficacy: 17-item questionnaire
Mailey (2010)	$N=47$ (IG = 23, CG = 24) Age: 25 Female ratio = 68.10% General; USA	RCT; PP	Pedometer-monitored + sessions + internet	SCT	10 weeks	1. PA: TPA from accelerometers 2. Self-efficacy: seven-item questionnaire

Abbreviations: AT: activity tracker; CG: control group; IG: intervention group; ITT: intention-to-treat; PA: physical activity; PP: per-protocol; RCT: randomized controlled trial; SB: sedentary behavior; SCT: social cognitive theory; SDT: self-determination theory; SET: self-efficacy theory; TPA: total physical activity; TPB: theory of planned behavior; TTM: transtheoretical model.

arising from the imposition of financial incentives in the trial.

Primary outcomes

A random effects model meta-analysis pooled nine effect sizes derived from nine studies. Results showed that the PABI significantly affected PA among university students (SMD = 0.41, 95% CI: 0.08, 0.74, $P=0.016$) compared to the control treatment. Effect sizes for each study were distributed from −0.25 to 1.8. Forest plots of the pooled effect sizes and effect sizes of each study are shown in Figures 4 and 5.

Health-related outcomes (weight, BMI, fat (%), and exercise self-efficacy)

Meta-analysis results of several health-related outcomes are presented in Figure 6. PABI had a significant effect on weight loss (MD = −1.56 kg, 95% CI: −2.40 kg, −0.73 kg, $P<0.01$) and improving BMI (MD = −0.33 kg/m^2, 95% CI: −0.66 kg/m^2, 0.00 kg/m^2, $P=0.05$) (typically, a P-value equal to 0.05 is considered statistically significant) compared to control treatment. However, there is no significant effect on improving body fat (%) (MD = −0.27, 95% CI: −1.00, 0.46, $P=0.47$) and exercise self-efficacy (SMD = −0.04, 95% CI: −0.27, 0.19, $P=$ 0.73).

Subgroup analysis

The subgroup analyses of five categorical groups at post-intervention were conducted in this review, and the results are presented in Table 2. Compared to the control treatment, PABI effects from the groups of step (SMD = 0.62, 95% CI: 0.05, 1.19, $P=0.033$), general college students (SMD = 0.86, 95% CI: 0.54, 1.18, $P=0.001$), pedometer-based intervention (SMD = 0.63, 95% CI: 0.17, 1.09, $P=0.008$), with theory supporting (SMD = 0.62, 95% CI: 0.33, 0.91, $P=$ 0.001), and developed region (SMD = 0.47, 95% CI: 0.11, 0.82, $P=0.010$) can significantly improve PA.

Publication bias and sensitivity analysis for primary outcomes

The visual distribution of the funnel plot showed a basically symmetrical pattern (see Figure 6), and the P-value of the

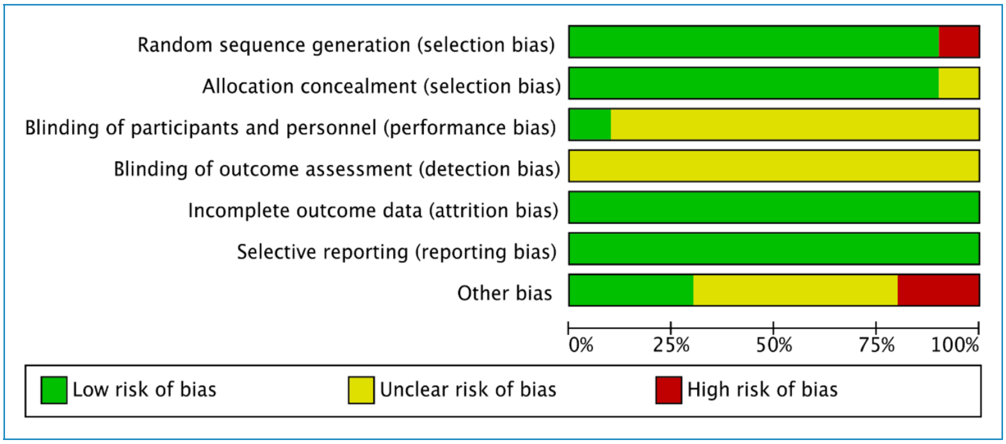

Figure 2. Risk of bias graph (each item presented as percentages).

