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ORIGINAL ARTICLE

mHealth Technologies to Influence Physical Activity and Sedentary Behaviors: Behavior Change Techniques, Systematic Review and Meta-Analysis of Randomized Controlled Trials

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Abstract

Background mHealth programs offer potential for practical and cost-effective delivery of interventions capable of reaching many individuals.

Purpose To (1) compare the effectiveness of mHealth interventions to promote physical activity (PA) and reduce sedentary behavior (SB) in free-living young people and adults with a comparator exposed to usual care/minimal intervention; (2) determine whether, and to what extent, such interventions affect PA and SB levels and (3) use the taxonomy of behavior change techniques (BCTs) to describe intervention characteristics.

Methods A systematic review and meta-analysis following PRISMA guidelines was undertaken to identify randomized controlled trials (RCTs) comparing mHealth interventions with usual or minimal care among individuals free from conditions that could limit PA. Total PA, moderate-to-vigorous intensity physical activity (MVPA), walking and SB outcomes were extracted. Intervention content was independently coded following the 93-item taxonomy of BCTs.

Results Twenty-one RCTs (1701 participants—700 with objectively measured PA) met eligibility criteria. SB decreased more following mHealth interventions than after usual care (standardised mean difference (SMD) −0.26, 95 % confidence interval (CI) −0.53 to −0.00). Summary effects across studies were small to moderate and non-significant for total PA (SMD 0.14, 95 % CI −0.12 to 0.41); MVPA (SMD 0.37, 95 % CI −0.03 to 0.77); and walking (SMD 0.14, 95 % CI −0.01 to 0.29). BCTs were employed more frequently in intervention (mean = 6.9, range 2 to 12) than in comparator conditions (mean = 3.1, range 0 to 10). Of all BCTs, only 31 were employed in intervention conditions.

Conclusions Current mHealth interventions have small effects on PA/SB. Technological advancements will enable more comprehensive, interactive and responsive intervention delivery. Future mHealth PA studies should ensure that all the active ingredients of the intervention are reported in sufficient detail.

Keywords Mobile health · Behavior change techniques · Physical activity · Sedentary behavior · Meta-analysis

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Despite the established health benefits of regular physical activity (PA) in preventing and attenuating the consequences of many non-communicable diseases [1] (e.g. cardiovascular disease, obesity, diabetes, cancer, hypertension, depression and osteoporosis) and premature death [2], worldwide data show 31.1 % of adults (30.9 to 31.2 95 % CI) and 80.3% of adolescents (80.1 to 80.5 95 % CI) fail to meet PA guidelines [3].

Even though physical activity is a modifiable behavior and there is evidence of success for interventions aiming to promote PA when individual- and/or group-tailored support is offered [4], face-to-face approaches have high resource requirements and are impractical for widespread implementation. Other delivery methods offer advantages in terms of resource use, reach and dissemination. Interventions for promoting PA delivered via remote and web technologies, such as when the Internet and telephone are used to provide feedback and support behavior change, have shown moderate-sized positive effects [5]. Finding cost-effective and easy to disseminate methods to promote PA is required to alleviate an already burdened healthcare system.

Remote technologies offer a novel delivery mode for promoting PA. Among these is the use of mobile technologies, such as phones, tablets and tracking devices to aid and improve public health practice (termed mHealth) [6]. By 2015, global mobile penetration was 125.7 and 93 % in developed and developing countries, respectively [7]. Among mobile phone owners in the USA, smartphone ownership increased from 35 % in 2011 to 64 % in 2014 [8] and, importantly, 62 % of those have used their smartphone to look for help and information about a health condition [8]. Thus, mHealth interventions for promoting PA may be a cost-effective and feasible way to reach the population.

Previous systematic reviews investigating mHealth interventions aimed at influencing PA reported positive effects, but these predominantly included studies where mHealth devices were mostly used to aid data collection (e.g., measurement of PA) and/or as a supplement to other intervention components [9]. A systematic review investigating the effectiveness of mHealth-delivered interventions to promote PA found some support for such interventions to increase PA levels, particularly for those using text messaging communication and/or promoting self-monitoring [10]. Despite text messaging interventions being the main mHealth technology explored in systematic reviews and meta-analysis [11], texting is only one of many functions of mobile phones and a basic functionality of smartphones. A more recent review assessing mHealth-delivered interventions' effectiveness on obesity-related outcomes in young people found that most studies describe the feasibility and acceptability of these approaches, but there are few effects on outcomes such as increases in PA [12]. Although earlier reviews have explored the use of mHealth technologies for the promotion of PA, none have specifically focussed on randomized controlled trials (RCTs), and there is no effect estimate from meta-analytical procedures of this study design type.

In summary, the evidence of effectiveness in PA outcomes is inconsistent. Inconsistency is likely due to the large variation in study design (e.g. technologies employed, comparator groups) and methodological quality (e.g. study design, instruments to measure outcomes assessed). Differences in intervention content, including the behavior change techniques (BCTs) employed, is also likely a factor. BCTs are 'observable, replicable, and irreducible' [13] components of interventions designed aimed at behavior change. Extracting information about intervention content using an established taxonomy will provide insight into the active ingredients of mHealth interventions and may help guide future intervention development. Finally, it is unclear whether mHealth interventions can also reduce sedentary time. Therefore, the primary aim of this systematic review and meta-analysis was to determine the effectiveness of mHealth on PA and SB outcomes in free-living individuals. Since self-report PA questionnaires are susceptible to bias through social desirability [14] and have been shown to correlate poorly with accelerometer-measured PA [15–17], the secondary aims were to investigate the relationship between the effect size and the nature of PA/SB outcomes (i.e. measured objectively or self-reported) and to describe the behavior change techniques used in the interventions using the behavior change techniques taxonomy.

Methods

Selection Criteria

The criteria for considering studies for this review and the outcomes of interest, as well as the methods for data extraction, assessing risk of bias, and statistical analysis were prespecified (a protocol was not published). Eligible studies were RCTs that compared mHealth interventions with usual care, minimal or no intervention, among free-living individuals (young people ≤18 years and adults ≥18 years) with no pre-existing medical conditions or contraindications that could limit participation in PA (e.g. CVD, heart failure, pulmonary conditions). mHealth technology-based interventions were considered according to the definition of the Global Observatory for eHealth as 'medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices.' [6] Studies were accepted if they used short messaging service (SMS) and more complex functionalities, such as Bluetooth technology and smartphone applications. The intervention had to be primarily mobile phone-based (i.e. mHealth device was the main mode of delivery (e.g. a multi-component school-based intervention involving face-to-face sessions where the mobile phone was used to

support the main intervention was not included [18]), and utilized either as a stand-alone program or as part of the intervention package, of any dose, intensity and/or length. The comparison conditions permitted were usual or minimal care, such as a different treatment not involving mobile phone technologies (e.g. print-based materials), or a different mHealth technology (e.g. application × different app). PA and SB outcomes of interest were duration (e.g. total minutes sitting, moderate-to-vigorous-intensity physical activity (MVPA) time) or an estimate of energy expenditure. Outcomes could be either objectively measured (e.g. by accelerometers, pedometers) or self-reported. Studies with health promotion or prevention goals (e.g. weight management, cardiovascular risk reduction) were included if PA and/or SB related outcomes were reported.

