Do smartphone applications and activity trackers increase physical activity in adults? Systematic review, meta-analysis and metaregression

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ABSTRACT

Objective To determine the effectiveness of physical activity interventions involving mobile applications (apps) or trackers with automated and continuous self-monitoring and feedback.

Design Systematic review and meta-analysis.

Data sources PubMed and seven additional databases, from 2007 to 2020.

Study selection Randomised controlled trials in adults (18–65 years old) without chronic illness, testing a mobile app or an activity tracker, with any comparison, where the main outcome was a physical activity measure. Independent screening was conducted.

Data extraction and synthesis We conducted random effects meta-analysis and all effect sizes were transformed into standardised difference in means (SDM). We conducted exploratory metaregression with continuous and discrete moderators identified as statistically significant in subgroup analyses.

Main outcome measures Physical activity: daily step counts, min/week of moderate-to-vigorous physical activity, weekly days exercised, min/week of total physical activity, metabolic equivalents.

Results Thirty-five studies met inclusion criteria and 28 were included in the meta-analysis (n=7454 participants, 28% women). The meta-analysis showed a small-to-moderate positive effect on physical activity measures (SDM 0.350, 95% CI 0.236 to 0.465, I^2=69%, T^2=0.051) corresponding to 1850 steps per day (95% CI 1247 to 2457). Interventions including text-messaging and personalisation features were significantly more effective in subgroup analyses and metaregression.

Conclusion Interventions using apps or trackers seem to be effective in promoting physical activity. Longer studies are needed to assess the impact of different intervention components on long-term engagement and effectiveness.

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INTRODUCTION

Physical activity is essential to the prevention and treatment of multiple chronic conditions[1 2] and can prevent premature mortality.[3] Any intensity of physical activity substantially reduces risk of death in a dose–response manner.[4] Nonetheless, more than a quarter of adults worldwide are insufficiently active,[5] and physical inactivity represents a leading cause of death worldwide.[6] The global pandemic of physical inactivity is responsible for at least $67.5 billion of economic burden per year.[7]

Behaviour change interventions to promote physical activity can include several behaviour change strategies and components—so-called behaviour change techniques (BCTs).[8] Two BCTs seem to be particularly effective: self-monitoring and feedback on behaviour.[9] For instance, interventions using pedometers can facilitate self-monitoring and feedback on step counts, having shown significant improvements in the short term (4 months).[10 11] However, these pedometer interventions are burdensome to maintain, as users have to use a step diary to keep track of their step counts.

In contrast, modern-day smartphone applications (apps) and activity trackers (eg, wearable fitness bands and smartwatches) enable automated and continuous self-monitoring and feedback on physical activity. Current smartphones and trackers enable the burdenless measurement of activity with acceptable accuracy,[12] as well as allow for continuous access to recorded data (longitudinally and in real time), via apps or the tracker's display. Nevertheless, a major challenge with apps and trackers is their high drop-off rate,[13] with reports of a third of users of activity trackers abandoning their device in the first 6 months.[14] It has been suggested that reducing user burden and providing features like goal setting, personalisation and game-like functionality (ie, gamification) may facilitate engagement, promote retention and increase intervention effectiveness.[15–17]

Existing reviews of apps and trackers have not yet focused on seemingly healthy adults[18–23] and technology enabling automated and continuous self-monitoring and feedback, with apps often still requiring users to connect an accelerometer to a computer periodically via a hardware connection.[20 22 24–30] These reviews of older apps and trackers have shown non-significant[22 24 26] or small-to-moderate positive results[20 25 28] with high heterogeneity, often mixing very different types of populations apart from healthy adults (eg, children,[26] elderly[22 27 28] and chronic conditions[20 25 27 28]). Furthermore, retention and engagement with these interventions, and effectiveness of different intervention features (eg, personalisation and gamification) have seldom been analysed.

The aim of this systematic review and meta-analysis was to evaluate the characteristics and effectiveness of interventions involving contemporary mobile apps or physical activity trackers (ie, enabling automated and continuous self-monitoring and feedback) in promoting physical activity, as well as in improving engagement and retention, in adults (18–65 years old) without chronic disease. A secondary aim was to explore and compare the effect of specific features in these interventions using metaregression.

METHODS

This systematic review is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[31] We followed a protocol registered with PROSPERO (CRD42017057854) for a broader review on physical activity, diet and weight loss. This paper focuses on physical activity; papers focusing on weight loss and diet were excluded at the full-text screening stage and will be analysed in a separate publication.

Search strategy

A search of the literature was performed in January 2017 (and updated continuously up to January 2020) using PubMed, Embase, CINAHL, PsycInfo, SciELO, ACM Digital Library, Cochrane Central Register of Controlled Trials and ClinicalTrials.gov. Articles were included if published between January 2007 and January 2020 since the launch of the first app stores. No language restrictions were applied. Search strings combined free terms (eg, smartphone, application and wearable) and controlled vocabulary (complete search strategy in online supplemental eMethods). Reference lists of relevant articles were also screened. Citations were uploaded to EndNote V.X9, where duplicates were removed.