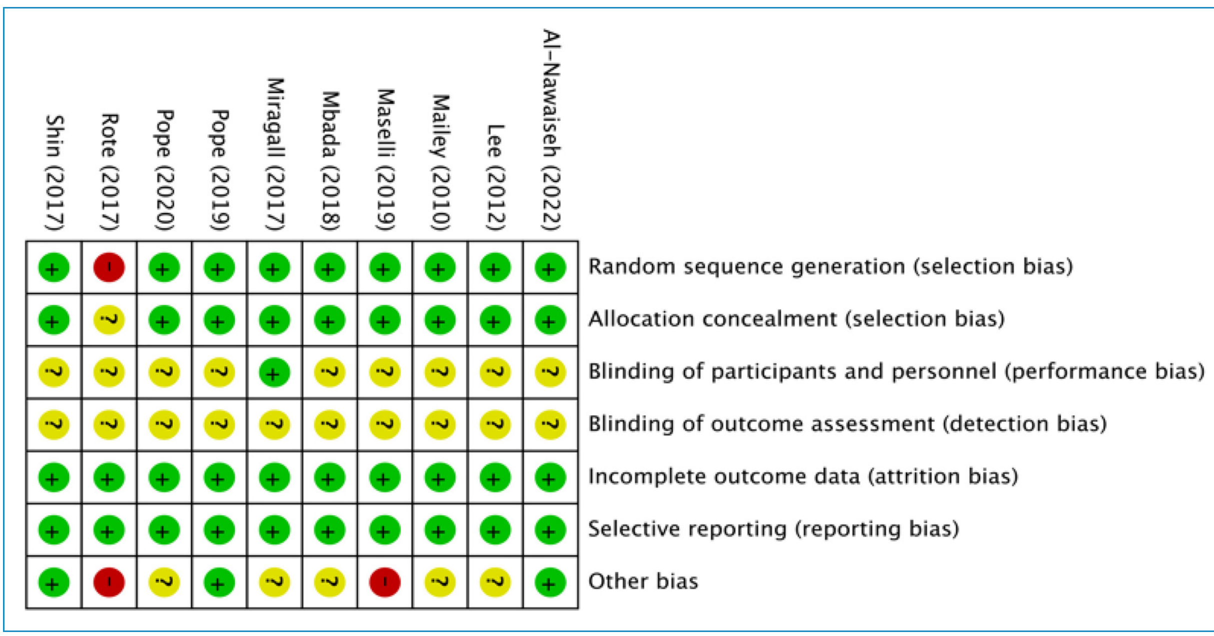

Figure 3. Risk of bias summary for included studies (green: low risk of bias; yellow: unclear risk of bias; red: high risk of bias).

Egger test was greater than 0.1 ($P = 0.124$), demonstrating no significant publication bias.

A sensitivity test using a literature-by-literature exclusion test for the stability of the pooled effect sizes showed that the effect sizes were robust for the PABI in improving PA, and details of the sensitivity analysis are shown in Figure 7.

Discussion

This systematic review and meta-analysis synthesizes the evidence to date about the effectiveness of PABI on promoting objectively measured PA and other health-related outcomes among college students. The pooled data were derived from the outcomes of nine RCTs with objectively measured outcomes (self-reported questionnaires for exercise self-efficacy). This study found that PABI significantly improved PA levels with small to moderate effect sizes (SMD = 0.41, 95% CI: 0.08, 0.74, $P = 0.016$). Furthermore, PABI significantly contributed to college students' weight loss (MD = −1.56 kg, 95% CI: −2.40 kg, −0.73 kg, $P < 0.01$) and BMI (MD = −0.33 kg/m^2, 95% CI: −0.66 kg/m^2, 0.00 kg/m^2, $P = 0.05$) reduction but have trivial effects for body fat (%) reduction and increasing exercise self-efficacy.

The findings of PABI significantly improving PA among college students are consistent with previous reviews conducted among general adults,[15,29,30,32,33] school-based children,[39] elders,[40,41] clinical population,[42] and rehabilitation populations.[52] An umbrella review from Ferguson et al.[53] synthesized 39 reviews and found that the effect sizes of

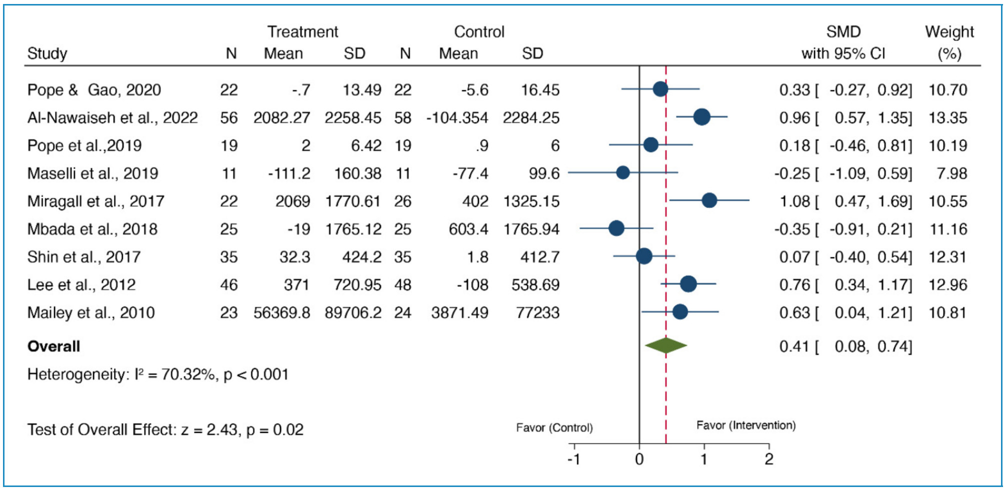

Figure 4. Meta-analysis of effects of PABI interventions on PA versus control.
PABI: pedometer- and accelerometer-based interventions; PA: physical activity.

activity trackers' interventions in improving PA ranged from 0.3 to 0.6. The effect sizes combined in this review among college students strongly support their study. Nevertheless, the effect sizes of the PABI interventions varied across different participants. For instance, several meta-analyses[29,30,32,41] found just small to medium effect sizes in nonclinical participants. Conversely, Hodkinson et al.[42] combined a pooled effect size of 0.72 in the chronic patient population. Furthermore, another study[52] conducted among a clinical population also observed a significant effect size ranging from 0.54 to 0.87 across several PA outcomes. The larger effect sizes in the clinical population compared to the healthy population may be related to the preference of the clinical population to PABI interventions. The clinical and rehabilitation populations have a more substantial risk perception of inactivity and a higher positive outcome expectancy of more PA,[54] which may explain the larger effect sizes observed with PABI in these populations.