Search Methods

Seven electronic databases were searched from inception through 11 January 2015: The Ovid Cochrane Central Register of Controlled Trials, CINAHL, Ovid Embase, Ovid MEDLINE, Ovid PsycINFO, ISI Web of Science and PubMed. Search strategies were based on a previous Cochrane systematic review of PA interventions [5]. We adjusted the search strategy to each database by combining search terms for three topic areas: intervention (e.g. mobile device*, smartphone*, text messag*); outcomes (e.g. physical activity, inactiv*, sedentar*); and design (e.g. random sample, clinical trial). Full specific search details per database are included in the Electronic Supplementary Material 1. Searches were limited to human studies, with no restrictions on date (up to January 2015), sample size, age, gender and race or ethnicity. Only English language-published studies were accepted. Review articles and the reference lists of selected studies were searched for additional articles. Studies were excluded if: (1) the intervention reported was not primarily mHealth based, (2) researchers used non-random group allocation, (3) allocation procedure was not reported, (4) outcomes were only assessed at follow-up or baseline, or (5) studies included participants with unstable medical status or other issues (e.g. pregnancy, depression) that contraindicated or confounded the intervention. When studies measured physical activity at several time points, the measurement taken before or immediately after the end of the intervention period was included in analysis.

Study Selection

The citations and abstracts of all retrieved articles were imported into EndNote X6 and all duplicates were removed. Two authors (AD, JR) independently screened the titles and abstracts of the search results to identify articles that met inclusion criteria. Full-text articles were retrieved if the information provided in the title, abstract and descriptors/MeSH headings met the inclusion criteria or if there was uncertainty about eligibility. The retrieved full-text articles were then scanned by two authors (AD, JR) independently in an unblinded manner. If differences between reviewers persisted a third author (RM) reviewed the study and discrepancies were resolved by discussion until a consensus was reached.

Data Extraction

Data were extracted using a standardized extraction form informed by the PRISMA (Transparent Reporting of Systematic Reviews and Meta-analyses) guidelines [19] and the Cochrane Handbook for Systematic Reviews of Interventions [20]. For each included study, reviewers (AD, EC or JR) independently extracted data including (1) study background information (publication year, acronym, country, authors); (2) sample-related information (eligibility, number of participants, participants' characteristics); (3) intervention-related information (detailed description, devices/technologies, behavior change techniques, duration, intensity, setting); (4) comparator-related information; (5) outcome-related information (primary and secondary outcomes of interest such as PA levels, energy expenditure) and (6) internal validity related information (randomization process, allocation concealment, blinding of outcome assessment, attrition, intention-to-treat analysis). Intervention details, including BCTs employed, were coded using intervention information available in published papers (appendices, protocols, results) and clinical trial registries. Coders (AD, EC) were trained on BCT taxonomy v1 [13, 21]. Discrepancies were resolved by discussion. When multiple reports from the same intervention were found, relevant data were extracted from all reports. Authors were contacted via email when additional unpublished information was required.

Risk of Bias Assessment

The internal validity of the included studies was appraised (AD, RM) using the Cochrane Collaboration's tool for assessing risk of bias on each of the domains: selection, performance/detection, attrition and reporting. A judgement of high risk, low risk or unclear risk was given to the following sources of bias: (1) sequence generation, (2) allocation concealment, (3) blinding of personnel and outcome assessors, (4) incomplete outcome data, (5) selective outcome reporting and (6) other sources of bias (i.e. groups comparable at baseline, validated outcome measures, analysis adjusted for baseline PA levels, intention-to-treat analysis). Unclear risk of bias was assigned when there was lack of information or uncertainty. Bias was assessed at the study level. For

studies with health promotion or prevention goals where PA/SB-related outcomes were reported but were not the primary outcome, risk of bias was assessed for the PA/SB outcome.

Measures of Effect

Continuous outcomes were transformed to uniform measurement scales (e.g. minutes in MVPA/week was transformed to minutes/day; body mass was transformed to kilograms (1 lb = 0.45359 kg). We emailed corresponding authors requesting data where studies reported only one physical activity intensity. Where different intensities of activity were reported separately, we computed measures of total PA or MVPA by combining the intensities. When a study had more than one relevant arm for the review, using methods outlined in the Cochrane Handbook for Systematic Reviews of Interventions (section 16.5), we included each pair-wise comparison separately by including the intervention groups of interest and split the shared control group into two groups with an even, smaller sample size (mean and standard deviation left unchanged) [22]. We did not combine different arms of intervention groups to create a single pair-wise comparison as the characteristics of the intervention arms differed, nor did we select a single arm of multiple intervention groups within a study as such approach results in loss of information and is not recommended [20].

Because a wide range of measurement tools were used (different models of pedometers, accelerometers and self-report instruments), the units of the outcomes of interest (i.e. total PA, MVPA, walking, and SB) differed across studies. Given these are continuous variables, we calculated the standardised mean difference (SMD) between the post-intervention values of the study arms as a summary statistic.

Data Synthesis

To estimate an overall summary effect size (and 95 % confidence intervals) for total PA, MVPA, walking, and SB, we used a random effects model to incorporate heterogeneity between studies (Review Manager v5.3.5, The Nordic Cochrane Centre, Copenhagen) following established Cochrane methods [23]. Overall, a standardized mean difference of approximately 0.2 is classified as small, 0.5 as moderate, and 0.8 is large [24]. To assess heterogeneity qualitatively, we visually inspected forest plots and compared study characteristics; quantitatively, we used the I^2 statistic. Causes of heterogeneity were explored by conducting a posteriori subgroup analyses for hypothesis generation purposes. To assess publication bias, we examined funnel plots for asymmetry. Meta-analyses were performed with subgroups by type of outcome measurement to distinguish effects between objectively measured and self-reported outcomes.

Results

Literature Search

A total of 1850 study reports were identified from the database search and other sources, of which 815 were duplicates, leaving 1035 articles that were screened for eligibility. A total of 902 were deemed not relevant based on a review of the information provided in the title, abstract and descriptors/MeSH headings. One hundred thirty-three full-text articles were assessed for eligibility. After exclusion of 112 that did not meet the review inclusion criteria, 21 studies [25–45] were considered eligible and included in the review (see Fig. 1).

Description of Studies

Included articles were published between April 2007 and October 2014. Studies varied in size, duration, intervention and comparator type. The number of participants providing measures of PA in each study ranged from 20 to 301 (mean = 81, total = 1701); follow-up duration ranged from 1 to 52 weeks (median = 9 weeks). mHealth PA promotion interventions were compared against minimal contact/usual care groups using technology (e.g. podcast, pedometer) in eight studies [25, 28, 31, 33, 35, 37, 38, 46] and to non-technology-based treatments (e.g. print materials, counselling) in ten studies [26, 29, 30, 32, 36, 40–43, 45]. Only one study compared mHealth PA to no intervention [34]. Two studies had no ‘pure’ comparator groups (i.e. all conditions were interventions) [39, 44] and were not included in the meta-analysis—data are presented narratively. Twelve studies used a two-arm, parallel RCT design, and nine studies used a multi-arm design [30–32, 34, 36, 39, 40, 44, 46]; data were only extracted if the arm met eligibility criteria. Studies were conducted in the UK [25, 30, 31], USA [26–28, 32, 33, 35–40], Australia [29, 41, 43], Austria [34], Portugal [45], Ireland [42] and Canada [44]. Interventions were primarily delivered at an individual level, with no direct supervision of PA. mHealth technologies employed were PDA [26], mobile phones/SMS [25, 27, 29–31, 34, 35, 38, 40, 43, 45], biosensors [25, 32, 44], smartphones/apps [28, 33, 36, 39, 41–43], tablet computers [37] and websites [25, 40, 41, 43]. A summary of overall study characteristics is presented in Table 1. Specific study characteristics are presented in Electronic Supplementary Material 2.