Study selection criteria

We included randomised controlled trials (RCTs) where the population of interest was adults aged 18–65 years old without chronic disease; high adiposity or high body mass index (risk factors for chronic disease) were not exclusion criteria. We selected this study population because the relative homogeneity allows for comparing specific features and because youth, the elderly and those living with chronic diseases have different needs, barriers and enablers regarding physical activity that may not generalise to the general population. The intervention included a mobile app or an activity tracker enabling automated and continuous self-monitoring and feedback on physical activity measures. Our definition excludes pedometers and accelerometers if they did not offer ongoing access to tracked measures throughout time (either via the tracker's display or by wirelessly syncing with an app). Given that this definition is compatible with the state-of-the-art in technologies to promote physical activity, we simply refer to them as 'smartphone apps' and 'activity trackers' throughout the paper.

The comparison group was either a true control (eg, given no intervention—usual care, waiting list—or an intervention not including an app or a tracker) or was an active control (ie, receiving a control intervention including an app or a tracker); and the main outcomes were measures of physical activity (online supplemental eTable 1 and eMethods 2).

Screening and data extraction

Title and abstract screening and full-paper screening were conducted by six pairs of independent investigators. Two investigators extracted information from the included studies into a Microsoft Excel spreadsheet (version 16.43): publication information, mobile technology, intervention characteristics, study duration, participant and setting characteristics, outcomes, behaviour change theories, retention rates (percentage completing follow-up assessment), engagement measures, funding sources, conflicts of interest, incentives for participation, adherence to reporting guidelines, personalisation and gamification features. Coding of BCTs according to the BCT taxonomy[8] was conducted by three trained investigators. Included studies were assessed independently by two researchers using Cochrane's risk of bias tool (domains assessed: random sequence allocation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data and selective reporting).[32 33] Disagreements in screening, data extraction and risk of bias assessment were resolved by a third investigator. Data extraction and coding of BCTs were not conducted independently. For multiarm trials, data extraction was conducted for the two arms of interest (online supplemental eMethods 3). Data extraction was complemented with information from protocol papers, trial registrations and emails to authors, as well as known basic features of commercial trackers and mobile apps.

Strategy for data synthesis

A narrative synthesis was conducted for all studies. Studies for which it was possible to calculate an effect size were combined for a summary effect. Outcomes from cluster RCTs were included when adjusted for the effects of clustering. Whenever a single study reported multiple outcomes, the outcome to be included in the meta-analysis was selected through consensus among the authors following predefined rules to minimise bias (online supplemental eMethods 3).

Continuous outcomes were pooled together and all effect sizes were transformed into the standardised difference in means (SDM).[34] Estimates of mean physical activity effect sizes were also converted from SDM to number of steps per day for ease of interpretation (online supplemental eMethods 4).

We used random effects models for all analyses; the between-studies variance (T^2) was estimated using the method of moments. We used I^2 to describe the proportion of the variance in observed effects that is due to variance in true effects.[35] The presence of publication bias was evaluated by the use of a funnel plot and the Duval and Tweedie trim-and-fill method.[35] We used the Grading of Recommendations Assessment, Development and Evaluation (GRADE) system for grading the body of evidence.[36]

Sensitivity analyses, subgroup analyses and metaregression

Seven sensitivity analyses were conducted to assess the robustness of the findings (online supplemental eMethods 5). The cause of observed statistical heterogeneity was explored using subgroup analysis. We conducted 27 subgroup analyses, of which 16 were planned and 11 were post hoc (online supplemental eMethods 6). We conducted metaregression with statistically significant moderators identified in subgroup analyses, a dichotomous variable representing studies where the app or tracker was the only difference between intervention and control, and continuous moderators (number of BCTs in the intervention, retention rate and study duration) for hypothesis-generating purposes. R^2 was calculated to determine the proportion of total between-study variance explained by the model. Comprehensive Meta-Analysis V.3 was used for all computations. The significance level for all statistical tests was set at a p value of <0.05, two-tailed; 95% CIs were calculated where applicable.

Patient and public involvement

Although this study contained no direct consumer involvement, post hoc subgroup analyses were informed by previous work where consumer perspectives and needs in a physical activity intervention were explored.[37] The results from the present study will be disseminated through the institutional websites and press releases.

RESULTS

The database search retrieved 10 548 articles, after 2662 duplicates were removed (figure 1). After title and abstract screening, 10 347 articles were excluded. Full-text screening was conducted for the remaining 201 papers; 44 additional articles were found via updates of the database searches and reference lists of included papers. A further 210 articles were excluded (online supplemental eResults 1). The kappa statistic was 0.57 (fair agreement) for the title and abstract screening and 0.78 (substantial agreement) for the full-text screening, before consensus agreement was reached (online supplemental eTable 2). Although 35 studies met inclusion criteria, in 7 studies it was not possible to calculate an effect size to include in the meta-analysis (online supplemental eTables 3-5). The final number of included studies was 28.[38–65] Of these, one was a doctoral thesis[40] and another was a working paper[57]; the remaining were published articles.