Regarding the issue of heterogeneity, the syntheses of effect sizes for several health-related outcomes revealed low heterogeneity. This review also sought to minimize heterogeneity by adopting the same method employed in the review of Casado-Robles et al.,[39] which only combining PA outcomes from objective measurements, but this review still yielded moderate heterogeneity. Given this, the source of heterogeneity needs to be further explored.

The five exploratory subgroup analyses conducted in this review yielded significant findings regarding the primary outcomes. In the subgroup analysis of PA outcomes, the step count group reached the largest significant moderate effect size, which is consistent with the results of previous reviews[32,38,40] and further confirms the positive effect of PABI in increasing steps. Daily step count is an essential indicator of TPA, and a significant increase in step count positively impacts TPA.[55] In the participant subgroup, we found that there is significant difference in effect sizes between groups and the general college students group achieved a moderate-to-high effect size of PABI, contrary to the findings of previous studies that favor the inactive group.[56,57] A possible explanation for this phenomenon might be that college students have a relatively high rate of PABI-related device ownership and that the inactive group is difficult to motivate to more PA through a simple technical incentive.[58]

A notable discovery from the subgroup analysis of the two different interventions, namely, pedometer-based and accelerometer-based, was that the heterogeneity in the accelerometer group dropped to zero, and the effect was insignificant. In contrast, the pedometer group had a significantly moderate effect size. Cooper et al.[41] also separated the two intervention modalities to combine effect sizes among older people but achieved the opposite findings. This finding may demonstrate that there may be significant moderating effects across populations and intervention modalities in promoting PA using PABI. Furthermore, in subgroup analyses of the presence or absence of a theory, the group with theory had a significant and larger effect size, consistent with the findings of several studies.[9,42,52] Of the theories applied, SCT was the most used, with self-efficacy, a cardinal component of SCT, being a crucial psychological determinant of PABI-facilitated behavior change.[59] This review also conducted a subgroup analysis based on the region where the trials were performed and found that PABI trials conducted in developed countries had significant effects and a larger effect size. This difference may be related to the different regions' economic level and cultural background. After all, PABI as a