Description of Participants

Participants were recruited from community and primary health care settings. The median age of the 1701 participants with post-intervention data was 40.1 years (range 8.4–71.7), 1089 were female and 612 male. One study each included females [29] and males only [41], and 19 included both

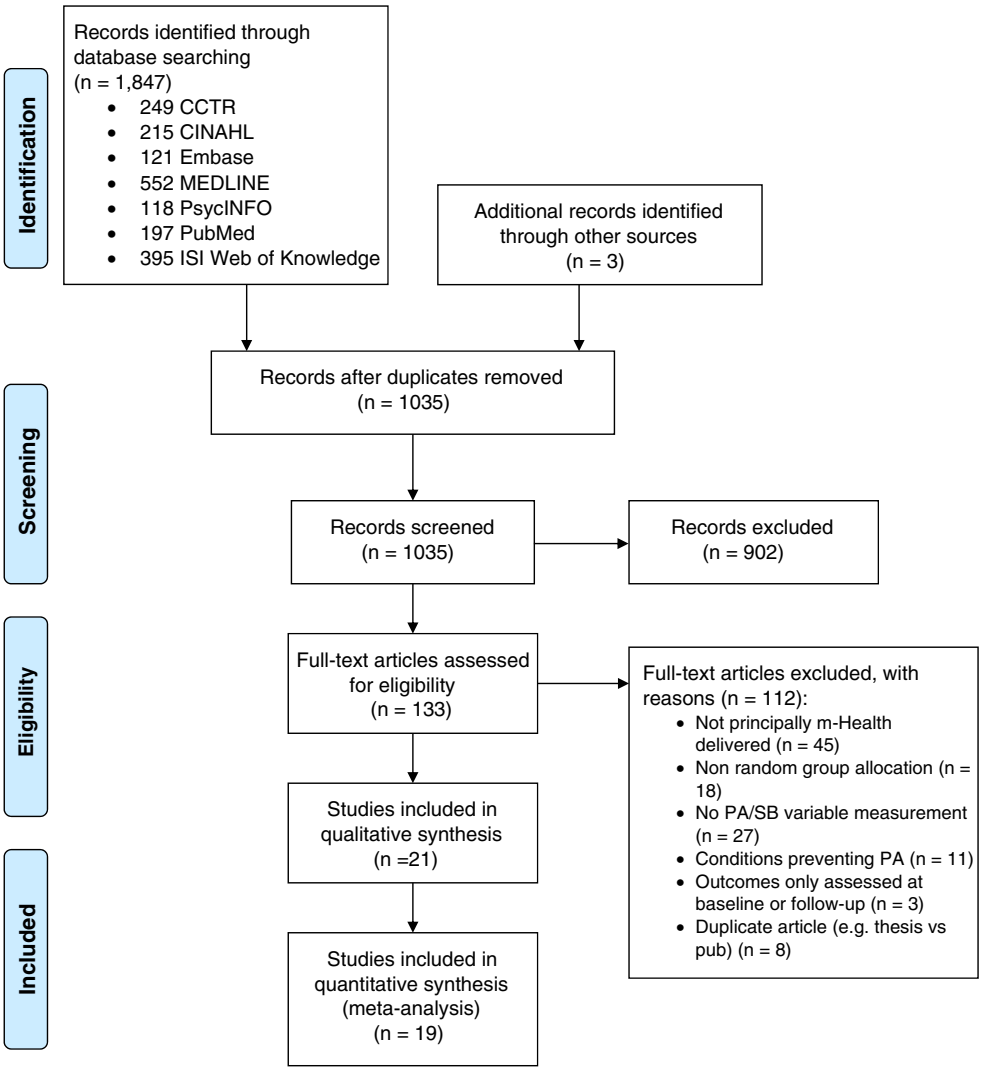


Fig. 1 Flow diagram of the study selection process

females and males. Of the latter, the proportion of females ranged from 36 to 90 %, median 70 %.

Outcome Measures

Of the 21 eligible studies, 7 [30, 32–34, 38, 41, 43] reported a measure of total PA (e.g. total PA duration, total energy expenditure, metabolic equivalent of task (MET)); 9 [26, 28, 29, 31, 32, 40, 43, 45, 46] reported MVPA (e.g. MVPA duration, exercise duration); 8 [28–30, 32, 35, 37, 38, 42] reported walking (e.g. walking duration, step count) and 5 [27, 28, 40, 43, 45] reported a measure of SB (e.g. sitting duration, TV viewing duration). Nine [25, 32, 34, 35, 37, 38, 42–44] studies measured outcomes objectively (e.g. accelerometry, pedometers); 12 [26–31, 33, 36, 39–41, 45] used self-report measures and 4 [25, 38, 43, 44] employed both. We emailed the corresponding authors requesting additional data where a publication reported measurement of PA using an instrument that allowed computation of other PA outcomes besides those reported. Four authors provided additional unpublished data. Baseline and post-intervention outcome data for the included studies is presented in Electronic Supplementary Material 3 in Tables 2 and 3, respectively.

Risk of Bias

Assessments about each risk of bias item for each included study are presented in Fig. 2 (support for judgement is presented in Electronic Supplementary Material 2). Four studies had published protocols [32, 40–42], and eight studies were registered in a clinical trial registry [28, 32, 33, 35, 38, 40–42]. Incomplete reporting of methods hindered risk of bias judgement for several studies. All studies used an RCT design, and most described adequate approaches to allocation sequence generation with the exception of one [38]. The remaining studies were classified as having an unclear risk of bias [28, 34, 36, 40]. Allocation concealment approaches were mainly judged at unclear risk of bias except on four studies