Description of included studies

The 28 studies were published between 2014 and 2019, and were mainly (n=20) conducted in the USA[39 40 45 47–61 63 64] (table 1). Study duration varied between 2 and 40 weeks (mean duration: 13 weeks). Studies involved a total of 7454 participants, including 2107 (28%) women; 14 studies had a sample size smaller than 100, and 17 studies had less than 50 participants in the active intervention arm. In 12 studies, recruitment included only physically inactive or sedentary adults,[40–42 46–48 51 54 55 57 58 64] and in 6 studies, recruitment included only overweight or obese individuals.[38 41 47 50 53 64] Risk of bias was assessed as low for at least 4 out of 6 categories in 17 studies[38 40 42–45 48–50 52 53 56 58 60 61 64 65] (online supplemental eTable 6). In seven articles, the authors declared relevant conflicts of interest[38 45 48 50 53 56 60] (three papers had no conflict of interest statement, online supplemental eTable 7). Adherence to reporting guidelines was explicitly mentioned in eight studies[40–43 48 49 58 65] (online supplemental eTable 7). Physical activity outcomes were measured with a research-grade accelerometer in 11 studies,[38 40 42–44 46 47 51 55 59 64] self-reported (questionnaire) in 3 studies,[39 41 63] and assessed with a mobile app or consumer-grade activity tracker in 14 studies[45 48–50 52–54 56–58 60–62 65] (online supplemental eTable 8). Daily step count was the outcome in 21 studies[38 40 42 43 45 46 48–54 56 57 59–62 64 65] and moderate-to-vigorous physical activity was the outcome in four studies[44 47 55 58]; three studies had different outcomes (all self-reported)—weekly days exercised, total physical activity (min/week) and metabolic equivalents per week (online supplemental eTable 8). All extracted outcomes are openly available online (https://osf.io/d3rnu/).

Participant engagement with the intervention was mentioned in 18 studies (online supplemental eTable 9). There was inconsistency in metrics reported. The most commonly reported measure across studies was the percentage of daily usage (six studies),[41 42 45 47–49] which varied between 58.3% and 97.4% (mean 79.9, SD 14.5). Four studies reported on engagement changes throughout time, showing progressively

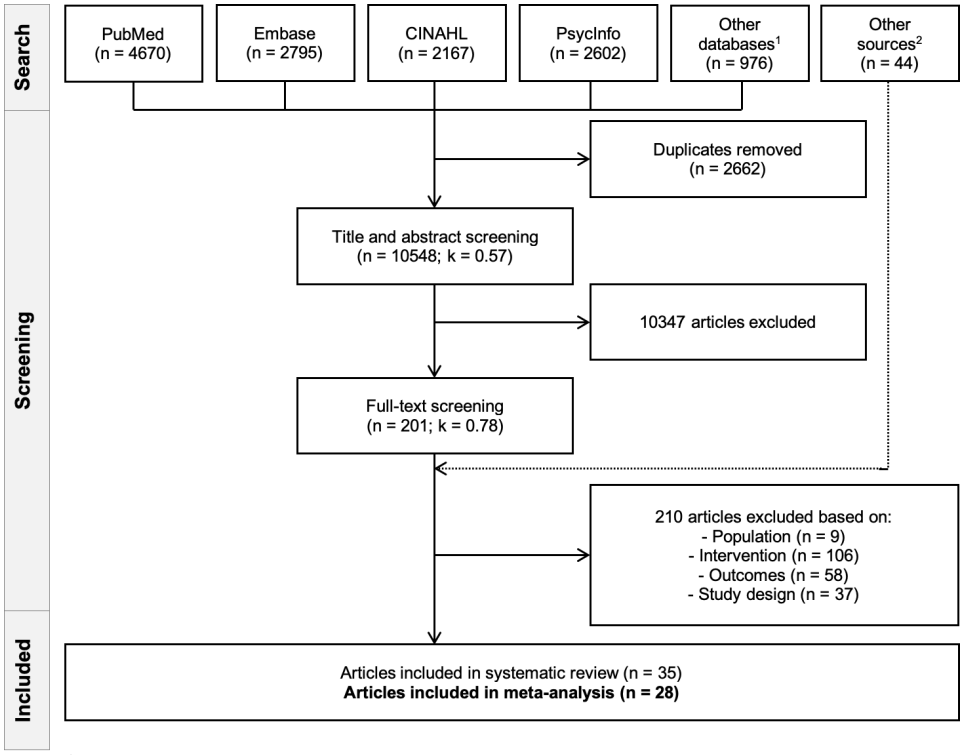

Figure 1 Flowchart of included studies. A total of 28 studies were included in the meta-analysis. [1]Other databases include SciELO, Cochrane Central Register of Controlled Trials and ACM Digital Library. [2]Other sources include reference lists of included articles and database search updates.