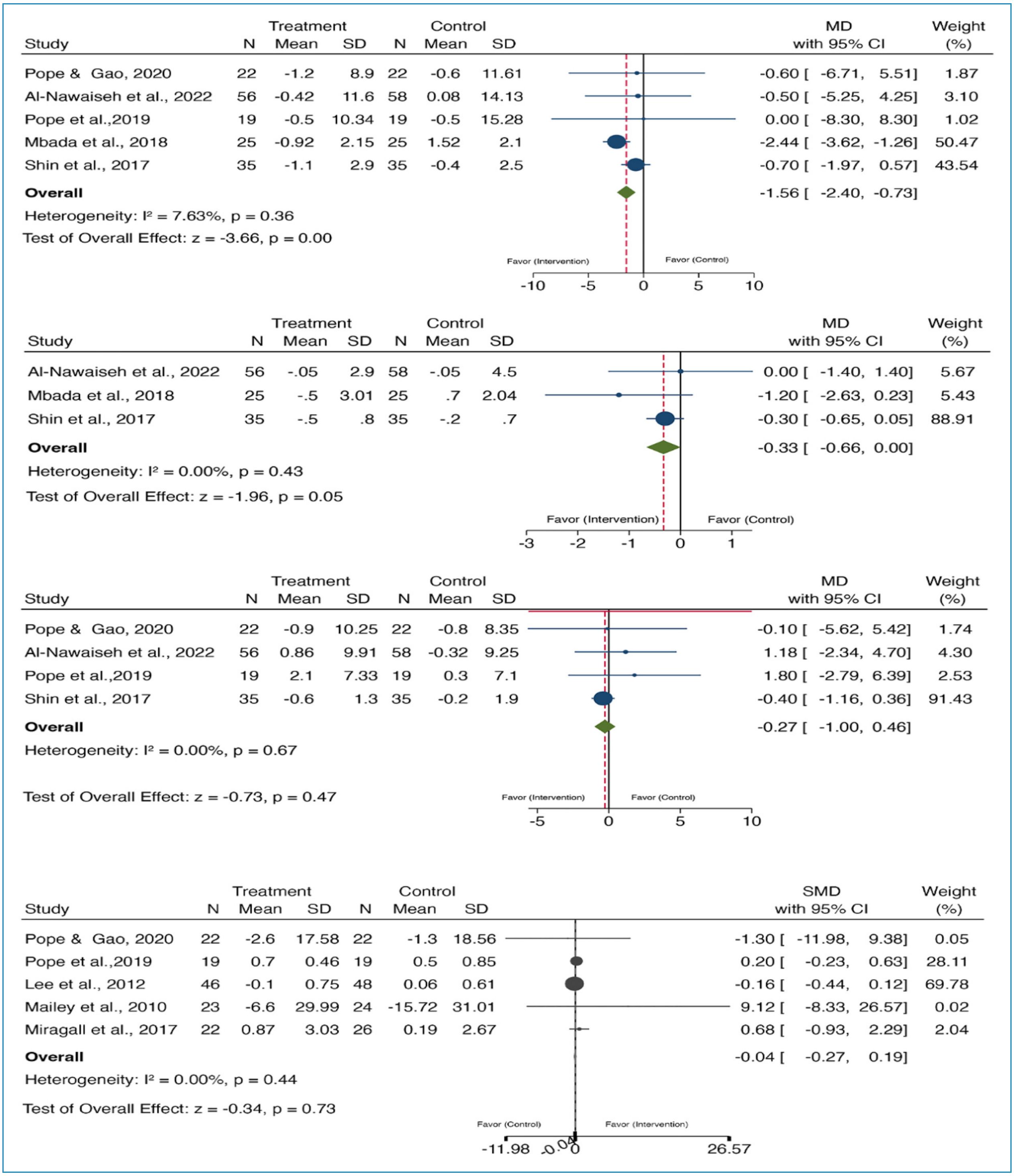

Figure 5. Meta-analysis of effects of PABI on health-related outcomes versus control.
PABI: pedometer- and accelerometer-based interventions.

technological intervention presents a challenge to implement regarding equipment costs and participant acceptance and adherence.

Two of the three body composition indicators in this study's second outcomes exhibited significant effects, including 1.56 kg weight loss (MD) and 0.53 BMI reduction (MD) following the PABI, indicating that PABI significantly contributed to weight loss and BMI reduction. This finding is consistent with previous studies[34,60] and provides strong evidence to support the use of PABI to improve

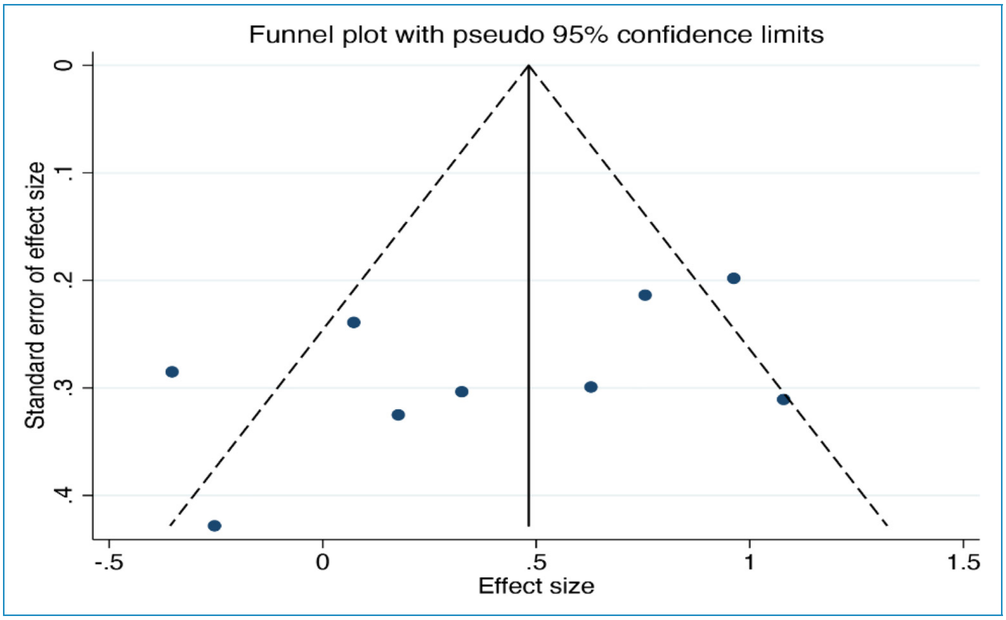

Figure 6. Funnel plot of PABI in improving PA.
PA: physical activity; PABI: pedometer- and accelerometer-based interventions.

weight loss. However, assessing the intervention effects solely from the *P*-value in the results of a meta-analysis is not rigorous and should be interpreted with prudence considering the context of the studies, the research questions, and the effect sizes.[61] Although no significant effect was observed, the effect size indicated a 0.27 percentage point decrease in body fat (%), suggesting an efficiency of PABI in reducing body fat. Given the limitations of body fat (%) measurement, future studies should adopt a more homogeneous measurement method. Moreover, as a feature of this review, the effect sizes of exercise self-efficacy were pooled to identify the effectiveness of PABI. Still, unfortunately, a significant effect wasn't found. It is worth being concerned that the questionnaires used to measure self-efficacy in the included studies were inconsistent, which created bias that may have affected the accuracy of the results. Exercise self-efficacy is an essential psychological determinant of behavior change from motivation to intention to action[62] and is a crucial component of the mechanisms underlying PABI. If increased exercise self-efficacy can be observed, it will better confirm the robust mechanism of PABI's effects. Further exploration is expected in future studies.