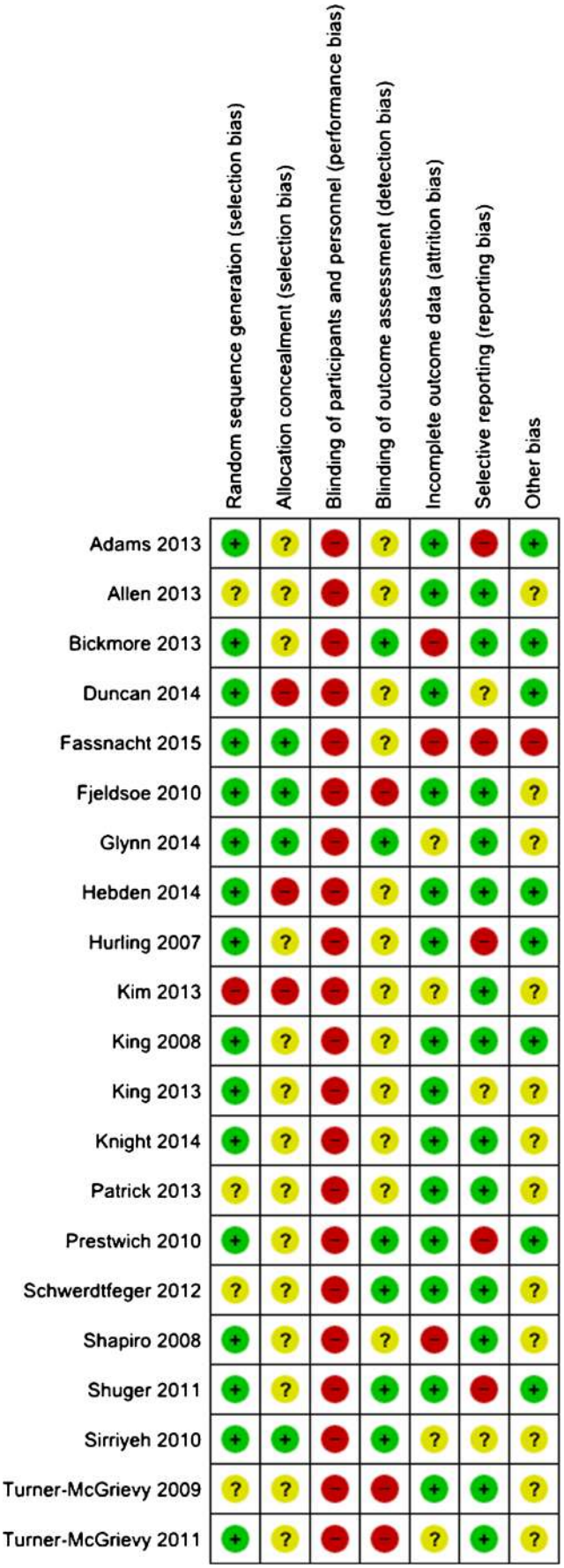
Table 1 Characteristics of intervention studies examining mHealth technologies to promote PA and reduce SB among free-living individuals, 2007–2015

Author, year, reference no.	*n*	Country	Design	Duration of study	PA/SB as primary outcome	Intervention component(s)	Comparator	Intervention frequency	Outcome	Outcome measurement	Intention-to-treat principle analysis
Hurling et al. 2007 [25]	77	UK	2-arm RCT	9 weeks	Yes	Internet + SMS + actiwatch	Actiwatch only	Varied (as appropriate)	Overall PA and leisure time PA (MET mins/week) (IPAQ-LF) + Sitting + MA Uniaxial accelerometer (wrist, 2-min epochs/day)	SR + OB	Yes
King et al. 2008 [26]	37	USA	2-arm RCT	8 weeks	Yes	PDA + Pedometer + printed materials	Standard educational printed materials	1 PDA assessment/ day	MVPA (min/week) (CHAMPS)	SR	Yes
Shapiro et al. 2008 [27]	24	USA	3-arm RCT (2 of interest)	8 weeks	No (acceptability)	Psychoeducational sessions + SMS + pedometer	Psychoeducational sessions + pedometer	1 session/week (total 3) + 2× SMS/day (1 self-monitoring + 1 feedback)	Exercise time + Screen time (not validated)	SR	No
Turner-McGrievy et al. 2009 [28]	77	USA	2-arm RCT	12 weeks	No (weight loss)	Theory-based podcast	Control podcast	2 podcasts/week	MVPA and Walking, (mins/week and days/week) (IPAQ-SF) + Sitting (hours/day)	SR	Yes
Fjeldsoe et al. 2010 [29]	88	Australia	2-arm RCT	12 weeks	Yes	Consultation + printed materials + magnet + tailored SMS	Consultation + printed materials	3–5 SMS/week	MVPA and walking frequency (days/week) + MVPA and walking duration (min/week) (AWAS)	SR	Yes
Prestwich et al. 2010 [30]	140	UK	3-arm RCT	4 weeks	Yes	Implementation intentions + SMS with plan reminders *OR* Implementation intention + SMS with goal reminders	Information on PA guidelines		No. days/week walked or exercised for ≥30 min (SWET)	SR	No
Sirriyeh et al. 2010 [31]	120	UK	4-arm RCT	2 weeks	Yes	SMS affective or SMS instrumental or SMS combined	SMS neutral	1× SMS/day	MV MET min/week (IPAQ-SF)	SR	No
Shuger et al. 2011 [32]	79	USA	4-arm RCT (3 of interest)	36 weeks	No (body weight)	SenseWear Armband and wrist watch alone or SenseWear Armband + Group sessions	Standard care weight loss program manual + self-monitoring	Armband worn 16 h/day, 7 days/week; Group sessions 14× month 0–4 + 6× one-on-one telephone month 5–9	Steps/day, MVPA (mins/day), Total and MVPA EE (Kcal/day)(SenseWear Armband, tri-axial accelerometer)	OB	Yes
Turner-McGrievy et al. 2011 [33]	96	USA	2-arm RCT	24 weeks	No (weight loss)	Podcast + FatSecret's Calorie Counter App + Twitter	Podcast only + Printed material	2 podcast/week month 0–3 + 2 minipodcasts/week months 3–6	PA EE (Kcals/day) (PPAQ)	SR	Yes
Schwerdtfeger AR, et al. 2012 [34]	42	Austria	3-arm RCT (2 of interest)	1 week	Yes	Psychoeducational session + SMS	No intervention (besides PA assessment)	1× psychoeducational group session + 1 SMS/day	Uniaxial accelerometer (ankle) (counts/min)	OB	No
Adams, et al. 2013 [35]	20	USA	2-arm RCT	36 weeks	Yes	Adaptive intervention: SMS or email + pedometer	Static intervention: SMS or email + pedometer	1 SMS every 9 days; Adaptive intervention: new goal/day	Steps/day	OB	Yes
Allen et al. 2013 [36]	43	USA	4- arm RCT	24 weeks	No (body weight)	Lose It! App or Intensive counselling + Lose It! App or Less intensive counselling + Lose It! App	Intensive counselling	App: as appropriate Intensive: 1×/week 0–1 month and 1×/2 weeks 2–6 months orLess intensive: 2×/month 0–1 month and 1×/month 2–6 months	MVPA (hours/week) (Stanford 7-Day PA Recall)	SR	Yes (bu completers only reported)

Table 1 (continued)