Table 1 Characteristics of studies included in the meta-analysis

First author, year, country*	Participants†	N (I, C),‡ women (n)	Duration
True control group: no tracker or app component			
Wyke, 2019, Netherlands, Norway, Portugal[38]	Men, BMI≥27, 30–65 years	1113 (560, 553), 0	3months
Donoghue, 2018, USA[39]	17–50 years, first year medical students	3-arm N 120 (40, 40), 41	10months
Pope, 2018, USA[40]	Inactive,§ BMI≥18.5, 18–35 years	38 (19, 19); 28	3months
Vandelanotte, 2018, Australia[41]	Inactive,§ BMI 25–40,≥18 years	243 (121, 122), 182	3months
Ashton, 2017, Australia[42]	Men, inactive,§ 18–25 years	50 (26, 24), 0	3months
Brakenridge, 2016, Australia[43]	Desk-based office workers	153 (66, 87), 70	3months
Finkelstein, 2016, Singapore[44]	21–65 years, office workers (13 worksites)	4-arm N 800 (203, 201), 212	6months
Poirier, 2016, USA[45]	Office workers	265 (133, 132), 175	1.5months
Ashe, 2015, Canada[46]	Women, inactive,¶ 55–70 years	25 (13, 12), 25	6months
Cadmus-Bertram, 2015, USA[47]	Women, inactive,** BMI≥25, postmenopause	51 (25, 26), 51	4months
Martin, 2015, USA[48]	Inactive,†† 18–69 years, CVD prevention centre	3-arm N 48 (16;16); 15	5 weeks
Thorndike, 2014, USA[49]	21–45 years, medical residents	104 (52, 52), 54	1.5months
Active control with a tracker or app component			
Patel, 2019, USA[50]	BMI≥25	4-arm N 602 (150, 151), 175	6months
Ellingson, 2019, USA[51]	Inactive,§ 24–65 years	91 (45, 46), 48	3months
Zhang, 2019, USA[52]	Women, 18–35 years, African–American	91 (44, 47), 91	3months
Patel, 2018, USA[53]	BMI≥27, university staff	4-arm N 209 (44, 65), 160	13 weeks
Robinson, 2018, USA[54]	Inactive,§ 35–69 years	63 (31, 32), 45	5 weeks
Fanning, 2017, USA[55]	Inactive,** 30–54 years	4-arm N 116 (29, 87), 93	3months
Patel, 2017, USA[56]	Family members in Framingham Study	206 (102, 104), 112	3months
John, 2016, USA[57]	Inactive,‡‡ AchieveMint users	2055 (1027, 1028),NR	2 weeks
King, 2016, USA[58]	Inactive** or sedentary,§§ ≥45 years	4-arm N 95 (22, 27), 36	2months
Melton, 2016, USA[59]	African–American women, 18–24 years	69 (28, 41), 69	2months
Patel, 2016, USA (I)[60]	Employees	4-arm N 304 (68, 80), 108	13 weeks
Patel, 2016, USA (II)[61]	Employees/family members of employees	4-arm N 288 (64, 100), 124	13 weeks
Walsh, 2016, Ireland[62]	Healthy adults	58 (29, 29), 40	5 weeks
Cowdery, 2015, USA[63]	18–69 years	40 (20, 20), 34	3months
Wang, 2015, USA[64]	Inactive,§ BMI≥25, 18–69 years	67 (33, 34), 61	1.5months
Glynn, 2014, UK[65]	Adults	90 (45, 45), 58	2months

*Ordered by study year.
†Participant eligibility criteria, organised by gender, level of physical activity, BMI, age, other characteristics, where reported.
‡In studies with more than two arms, the intervention of interest and control groups were selected as per defined in the methods.
§<150–300 min/week of MVPA.
¶<30min/week MVPA.
**<60 min/week MVPA.
††<90 min/week MVPA.
‡‡<70th percentile for mean daily steps in AchieveMint platform.
§§Sitting time ≥10 hours/day.
app, smartphone application; BMI, body mass index; C, control; CVD, cardiovascular disease; I, intervention; MVPA, moderate-to-vigorous physical activity; NR, not reported.

lower engagement with the intervention.[43 44 51 55] Retention rates varied between 61% and 100% for the intervention group (mean 90.5%, SD 10.2) (online supplemental eTable 9). In 15 studies, participants received incentives for study compliance and completion, most commonly gift vouchers[38 40–42 44 45 47 50 52–54 56 58–60] (online supplemental eTable 10).

Intervention and control group components and BCTs

Studies were grouped according to whether or not the control group involved a smartphone app or tracker enabling automatic self-monitoring and feedback: true control (12 studies)[38–49] or active control (16 studies)[50–65] (table 2). Most interventions (n=20) included a physical activity tracker, with or without a mobile app[38–49 51 52 54 56 57 59 64] (12 studies included a tracker with an app); eight interventions used a smartphone app without a tracker[53 55 58 60–63 65] (table 2 and online supplemental eTable 11). Other common intervention components included email,[39 43 45 48 49 53–57 59–61 63] human involvement (face-to-face or phone calls)[38 42 43 46 47 49 51 55 62 64 65] and text messaging.[45 48 53 55 56 60 61 64 65] There were only five studies where the only different components between intervention and control were the tracker or the smartphone app for self-monitoring and feedback on physical activity.[40 41 43 58 59]

Behaviour change theories were mentioned in 19 studies,[38 40–42 44–48 50–52 54–58 62 63] the most common being social cognitive theory[40–42 46 52 55 58] (online supplemental eTable 11). The mean number of BCTs present in interventions was 8.1 (SD 3.2) and in controls it was 2.9 (SD 2.3). Apart from BCTs in the 'feedback and monitoring' group, the most common groups of BCTs present in the intervention were 'goals and planning' and 'reward and threat' (figure 2 and online supplemental eTable 11), and the most frequent techniques were goal setting,[38 39 41 42 44–48 50 51 54 55 60–65] prompts/cues,[43 45 48–52 54 55 57–59 62–65] instruction on how to perform the behaviour[38 40 42–44 46 48 51 54 55 58 62 63 65] and social support.[38 41 42 44–46 51 52 58] Gamification or exergames were present in 14 studies[38 39 44–46 49 50 53 55–58 60 63] (online