With the rapid advancement of ICT, PABI hold great promise from the perspectives of both public health and health education. PABI have been shown to significantly promote PA and weight loss and improve body composition in college students. Furthermore, recent evidence suggests that any form of PA, regardless of intensity, is associated with a dose-dependent reduction in the risk of mortality.[2] Wearable devices such as pedometers and accelerometers, as well as smartphones, have become ubiquitous in people's lives. Consequently, an increasing number of college students are utilizing these devices to monitor and record their PA levels and overall health status.[63] This trend provides an excellent foundation for promoting the implementation of PABI. However, existing evidence has also found that the effectiveness of a single PABI-related technology is often limited, and better results can be achieved when adopting multimodal approaches, such as combining with information messages, personalized interventions, and so on.[15] Moreover, we should take a forward-looking perspective on the positive role of artificial intelligence (AI) in health promotion, and the integration of AI into PABI also presents significant potential and holds promise for further advancements.

To the best of our knowledge, this is the first systematic review and meta-analysis that investigated the effects of PABI on improving PA, body composition outcomes, and exercise self-efficacy among college student population. This review adopted PA outcomes objectively measured to combine effect sizes, ensuring the validity of the measures. The stability of the combined effects was verified by sensitivity analysis. However, it is important to acknowledge that this study has certain limitations. First, despite conducting an exhaustive search, the sample size was small for the pooled effect sizes of some outcomes due to the limited number of included studies, which led to modest interpretations of the results. Second, this study only synthesized the effect sizes at post-intervention without investigating the long-term effects during

Table 2. Subgroup analysis of PA at post-intervention.

			Heterogeneity test			
Categories	Category	Studies	*P*	I^2 (%)	SMD and 95% CI	*P*
Outcome	TPA	2	0.147	52.4	0.32 (−0.22, 0.86)	0.244
	MVPA	3	0.541	0.0	0.15 (−0.24, 0.53)	0.451
	Step	4	0.001	82.3	0.62 (0.05, 1.19)	0.033
	Overall	9	0.001	70.3	0.41 (0.08, 0.74)	0.016
	Between		0.405			
Participant	Inactive	7	0.005	68.0	0.28 (−0.10, 0.66)	0.145
	General	2	0.159	45.5	0.86 (0.54, 1.18)	0.001
	Overall	9	0.001	70.3	0.41 (0.08, 0.74)	0.016
	Between		0.023			
Intervention	Pedometer	5	0.002	76.4	0.63 (0.17, 1.09)	0.008
	Accelerometer	4	0.732	0.0	0.12 (−0.18, 0.42)	0.438
	Overall	9	0.001	70.4	0.41 (0.08, 0.74)	0.016
	Between		0.070			
Theory	Yes	5	0.251	25.6	0.62 (0.33, 0.91)	0.001
	No	4	0.001	84.2	0.15 (−0.52, 0.81)	0.670
	Overall	9	0.001	70.3	0.41 (0.08, 0.74)	0.016
	Between		0.538			
Region	Developing	2	0.002	89.6	0.22 (−0.87, 1.30)	0.695
	Developed	7	0.015	63.9	0.47 (0.11, 0.82)	0.010
	Overall	9	0.001	70.3	0.41 (0.08, 0.74)	0.016
	Between		0.667			

Abbreviations: CI: confidence interval; MVPA: moderate-to-vigorous intensity PA; SMD: standardized mean differences; TPA: total PA. Note: Significance at $P < 0.05$.

follow-up periods. Long-term maintenance of PA is the ultimate goal of the PA interventions, and it is anticipated that more trials will be conducted to explore this aspect. Third, although we took a more tailored approach to pool effect sizes and adopted a subgroup exploration approach to reduce heterogeneity, the sources of moderate heterogeneity need to be further explored. Fourth, given the limited availability of literature, our analysis only combined effect sizes for single interventions of PABI. We did not compare their effects with those of multiple interventions, which may have resulted in an incomplete exploration of the combined effectiveness of PABI.

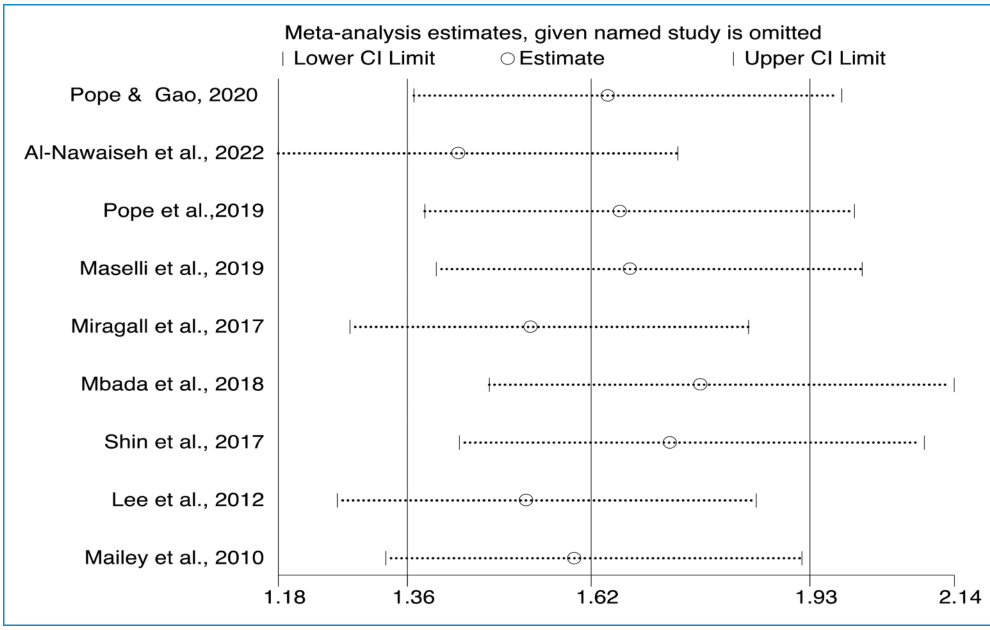

Figure 7. Sensitive analysis of PABI in improving PA.
PA: physical activity; PABI: pedometer- and accelerometer-based interventions.