Author, year, reference no.	*n*	Country	Design	Duration of study	PA/SB as primary outcome	Intervention component(s)	Comparator	Intervention frequency	Outcome	Outcome measurement	Intention-to-treat principle analysis
Bickmore et al. 2013 [37]	200	USA	2- arm RCT	8 weeks	Yes	Tablet with Embodied conversational agent (ECA) + pedometer	Pedometer + self-monitoring	1 'dialogue' with ECA/day	Steps/day	OB	Reports yes but appears completers only for step data
Kim and Glanz 2013 [38]	36	USA	2-arm RCT	6 weeks	Yes	SMS + pedometer + printed material	Pedometer + printed material	3×, 3 days/week	Steps/day + total PA MET (Godin LTEQ)	OB + SR	Yes (but completers only reported)
King et al. 2013 [39]	61	USA	3-arm RCT	8 weeks	Yes	Social app (social influence theory) or Affective app (avatar) or Analytical app (self-regulatory BCTs)	No comparator	Ad-libitum	Walking (min/week) + MVPA (min/week) (CHAMPS) + TV viewing (hours/day) (MOST)	SR	?
Patrick et al. 2013 [40]	49	USA	4-arm RCT (2 of interest)	52 weeks	No (BMI *z* score)	Website + SMS	Printed materials + 3 group sessions	≥3× SMS/week	MVPA (min/week) (7-day PA recall interview) + SB (hours/day) (Robinson survey)	SR	Yes
Duncanet al. 2014 [41]	301	Australia	2-arm RCT	36 weeks	Yes	Website + mobile phone app with automated-feedback + interaction	Printed materials + self-monitoring	Ad libitum	Total PA (min/week and sessions/week) (AAS)	SR	Yes (completers only reported)[a]
Fassnacht et al. 2015 [45]	49	Portugal	2-arm RCT	8 weeks	No (FV intake)	Educational sessions + SMS + pedometer	Group educational session	1 SMS prompt/day + reply	MVPA (hours/day) + Screen time (hours/day) (FEAHQ)	SR	No
Glynn et al. 2014 [42]	66	Ireland	2- arm RCT	8 weeks	Yes	Accupedo-Pro Pedometer App + goal 10,000 steps/day	Printed materials + goal walking 30 min/day	Ad libitum, carry phone during waking hours	Steps/day	OB	No
Hebden et al. 2014 [43]	51	Australia	2-arm RCT	12 weeks	No (body weight)	SMS + e-mails + research developed App + Internet forum + printed materials	Printed materials	2 SMS + 2 e-mails/week + app to use ad-libitum	MVPA + LPA + Sedentary (min/day) + Total PA (min/week and MET min/week) + Sitting (min/day) (Accelerometer GT1M + IPAQ)	OB + SR	Yes
Knight et al. 2014 [44]	45	Canada	3-arm RCT	12 weeks	Yes	Smartphone + pedometer + glucometer + blood pressure monitor to increase PA or to decrease SB or to increase PA and reduce SB	No comparator	Ad-libitum?	Steps/day	OB + SR	Yes

RCT randomized controlled trial, *OB* objective, *SR* self-reported, *IPAQ* International Physical Activity Questionnaire, *LF* long-form, *SF* short-form, *PDA* portable digital assistant, *SMS* short message service, *PA* physical activity, *MVPA* Moderate-to-vigorous-intensity physical activity, *MA* moderate activity, *MV* moderate-to-vigorous, *MET* metabolic equivalent of task, *SB* sedentary behavior, *AWAS* Australian Women's Activity Survey, *SWET* self-report walking and exercise tables, *PPAQ* Paffenbarger Physical Activity Questionnaire, *LTEQ* Leisure Time Exercise Questionnaire, *CHAMPS* Community Healthy Activities Model Program for Seniors, *MOST* measure of older adults' sedentary time, *AAS* Active Australia Survey, *FEAHQ* Family Eating and Activity Habits Questionnaire;



◀ **Fig. 2** Assessments about each risk of bias item for each included study

[29, 31, 42, 45]. Studies were judged at high risk of performance bias since it is impractical and very hard to blind participants to a PA behavior change intervention. Five studies described blinded outcome assessment [30–32, 37, 42], three described outcome assessors as not blinded to participants' allocation [28, 29, 33], and the majority did not provide sufficient information. Fourteen studies [25, 26, 28–30, 32, 34–36, 39–41, 43, 44] were judged as being at low risk of attrition bias, and three were judged as being at high risk of bias for either not reporting reasons for participant dropouts [45] or imbalanced dropout [27, 37]. Attrition rates varied from 0 to 53 %. Three studies had 100 % retention [25, 26, 44], ten studies reported PA data analyses following intention-to-treat principles [28, 29, 32, 33, 35, 36, 38, 40, 41, 43], eight studies analysed completers only [27, 30, 31, 34, 37, 42, 45], and procedures were insufficiently described in one study [39]. Most studies dealt with missing data at follow-up by imputing replacement values (e.g. last observation carried forward). Five studies had a high risk for reporting bias, four for presenting a subset of the outcome variables recorded/specified [25, 30, 35, 45] and one for inconsistencies between the trial registry, protocol and results paper regarding secondary and tertiary outcomes [32]. Other potential sources of bias considered were lack of a valid PA outcome measurement instrument [31, 45, 46], comparability of groups at baseline [29, 42], contamination between groups [36] and failure to adjust data analyses for baseline PA [34, 39, 40, 44].

Effects of Interventions

Total Physical Activity Seven studies (n = 745 participants) [30, 32–34, 38, 41, 43] reported intervention effects on total PA-related outcomes (kcals/day, min/day). Total PA did not differ significantly between mHealth and comparators. The pooled effect was positive and small (SMD = 0.14, 95 % CI −0.12 to 0.41), and heterogeneity was statistically significant (I^2 = 60 %; χ^2 = 20.09; P = 0.01). Subgroup analyses showed PA levels did not differ between studies with objective (SMD = 0.20, 95 % CI −0.21 to 0.60) or self-reported measurement (SMD = 0.14, 95 % CI −0.20 to 0.48) following mHealth interventions (Fig. 3).

Moderate-to-Vigorous Physical Activity Nine studies (n = 533 participants) [26, 28, 29, 31, 32, 40, 43, 45, 46] reported effects for MVPA-related outcomes (kcals/day, min/day). The pooled effect was positive and moderate in size (SMD = 0.37, 95 % CI −0.03 to 0.77), but statistically non-significant. Heterogeneity was statistically significant (I^2 = 78 %; χ^2 = 50.74; P <0.001). Subgroup analyses showed the SMD did not differ significantly between self-reported