Table 2 Components and BCTs in intervention and control groups*†

Author	Characteristics and BCTs of the intervention: Tracker and/or app‡	Characteristics and BCTs of the intervention: Other intervention components	Characteristics of the control§
True control group: no app or tracker component			
Wyke[38]	Tracker+app: social support and comparison	Group meetings: goal setting, action planning, review goals, social support, instruction on doing the behaviour, info on health consequences and emotional consequences, behavioural practice, graded tasks, credible source, identity associated with new behaviour	None
Donoghue[39]	Tracker (Fitbit)	Emails, mentored walks/runs: goal setting, social comparison, behaviour practice and substitution, graded tasks, restructuring the physical environment	None
Pope[40]	Tracker+app (Polar)	Facebook group: instruction on doing the behaviour	Facebook group
Vandelanotte[41]	Tracker (Fitbit)	Website: goal setting, problem solving, action planning, feedback, self-monitoring, social support, info on health consequences	Website
Ashton[42]	Tracker+app (Jawbone): goal setting	Facebook group, website, meetings, resistance band, leaflet: problem solving, review goals, social support, instruction on doing the behaviour, demonstration of the behaviour, behaviour practice, habit formation, credible source; adding objects	None
Brakenridge[43]	Tracker+app (LUMOback)	Leaflet, emails, meetings: feedback, instruction on doing the behaviour, info on health consequences and on others approval, cues	Leaflet, emails, meetings
Finkelstein[44]	Tracker (Fitbit)	Fitbit website+control: goal setting, social support and comparison, unspecific reward	Leaflets
Poirier[45]	Tracker (Pebble+)	Website (+SNS), emails, SMS: goal setting, social support and comparison, cues, graded tasks, unspecific reward	None
Ashe[46]	Tracker+app (Fitbit)	Fitbit website, meetings, transport tickets: goal setting, problem solving, action planning, review goals, social support and comparison, instruction on doing the behaviour, info on health consequences, graded tasks, adding objects	Meetings
Cadmus[47]	Tracker (Fitbit)	Fitbit website, meeting: goal setting, action planning, review goals, commitment	Pedometer, leaflet
Martin[48]	Tracker+app (Fitbug)	Website, emails, SMS: goal setting, instruction on doing the behaviour, cues, habit formation, credible source, unspecific reward	None
Thorndike[49]	Tracker (Fitbit): reward	Fitbit website+control	Gym access, personal training, meetings, emails
Active control with an app or tracker component			
Patel, 2019[50]	Tracker (Withings Activité Steel)+app	SMS/emails, gamification: goal setting, behavioural contract, commitment, anticipated regret, social comparison, cues, removal of aversive stimulus, graded tasks, non-specific incentive+reward, future punishment, punishment	Tracker (Withings Activité Steel)+app+SMS/emails
Ellingson[51]	Tracker+app (Fitbit)	Motivational interviewing, habit education (meetings+phone): goal setting, problem solving; instruction on doing the behaviour, social support, cues, habit formation	Tracker+app (Fitbit)
Zhang[52]	Tracker (Fitbit)+app+social features: social support and comparison, cues	None	Tracker (Fitbit), app
Patel, 2018[53]	App (Moves)	Combined financial incentives, goal achievement feedback (SMS/emails): goal setting, anticipated regret, material incentive+reward, future punishment	App (Moves), goal achievement feedback (SMS/emails)

Continued

Table 2 Continued

Author	Characteristics and BCTs of the intervention: Tracker and/or app‡	Other intervention components	Characteristics of the control§
Robinson[54]	Tracker (Fitbit)	Emails (+incentive reminders), online resources: goal setting, problem solving, action planning, instruction on doing the behaviour, cues, habit formation, graded tasks, reduce negative emotions, framing/reframing	Tracker (Fitbit), emails
Fanning[55]	App+goal setting, gamification: goal setting, review goals, discrepancy between behaviour and goal, instruction on doing the behaviour, unspecific incentive+reward	Meeting, emails, SMS: goal setting, review goals, cues, graded tasks, credible source, unspecific reward	App, meeting, emails, SMS, workbook
Patel, 2017[56]	App (Moves) OR tracker (Fitbit)	SMS/emails, gamification: goal setting, behavioural contract, commitment, social support, anticipated regret, graded tasks; material incentive+reward; unspecific incentive +reward; future punishment	App (Moves) OR tracker (Fitbit), SMS and/ or emails
John[57]	App (AchieveMint)+Tracker (Fitbit): material incentive	Emails (+extra emails about rewards), monetary reward: cues, cue signalling reward, material reward	App, Fitbit, monetary reward, emails
King[58]	Social app: problem solving, social support and comparison, instruction on doing the behaviour, cues	None	Dietary app
Melton[59]	Tracker+app (Jawbone)	Emails: cues	MyFitnessPal app, emails
Patel,2016 I[60]	App (Moves)	SMS/email/automated voice call, individual+team incentives: goal setting, social comparison, material incentive+reward, social incentive+reward	App (Moves), SMS/email/automated voice call
Patel, 2016 II[61]	App (Moves)	Feedback on team performance compared with the 75th percentile (email/SMS): goal setting, social comparison	App (Moves), feedback on team performance compared with the 50th percentile
Walsh[62]	App (Accupedo-Pro) with widget: discrepancy between current behaviour and goal, cues	Meeting, leaflet: goal setting, instruction on doing the behaviour, info on health consequences, demonstration of the behaviour	App, Meeting, leaflet
Cowdery[63]	Apps (exergame+Moves): unspecific incentive+reward, distraction	Emails: social support, instruction on doing the behaviour, cues	App (Moves)
Wang[64]	Tracker+app (Fitbit)	SMS, Fitbit website, meeting: goal setting, problem solving, cues	Tracker+app/website (Fitbit), meeting
Glynn[65]	App (Accupedo-Pro) with widget: cues	Leaflet, SMS, call: goal-setting, instruction on doing the behaviour, info on health consequences, cues, credible source	App, leaflet, SMS, call