Conclusion

This systematic review and meta-analysis revealed a significant positive effect of PABI in promoting PA among college students, as well as yielding reductions in weight and BMI. In addition, although the improvement in body fat (%) did not demonstrate a significant effect, the trend of reduction suggests the effectiveness of PABI in reducing body fat. Objective and accurate assessment of self-efficacy warrants the development of uniform and validated measurement instruments. The effectiveness of the PABI in enhancing behavioral psychological factors needs to be explored by incorporating additional psychological indicators and conducting a comprehensive investigation. As digital natives, college students exhibit a natural inclination toward electronic technology, and the dissemination and implementation of PABI on college campuses are promising. Furthermore, the trend of technological interventions in the health field is shifting toward more personalized and diverse interventions combined with PABI, and further research is warranted to address and explore this promising approach.

Acknowledgments: We would like to thank the School of Educational Studies of Universiti Sains Malaysia (USM) for facilitating this study.

Contributorship: PSY, ATO, and AZK conceptualized and designed this study. PSY, ZXG, and YF constructed the search strategies. PSY and YF performed the literature search and article screening, with GZ the third reviewer. PSY and YF performed the risk of bias assessment, data extraction, and analysis. PSY drafted the manuscript. ATO, AZK, and PSY contributed to the writing and critically revised the manuscript. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

Declaration of Conflicting Interests: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding: The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The Discipline Building Reserve Project of Hohai University (2023).

Guarantor: PSY.

ORCID iD: Ahmad Zamri Khairani https://orcid.org/0000-0002-3832-8103
Sanying Peng https://orcid.org/0000-0001-6007-7403

Registration and protocol: The protocol was registered on the PROSPERO (CRD42023407636).

Supplemental material: Supplemental material for this article is available online.

References

1. OECD and Organization WH. *Why physical activity?* 2023.
2. Ekelund U, Tarp J, Steene-Johannessen J, et al. Dose-response associations between accelerometry measured physical activity