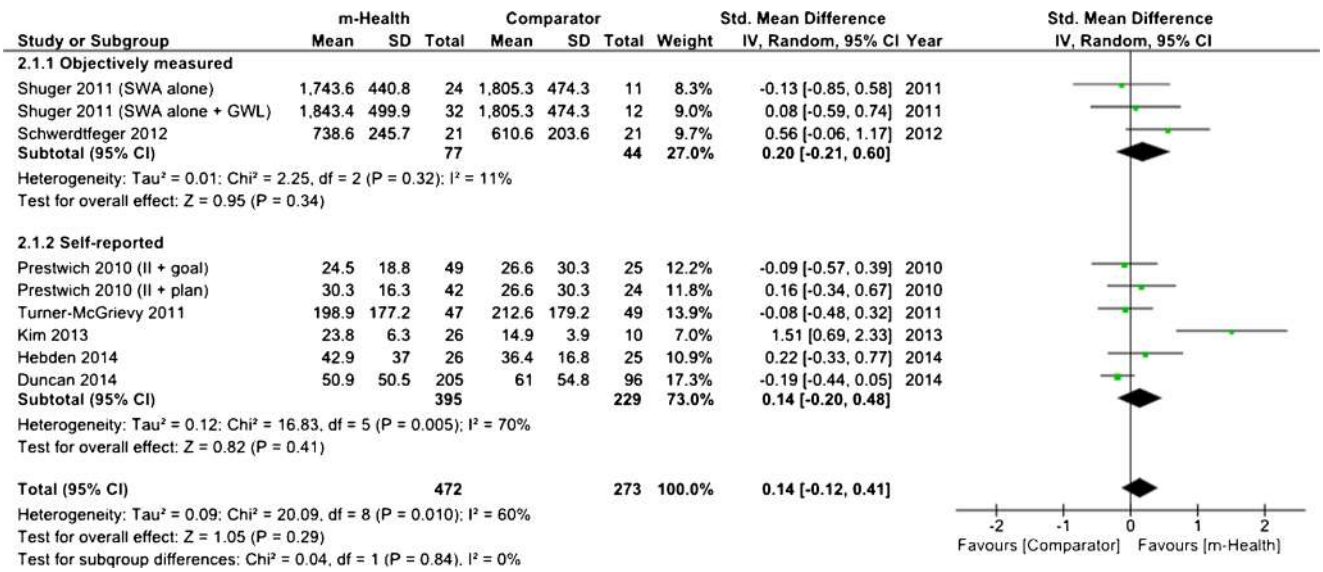


Fig. 3 Forest plot for total physical activity; *SWA* sensewear armband, *GWL* group sessions, *II* implementation intentions

(SMD = 0.49, 95 % CI −0.04 to 1.01) or objectively measured (SMD = 0.03, 95 % CI −0.38 to 0.44) MVPA levels (Fig. 4).

One study reported changes in PA from baseline and could not be included in the pooled analysis of SMD [23]. Self-reported MVPA slightly increased for the smartphone-only group while decreasing in the other groups of counselling with/without a smartphone (average increase was 0.19 h/week) [36]. Another study where all conditions were interventions was not included in the pooled analysis. Self-reported MVPA significantly increased across three groups using smartphone apps. Post-intervention averages were 40.1, 45.5 and 38.2 min/day of MVPA for the respective analytical, social and affect app conditions [39].

Walking Eight studies (n = 703 participants) [28–30, 32, 35, 37, 38, 42] reported effects for walking-related outcomes (steps/day, walking duration/day). The pooled effect was positive and small (SMD = 0.14, 95 % CI −0.01 to 0.29). There was no evidence of heterogeneity (I^2 = 0 %; χ^2 = 5.76; P = 0.76). Subgroup analyses showed walking levels did not differ significantly between studies with objective (SMD = 0.13, 95 % CI −0.07 to 0.34) or

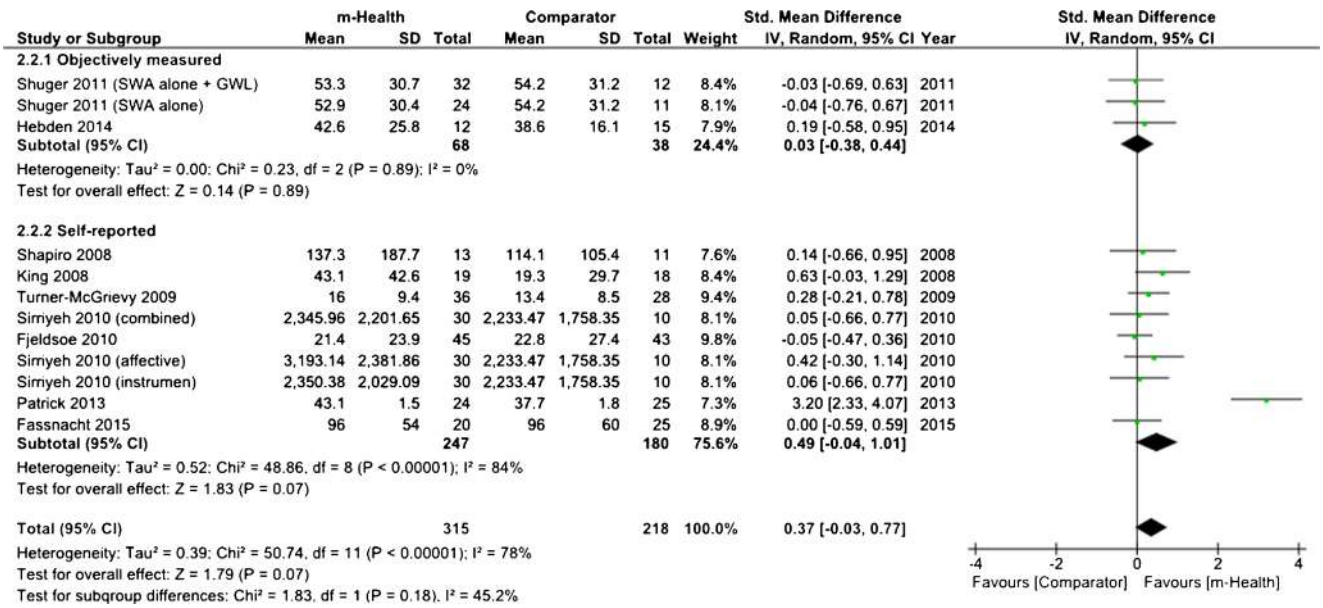


Fig. 4 Forest plot for moderate-to-vigorous intensity physical activity; *SWA* sensewear armband, *GWL* group sessions, *II* implementation intentions

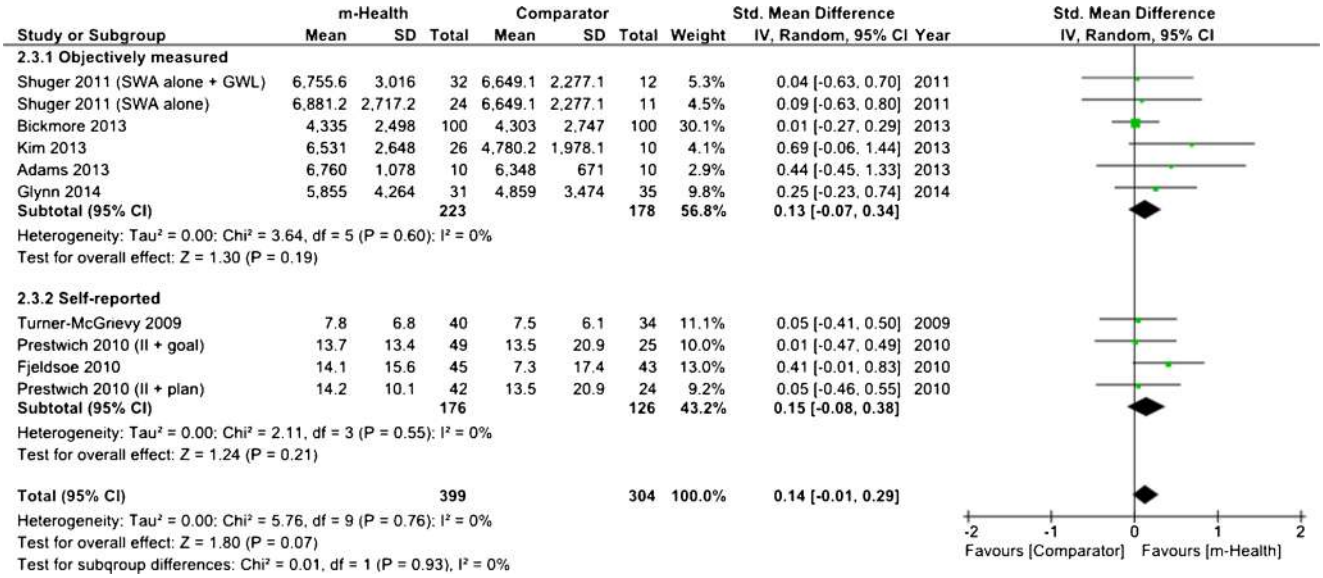


Fig. 5 Forest plot for walking; *SWA* sensewear armband, *GWL* group sessions, *II* implementation intentions

self-reported measurement (SMD = 0.15, 95 % CI −0.08 to 0.38) following mHealth interventions (Fig. 5).