*Components that distinguish the intervention from the control are underlined.
†Some BCTs were abbreviated for conciseness—check online supplemental materials for complete table.
‡By definition of the inclusion criteria, all mHealth technology components include self-monitoring of behaviour and feedback on behaviour, so these BCTs are not shown in intervention columns.
§BCTs for the control group are available in online supplemental file 1.
app, application; BCT, behaviour change technique; info, information; SMS, short message service; SNS, social networking site.

supplemental eTable 12). Personalisation features were mentioned in 12 studies,[38 41 42 44–49 54 55 58] most commonly in the form of personalised goal setting,[38 42 45 47 58] feedback[42 44 46 49 54 58] and content[41 44 48] (online supplemental eTable 13).

Meta-analysis and metaregression

The meta-analysis showed a positive effect on physical activity favouring interventions, including smartphone apps or activity trackers versus true and active control (SDM 0.350, 95% CI 0.236 to 0.465, p<0.0001, I^2=69%, T^2=0.051), corresponding to an increase of 1850 steps per day (95% CI 1247 to 2457) (figure 3). Despite signs of publication bias in the funnel plot, the Duval and Tweedie trim-and-fill method showed the adjusted estimate remained significant (online supplemental eFigure 1). We conducted seven sensitivity analyses and their results were consistent with the main analysis, showing a significant positive effect on physical activity favouring interventions including smartphone apps or activity trackers (online supplemental eTable 14). Grouping of studies by outcome type did, however, reveal a lower raw difference in means for daily step count (21 studies; 753.2, 95% CI 440.4 to 970.7). Forest plots of effect sizes ordered by retention rate, study duration and risk of bias are shown in online supplemental eFigures 2-4.

Six of 27 subgroup analyses (3 out of 16 planned analyses) were statistically significant (online supplemental eFigures 5-10 and online supplemental eTable 15), namely, studies where the intervention had goals and planning (SDM 0.446, 95% CI 0.33 to 0.562, p<0.0001) or 'graded tasks' (SDM 0.512, 95% CI 0.337 to 0.687, p=0.031) BCTs, text messaging (SDM 0.495, 95% CI 0.335 to 0.654, p=0.028), personalisation (SDM 0.541, 95% CI 0.365 to 0.718, p=0.006), studies where the authors mentioned conflicts of interest (SDM 0.529, 95% CI 0.388 to 0.671, p=0.004) and studies mentioning behaviour change