and sedentary time and all cause mortality: systematic review and harmonised meta-analysis. *Bmj-Br Med J* 2019; 366. DOI: ARTN l457010.1136/bmj.l4570
3. Guthold R, Stevens GA, Riley LM, et al. 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–e1086. 20180904.
4. Duan Y, Liang W, Wang Y, et al. The effectiveness of sequentially delivered web-based interventions on promoting physical activity and fruit-vegetable consumption among Chinese college students: mixed methods study. *J Med Internet Res* 2022; 24: e30566. 20220126.
5. Owens CS, Crone D, De Ste Croix MB, et al. Physical activity and screen time in adolescents transitioning out of compulsory education: a prospective longitudinal study. *J Public Health (Oxf)* 2014; 36: 599–607. 20131222.
6. Pengpid S, Peltzer K, Kassean HK, et al. Physical inactivity and associated factors among university students in 23 low-, middle- and high-income countries. *Int J Public Health* 2015; 60: 539–549.
7. Hagger MS, Cameron LD, Hamilton K, et al. *The handbook of behavior change*. Cambridge: Cambridge University Press, 2020.
8. Stacey FG, James EL, Chapman K, et al. A systematic review and meta-analysis of social cognitive theory-based physical activity and/or nutrition behavior change interventions for cancer survivors. *J Cancer Surviv* 2015; 9: 305–338. 20141129.
9. Gourlan M, Bernard P, Bortolon C, et al. Efficacy of theory-based interventions to promote physical activity. A meta-analysis of randomised controlled trials. *Health Psychol Rev* 2016; 10: 50–66. 20150410.
10. Bluethmann SM, Bartholomew LK, Murphy CC, et al. Use of theory in behavior change interventions. *Health Educ Behav* 2017; 44: 245–253. 20160710.
11. Abdi J, Eftekhar H, Estebsari F, et al. Theory-based interventions in physical activity: a systematic review of literature in Iran. *Glob J Health Sci* 2014; 7: 215–229. 20141130.
12. McEwan D, Beauchamp MR, Kouvousis C, et al. Examining the active ingredients of physical activity interventions underpinned by theory versus no stated theory: a meta-analysis. *Health Psychol Rev* 2019; 13: 1–17. 20181120.
13. Rhodes RE, Janssen I, Bredin SSD, et al. Physical activity: health impact, prevalence, correlates and interventions. *Psychol Health* 2017; 32: 942–975. 20170530.
14. Schroé H, Van Dyck D, De Paepe A, et al. Which behaviour change techniques are effective to promote physical activity and reduce sedentary behaviour in adults: a factorial randomized trial of an e-and m-health intervention. *Int J Behav Nutr Phys Activity* 2020; 17: 1–16.
15. Laranjo L, Ding D, Heleno B, et al. Do smartphone applications and activity trackers increase physical activity in adults? Systematic review, meta-analysis and metaregression. *Br J Sports Med* 2021; 55: 422–432. 2020/12/24.
16. Anikwe CV, Nweke HF, Ikegwu AC, et al. Mobile and wearable sensors for data-driven health monitoring system: state-of-the-art and future prospect. *Expert Syst Appl* 2022; 202: 117362.
17. Franssen W, Franssen GH, Spaas J, et al. Can consumer wearable activity tracker-based interventions improve physical activity and cardiometabolic health in patients with chronic diseases? A systematic review and meta-analysis of randomised controlled trials. *Int J Behav Nutr Phys Activity* 2020; 17: 1–20.
18. Corder K, Brage S and Ekelund U. Accelerometers and pedometers: methodology and clinical application. *Curr Opin Clin Nutr Metab Care* 2007; 10: 597–603.
19. Direito A, Carraca E, Rawstorn J, et al. Mhealth technologies to influence physical activity and sedentary behaviors: behavior change techniques, systematic review and meta-analysis of randomized controlled trials. *Ann Behav Med* 2017; 51: 226–239. 2016/10/21.
20. Finkelstein EA, Haaland BA, Bilger M, et al. Effectiveness of activity trackers with and without incentives to increase physical activity (TRIPPA): a randomised controlled trial. *Lancet Diabet Endocrinol* 2016; 4: 983–995.
21. Miragall M, Dominguez-Rodriguez A, Navarro J, et al. Increasing physical activity through an internet-based motivational intervention supported by pedometers in a sample of sedentary students: a randomised controlled trial. *Psychol Health* 2018; 33: 465–482. 20170907.
22. Al-Nawaiseh HK, McIntosh WA and McKyer LJ. An-m-Health intervention using smartphone app to improve physical activity in college students: a randomized controlled trial. *Int J Environ Res Public Health* 2022; 19, Article 2022/06/25. DOI: 10.3390/ijerph19127228.
23. de Vries HJ, Kooiman TJ, van Ittersum MW, et al. Do activity monitors increase physical activity in adults with overweight or obesity? A systematic review and meta-analysis. *Obesity* 2016; 24: 2078–2091.
24. Hartman SJ, Nelson SH, Myers E, et al. Randomized controlled trial of increasing physical activity on objectively measured and self-reported cognitive functioning among breast cancer survivors: the memory & motion study. *Cancer* 2018; 124: 192–202.
25. Shin DW, Yun JM, Shin JH, et al. Enhancing physical activity and reducing obesity through smartcare and financial incentives: a pilot randomized trial. *Obesity (Silver Spring)* 2017; 25: 302–310. 2017/01/08.
26. Mailey EL, Wojcicki TR, Motl RW, et al. Internet-delivered physical activity intervention for college students with mental health disorders: a randomized pilot trial. *Psychol Health Med* 2010; 15: 646–659. 2010/12/15.
27. Pope ZC and Gao Z. Feasibility of smartphone application- and social media-based intervention on college students' health outcomes: a pilot randomized trial. *J Am Coll Health* 2020; 70: 89–98. 20200309.
28. Mbada CE, Akinola O, Olumomi GO, et al. Effect of structured short message service-based educational programme on physical activity and body weight status among Nigerian female undergraduates. *Nigerian J Health Sci* 2018; 18: 37–42.
29. Brickwood K-J, Watson G, O'Brien J, et al. Consumer-based wearable activity trackers increase physical activity participation: systematic review and meta-analysis. *JMIR Mhealth Uhealth* 2019; 7: e11819.
30. Goode AP, Hall KS, Batch BC, et al. The impact of interventions that integrate accelerometers on physical activity and weight loss: a systematic review. *Ann Behav Med* 2017; 51: 79–93.
31. Lewis ZH, Lyons EJ, Jarvis JM, et al. Using an electronic activity monitor system as an intervention modality: a systematic review. *Bmc Public Health* 2015; 15: 1–15.
32. Tang MSS, Moore K, McGavigan A, et al. Effectiveness of wearable trackers on physical activity in healthy adults:

systematic review and meta-analysis of randomized controlled trials. *JMIR Mhealth Uhealth* 2020; 8: e15576. Review 20200722.
33. Larsen RT, Wagner V, Korfitsen CB, et al. Effectiveness of physical activity monitors in adults: systematic review and meta-analysis. *Br Med J* 2022; 376: e068047. 20220126.
34. Ringeval M, Wagner G, Denford J, et al. Fitbit-based interventions for healthy lifestyle outcomes: systematic review and meta-analysis. *J Med Internet Res* 2020; 22: e23954. 2020/10/13.
35. Lyzwinski LN. A systematic review and meta-analysis of mobile devices and weight loss with an intervention content analysis. *J Pers Med* 2014; 4: 311–385. 20140630.
36. Böhm B, Karwiese SD, Böhm H, et al. 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.
37. Mercer K, Li M, Giangregorio L, et al. Behavior change techniques present in wearable activity trackers: a critical analysis. *JMIR Mhealth Uhealth* 2016; 4: e40. 20160427.
38. He Z, Wu H, Yu F, et al. Effects of smartphone-based interventions on physical activity in children and adolescents: systematic review and meta-analysis. *JMIR Mhealth Uhealth* 2021; 9: e22601. 2021/02/02.
39. Casado-Robles C, Viciana J, Guijarro-Romero S, et al. 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. 2022/02/01.
40. Liu JY, Kor PP, Chan CP, et al. The effectiveness of a wearable activity tracker (WAT)-based intervention to improve physical activity levels in sedentary older adults: a systematic review and meta-analysis. *Arch Gerontol Geriatr* 2020; 91: 104211. Review 20200726.
41. Cooper C, Gross A, Brinkman C, et al. The impact of wearable motion sensing technology on physical activity in older adults. *Exp Gerontol* 2018; 112: 9–19. Review 20180810.
42. Hodkinson A, Kontopantelis E, Adeniji C, et al. Interventions using wearable physical activity trackers among adults with cardiometabolic conditions: a systematic review and meta-analysis. *JAMA Netw Open* 2021; 4: e2116382. Review 20210701.
43. Franssen WMA, Franssen G, Spaas J, et al. Can consumer wearable activity tracker-based interventions improve physical activity and cardiometabolic health in patients with chronic diseases? A systematic review and meta-analysis of randomised controlled trials. *Int J Behav Nutr Phys Act* 2020; 17: 57. Review 20200511.
44. Higgins JP, Thomas J, Chandler J, et al. *Cochrane handbook for systematic reviews of interventions*. Hoboken, NJ: John Wiley & Sons, 2019.
45. 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.
46. Higgins JP, Altman DG, Gotzsche PC, et al. The Cochrane collaboration's tool for assessing risk of bias in randomised trials. *Br Med J* 2011; 343: d5928. 20111018.
47. Higgins JP, Thompson SG, Deeks JJ, et al. Measuring inconsistency in meta-analyses. *Br Med J* 2003; 327: 557–560.
48. Egger M, Juni P, Bartlett C, et al. How important are comprehensive literature searches and the assessment of trial quality in systematic reviews? Empirical study. *Health Technol Assess* 2003; 7: 1–76.
49. Pope ZC, Barr-Anderson DJ, Lewis BA, et al. Use of wearable technology and social media to improve physical activity and dietary behaviors among college students: a 12-week randomized pilot study. *Int J Environ Res Public Health* 2019; 16, 20190925. DOI: 10.3390/ijerph16193579.
50. Maselli M, Gobbi E and Carraro A. Effectiveness of individual counseling and activity monitors to promote physical activity among university students. *J Sports Med Phys Fitness* 2019; 59: 132–140. 20171201.
51. Lee LL, Kuo YC, Fanaw D, et al. The effect of an intervention combining self-efficacy theory and pedometers on promoting physical activity among adolescents. *J Clin Nurs* 2012; 21: 914–922. 2011/11/16.
52. Singh B, Zopf EM and 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: 184–193. 2021/07/28.
53. 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–e626. Review.
54. Elshahat S, Treanor C and Donnelly M. Factors influencing physical activity participation among people living with or beyond cancer: a systematic scoping review. *Int J Behav Nutr Phys Activity* 2021; 18: 1–20.
55. Tudor-Locke C, Craig CL, Thyfault JP, et al. A step-defined sedentary lifestyle index: <5000 steps/day. *Appl Physiol Nutr Metab* 2013; 38: 100–114. 20121108.
56. Li C, Chen X and Bi X. Wearable activity trackers for promoting physical activity: a systematic meta-analytic review. *Int J Med Inform* 2021; 152: 104487. Review 20210514.
57. Peng S, Yuan F, Othman AT, et al. The effectiveness of E-health interventions promoting physical activity and reducing sedentary behavior in college students: a systematic review and meta-analysis of randomized controlled trials. *Int J Environ Res Public Health* 2022; 20, Review 20221225. DOI: 10.3390/ijerph20010318.
58. Gowin M, Wilkerson A, Maness S, et al. Wearable activity tracker use in young adults through the lens of social cognitive theory. *Am J Health Educ* 2019; 50: 40–51.
59. Tang MY, Smith DM, Mc Sharry J, et al. Behavior change techniques associated with changes in postintervention and maintained changes in self-efficacy for physical activity: a systematic review with meta-analysis. *Ann Behav Med* 2019; 53: 801–815. DOI: 10.1093/abm/kay090.
60. Ang SM, Chen J, Liew JH, et al. Efficacy of interventions that incorporate mobile apps in facilitating weight loss and health behavior change in the Asian population. *Syst Rev Meta-Anal, J Med Internet Res* 2021; 23: e28185. 2021/11/17.
61. Greenland S, Senn SJ, Rothman KJ, et al. Statistical tests, *P* values, confidence intervals, and power: a guide to misinterpretations. *Eur J Epidemiol* 2016; 31: 337–350. 20160521.
62. Williams SL and French DP. What are the most effective intervention techniques for changing physical activity self-efficacy and physical activity behaviour—and are they the same? *Health Educ Res* 2011; 26: 308–322.
63. Ráthonyi G, Ráthonyi-Odor K, Bendíková E, et al. Wearable activity trackers usage among university students. *Eur J Contemp Educ* 2019; 8: 600–612.