Two studies where all conditions were interventions were not included in the pooled analysis. In one, self-reported walking duration significantly increased across three groups using apps—post-intervention averages were 22.8, 28.5 and 25.6 min/day for the analytical, social and affect app, respectively [39]. In the other, pedometer-measured steps/day did not statistically increase for any of the three intervention groups using an mHealth package targeting either sedentary behavior, exercise or both [44].

Sedentary Behavior Five studies (n = 226 participants) [27, 28, 40, 43, 45] reported effects for sedentary behavior-related outcomes (sitting duration/day, screen time duration/day). Sedentary behavior level was statistically significantly lower following mHealth interventions compared with controls (SMD = −0.26, 95 % CI −0.53 to −0.00). There was no evidence of heterogeneity (I^2 = 0 %; χ^2 = 0.28; P = 0.99). Subgroup analyses showed SB level did not differ significantly between studies with objective (SMD = −0.24, 95 % CI −1.00 to 0.52) or self-reported measurement (SMD = −0.27, 95 % CI −0.55 to 0.01) following mHealth interventions (Fig. 6).

One study reported changes from baseline and could not be included in the pooled analysis of SMD [23]—self-reported sitting time was significantly lower compared to the control group (average decrease was −5.9 h/week; P = 0.03) [25]. Another study where all conditions were interventions could not be included in the pooled analysis. Self-reported TV viewing duration significantly decreased across three groups using smartphone apps (post-intervention averages were 126.6, 175.1 and 150.6 min/day for the analytical, social and affect app, respectively) [39].

Behavior Change Techniques

There was substantial heterogeneity in the terminology used to describe intervention (and comparator groups) content. Overall, studies included an average of 5.4 BCTs (SD = 2.6, range 0 to 12). More BCTs were employed with intervention groups (mean = 6.9, SD = 2.6, range 2 to 12) than with comparator groups (mean = 3.1, SD = 2.2 range 0 to 10). The percentage of inclusion of each one of the BCTs in intervention groups varied from 0 to 81 %. Frequently employed BCTs in intervention groups were ‘goal setting (behavior)’ (81 % of the studies), ‘self-monitoring of behavior’ (74 %), ‘social support (unspecified)’ (65 %), ‘feedback on behavior’ (55 %), ‘instruction on how to perform the behavior’ (55 %), ‘adding objects to the environment’ (48 %), ‘information about health consequences’ (45 %) and ‘prompts/cues’ (45 %). Other BCTs, such as ‘discrepancy between current behavior and goal’ (0 %), ‘behavioral contract’ (0 %), ‘behavioral experiments’ (0 %), and ‘review of behavior goal(s)’ (16 %), were never or seldom reported. The percentage of inclusion of each one of the BCTs in comparator groups varied from 0 to 53 %. Frequently employed BCTs in comparator groups were ‘goal setting (behavior)’ (53 % of the studies), ‘instruction on how to perform the behavior’ (47 %), ‘information about health consequences’ (37 %), and ‘self-monitoring of behavior’ (32 %). Specific excerpts per study and per study group can be found in Electronic Supplementary Material 4.

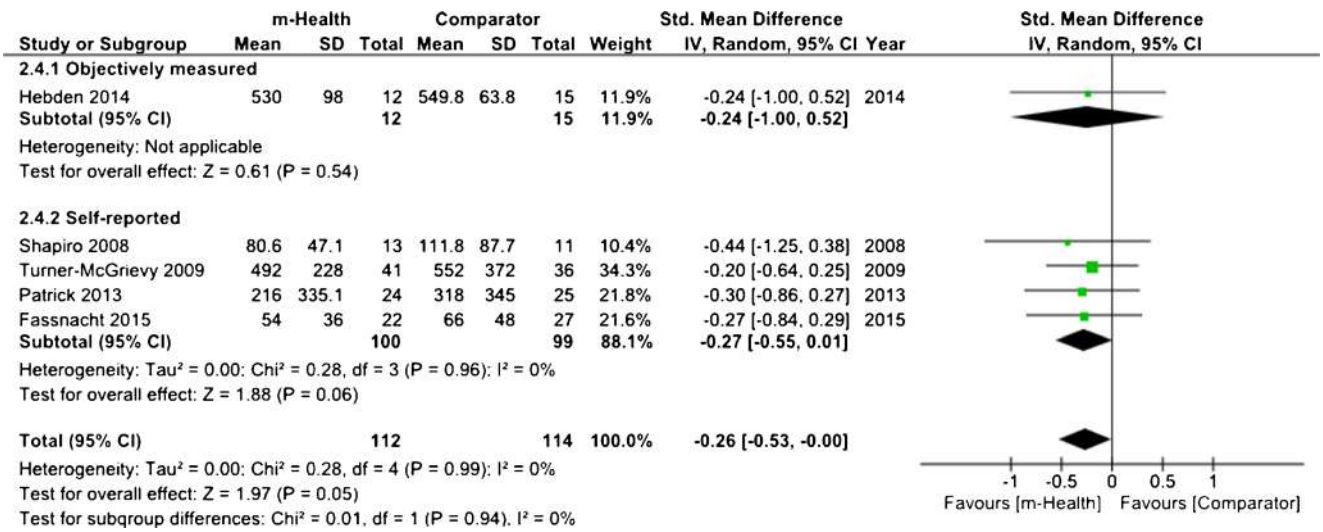


Fig. 6 Forest plot for sedentary behavior

Sensitivity Analysis

Post hoc exploratory sensitivity analysis indicated that one study [38] was the main source of heterogeneity between studies measuring total PA. A different study [40] was the main source of heterogeneity between those measuring MVPA. Heterogeneity decreased substantially after removing these studies (I^2 = 0 %, P = 0.44; SMD = −0.03, 95 % CI −0.19 to 0.12; and I^2 = 0 %, P = 0.91; SMD = 0.13, 95 % CI −0.06 to 0.32 for total PA and MVPA, respectively). Given between-study heterogeneity for total PA and MVPA outcomes and that small trials can be overweighted by a random effects model [47], we pooled studies using a fixed effects model to compare effect estimates. For total PA, the summary effect remained non-significant and its magnitude decreased (SMD = 0.02, CI −0.13 to 0.17); but for MVPA, the summary effect became statistically significant (SMD = 0.27, 95 % CI 0.09 to 0.45).