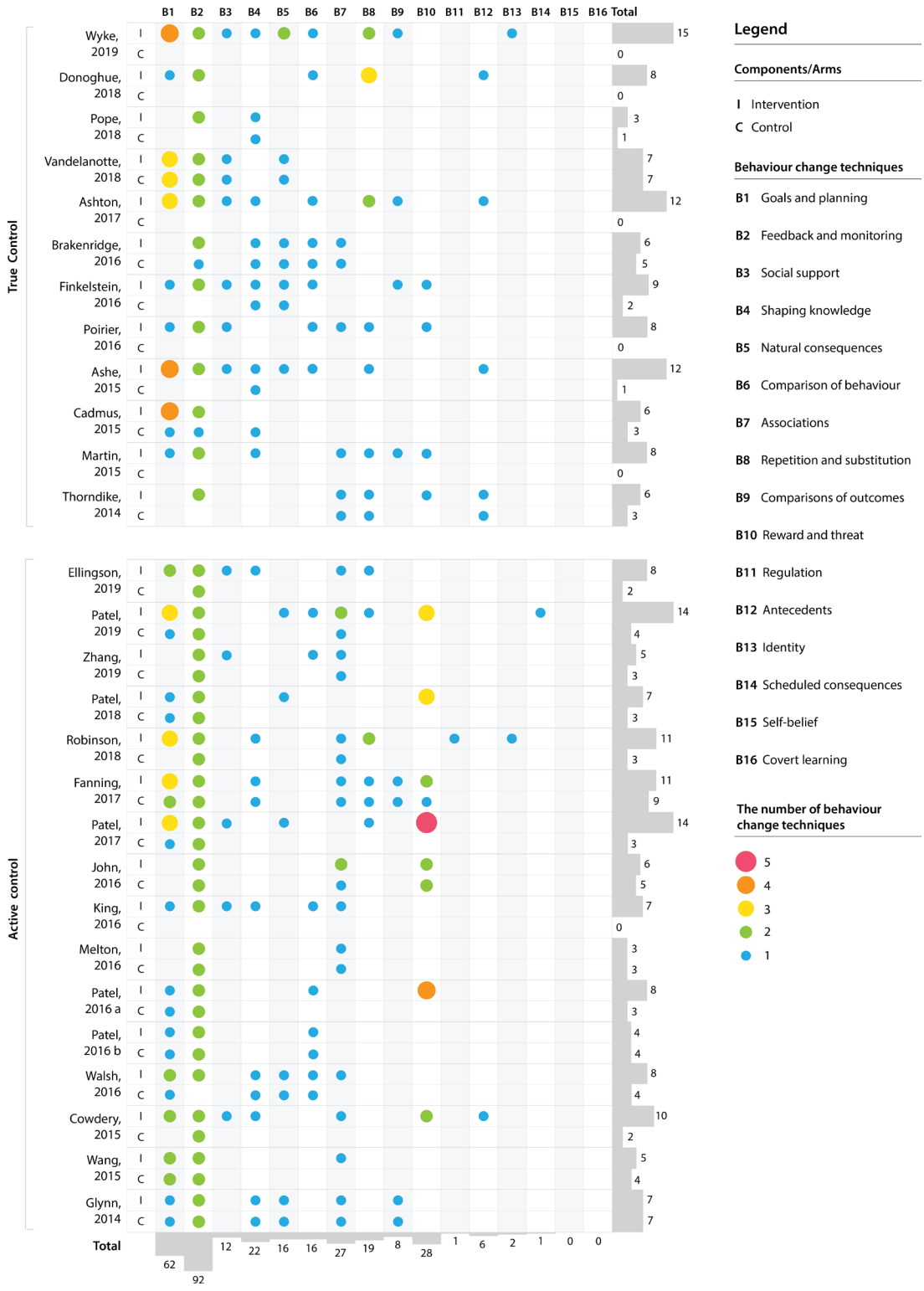

Figure 2 Mapping of BCTs in intervention and control groups of included studies. The most common BCTs present in the intervention were from the 'feedback and monitoring' group (B2, 60 BCTs across all 30 studies), followed by 'goals and planning' (B1, 47 BCTs across 22 studies) and 'reward and threat' (B10, 25 BCTs in 11 studies). BCT, behaviour change technique.

theories (SDM 0.449, 95% CI 0.312 to 0.587, p=0.018). Other subgroup analyses were not statistically significant, including analyses of studies where the intervention included an activity tracker or just an app, and studies where the tracker or the app were the only difference between intervention and control groups (online supplemental eTable 15). Heterogeneity was partially explained by differences in intervention components and populations: studies showing an I^2 lower than 40% included those providing action planning or human contact, as well as studies not including activity trackers or focusing on overweight populations (online supplemental eTable 15).

A metaregression model including the moderators that showed significance in the previously mentioned subgroup analyses showed an adjusted R^2 of 0.57 (table 3). A model including

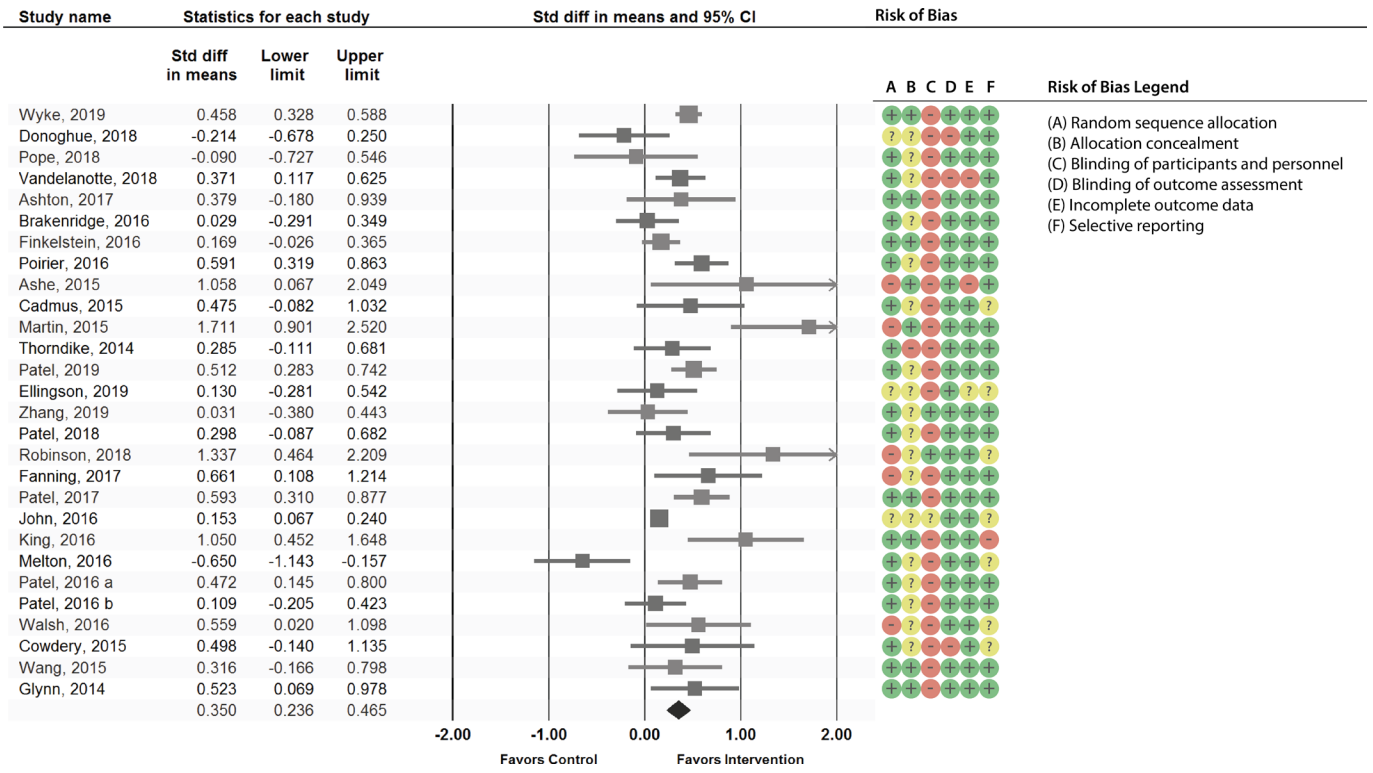

Figure 3 Forest plot of effect sizes and 95% CIs representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model) with risk of bias assessment. The meta-analysis showed a positive effect on physical activity favouring interventions, including smartphone apps or activity trackers (SDM 0.350, 95% CI 0.236 to 0.465, p<0.0001, I^2=69%, T^2=0.051), corresponding to an increase of 1850 steps per day (95% CI 1247 to 2457). Note: size of squares is proportional to study sample size. SDM, standardised difference in means.