There were no changes occurring on the direction of the summary effects; however, the meta-analysis results were not entirely robust to the inclusion of studies of young people. For MVPA outcomes, the summary effect differed in magnitude-based only on adult studies, SMD was 0.14 (CI −0.10 to 0.37). For SB outcomes, the summary effects estimate differed little but was no longer significant-based only on adult studies, SMD was −0.21 (CI −0.59 to 0.18).

Publication Bias

Despite the small number of included studies (n < 10) [47], funnel plots of the standardized mean differences showed little evidence of publication bias for walking and sedentary behavior outcomes. However, for total PA and MVPA there was a somewhat asymmetric scatter consistent with publication bias.

Discussion

The effectiveness of mHealth interventions on PA and SB was examined in 21 RCTs. The main findings of this systematic review and meta-analysis, incorporating published and unpublished data from RCTs on 1700 participants, were that mHealth PA/SB interventions promote small decreases in free-living individuals' SB. Results also indicated positive and small-to-moderate-sized effects for PA and walking outcomes; however, differences between mHealth intervention groups and the comparators did not reach statistical significance. Notably, mHealth groups were compared against standard treatment/usual care, which typically have been improving throughout time. Comparator groups included components such as print-based PA guidelines, self-guided manuals that encouraged self-monitoring or somewhat more interactive tools that allowed real time self-monitoring like a wrist watch. It is possible that such 'active' comparator groups contributed to smaller intervention effects.

Strengths and Limitations

The current meta-analysis is the first to assess mHealth PA/SB interventions including only RCTs. A comprehensive search strategy based on Cochrane systematic reviews of PA interventions, adjusting terms to each electronic database was employed. Subgroup analyses were selected a priori, based on evidence showing discrepancies between objective and self-reported measurement of PA. Given the small number of studies included per outcome we did not perform meta-regression analyses to investigate effect moderation by study level covariates (e.g. age, BCTs included).

Limitations of this review were the small number of included studies, small sample sizes of the included studies, limited duration of included interventions, insufficient follow-up, and

outcome measurement based on participants' self-report for many studies. While the review included 21 studies, less than half (i.e. n = 9) measured PA/sedentary behavior outcomes objectively. All interventions were delivered in high-income countries. However, while most targeted educated white adults, the review also included studies of young people and two specifically focussed on a minority population. Given the lack of data from low and middle-income countries, caution is warranted generalizing the meta-analysis findings to other population groups. Heterogeneity in the terminology and insufficient reporting of intervention content impaired coding of BCTs. We did not evaluate intervention fidelity; assessment of BCTs followed the coding manual instructions and does not include evaluation of the quality of intervention implementation. For example, an intervention package may include BCTs, but it is unclear whether participants used these (e.g. web tutorials for seeking social support, positive self-statement [40]).

The small to moderate effects observed for PA outcomes (albeit statistically non-significant) is likely attributed to the short duration of interventions (median= 9 weeks), which may be insufficient to influence PA and SB outcomes. This short duration precludes assessment of the longer-term effectiveness of mHealth interventions on PA/SB outcomes. Attempts to address the heterogeneity on the pooled intervention effects for total PA and MVPA using a fixed effects model resulted in decreased magnitudes of effect. Although for MVPA the summary effect became statistically significant, the effect was still small and data must be interpreted with caution given its exploratory nature.

Although statistically non-significant, subgroup analysis of MVPA found a larger SMD for self-reported versus objectively measured activity (SMD = 0.49 vs. 0.03, respectively). This is likely due to the larger number of studies that included self-report measures and the fact that people tend to over-estimate intensity of PA [48, 49]. For the other PA outcomes, effect estimates differed little between subgroups where assessment was performed via objective measurement or self-report.

Comparisons with Other Work

Our findings compare and contrast to previous reviews [9–12, 50]. Generally, previous systematic reviews have reported that mobile phone technologies are effective for promoting PA [9–12, 50]. The current meta-analysis contributes with important quantitative evidence of the effects of mHealth in PA outcomes as the evidence of RCTs grows in this area. However, given the short-duration of intervention and the wide confidence intervals observed, caution in interpretation is warranted. In contrast, our meta-analysis is the first to show that mHealth can reduce time spent sedentary. Furthermore, our description of the BCTs content of current mHealth PA interventions highlights qualitative aspects to inform the replication, refinement, and improvement of mHealth interventions in the future [51].

Despite having employed a more strict inclusion criteria for studies in that only RCTs where the intervention was principally delivered using mHealth technologies, we found considerable heterogeneity of intervention (and comparator) groups. There was substantial variation in the number and type of BCTs included in intervention and comparator groups. While we acknowledge that within a comprehensive taxonomy of BCTs not all will be useful to influence PA/SB behavior related changes, among 93 BCTs, only 31 were employed in the intervention groups. Moreover, 19 different BCTs were employed within comparator groups, which demonstrates the 'active' nature of the comparator groups included in this review. Albeit the number of BCTs employed providing an indication of the behavior change potential of the interventions, with previous eHealth research showing a positive association with effectiveness [52], a different aspect is the type of BCT. In their meta-regression, Michie and colleagues [53] have shown five BCTs associated with greater intervention effectiveness for modifying PA and diet behaviors (i.e. self-monitoring, intention formation, specific goal setting, review of behavioral goals and feedback on performance). Likewise, Williams and French [54] found that action planning, provision of instructions, and effort reinforcement were associated with greater levels of both PA behavior and self-efficacy. However, BCTs such as problem solving, action planning, review of behavior goals, or graded tasks, which likely play key roles on the initial attempts of individuals' health-related behavior changes, were not frequently used in the studies included in the present review. Taken together, these findings highlight the potential to explore BCTs not commonly used that may contribute to increased effectiveness of interventions to promote PA behaviors, such as 'review of behavioral goals' [53]. Concurrently, many interventions employed the BCT 'prompts/cues'. This BCT illustrates how mHealth can be harnessed to promote not only the main part of an intervention, but also to conduct brief follow-up prompts beyond the intervention core, which has been associated with behavior maintenance [55].

Future Research/Implications

Research is necessary to investigate the long-term effectiveness and cost-effectiveness of mHealth interventions to promote PA/SB changes. mHealth approaches may be an important tool to address high resource demand and the extensive contact time of traditional face-to-face approaches. Investigation of the dose-response relationship between intervention exposure and outcomes would also be useful. In order to assess the impact of BCTs, the reporting of intervention content will need to be improved. Most interventions were based on SMS; however, advancements in technology will

enable more comprehensive, interactive and responsive intervention delivery.

Conclusions

Current mHealth interventions have small effects on total PA, MVPA, walking and SB. Technological advancements will enable more comprehensive, interactive and responsive intervention delivery. Future mHealth PA studies should ensure that all the active ingredients of the intervention are reported in sufficient detail.

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Authors' Contributions AD contributed to the conception, design, research, analyses, interpreted the data, and led the writing of the article. AD, EC and JR contributed to acquisition of data. RM participated in the conceptualisation of the study, data extraction and resolution of discrepancies. All authors provided feedback on the manuscript, and have read and approved the final version.

Compliance with Ethical Standards

Authors' Statement of Conflict of Interest and Adherence to Ethical Standards Authors Direito, Carraça, Rawstorn, Whittaker, and Maddison declare that they have no conflict of interest. All procedures, including the informed consent process, were conducted in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000.

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