only the significant variables from the previous model, as well as two additional ones—retention rate in the intervention group and study duration—showed an adjusted R^2 of 0.64, but study duration was not significant. A model replacing study duration with a dichotomous variable representing studies where the app or tracker were the only difference between intervention and control showed an adjusted R^2 of 0.71, explaining 71% of the variance in effectiveness. Overall, text messaging, personalisation, and retention rate in the intervention were all significantly associated with intervention effectiveness, consistently across several models.

DISCUSSION

Main findings

This is the first systematic review and meta-analysis of physical activity RCTs testing mobile apps or activity trackers that enable automated and continuous self-monitoring and feedback, in adults without chronic disease. Our findings suggest that interventions using apps or trackers have small-to-moderate effects on physical activity at a mean follow-up of 13 weeks, with an average increase of 1850 steps per day, compared with control. The available evidence is of low-to-moderate quality according to the GRADE system[66] and should be interpreted within the context of existing heterogeneity and publication bias. However, adjusted results accounting for the presence of publication bias remained significant.

Interventions including text-messaging and personalisation features showed higher effectiveness, with moderate effect sizes. Some variables were significantly associated with higher effect sizes in subgroup analysis but not in the metaregression: interventions including BCTs from the goals and planning group or graded tasks, studies mentioning behaviour change theories and studies mentioning conflicts of interest. Retention rate in the intervention was significantly associated with intervention effectiveness. Engagement measures were seldom mentioned and varied between studies.

Comparison with existing literature

We found a significant improvement in physical activity with apps and trackers, consistent with several previous meta-analyses focusing on older mobile technologies.[10 11 20 25 28 67–69] Our meta-analysis included a higher number of RCTs (28 vs an average of 17) and showed lower heterogeneity than other meta-analyses on mobile technologies (I^2 of 69% vs an average of 75%).[10 11 20 22 24–26 28 67–71] The lower heterogeneity may reflect the specificity of our inclusion criteria regarding population selection (adults without chronic disease) and the intervention (smartphone app or activity tracker enabling automated and continuous self-monitoring and feedback).

This study is consistent with previous work showing higher intervention effectiveness with the use of self-regulation techniques (self-monitoring, feedback and goal setting).[9 11 72] Our review expands on this prior work by showing that automating self-monitoring and feedback does not seem to decrease intervention effectiveness, which could happen due to the lower effort and attention required from people to monitor their behaviour. In fact, lowering user burden may indeed contribute to higher engagement and effectiveness by decreasing the 'costs' of the intervention (such as the 'opportunity costs' of doing other valued activities).[73] Self-regulation techniques are recognisably important in promoting physical activity,[9 11 72] and self-regulation is a crucial concept in social cognitive theory, the

Table 3 Metaregression

Covariate*‡‡	Coefficient (95% CI)	P value	R^2 analogue
Model 0			
Intercept	−0.128 (-0.34 to 0.084)	0.237	0.57
Goals and planning	0.05 (-0.041 to 0.141)	0.281	
Text messaging	0.365 (0.107 to 0.624)	*0.006*	
Personalisation	0.252 (0.033 to 0.47)	*0.024*	
Conflicts of interest	0.072 (-0.222 to 0.366)	0.631	
Graded tasks	−0.132 (-0.424 to 0.159)	0.374	
Behaviour change theories	0.24 (-0.004 to 0.484)	0.054	
Model 1			
Intercept	−1.054 (-1.875 to -0.232)	*0.012*	0.67
Text messaging	0.302 (0.112 to 0.492)	*0.002*	
Personalisation	0.365 (0.16 to 0.57)	*0.001*	
Number of BCTs in the intervention	0.02 (-0.007 to 0.047)	0.151	
Retention in the intervention	0.011 (0.002 to 0.02)	*0.021*	
Model 2			
Intercept	−1.081 (-1.914 to -0.248)	*0.011*	0.64
Text messaging	0.334 (0.147 to 0.522)	*0.001*	
Personalisation	0.427 (0.236 to 0.619)	*<0.001*	
Retention rate in the intervention	0.012 (0.004 to 0.02)	*0.006*	
Model 3			
Intercept	−1.058 (-1.925 to -0.19)	*0.017*	0.64
Text messaging	0.32 (0.127 to 0.512)	*0.001*	
Personalisation	0.445 (0.252 to 0.639)	*<0.001*	
Retention rate in the intervention	0.013 (0.004 to 0.022)	*0.005*	
Study duration	−0.007 (-0.019 to 0.004)	0.192	
Model 4			
Intercept	−2.077 (-3.395 to -0.759)	*0.002*	0.71
Text messaging	0.422 (0.222 to 0.623)	*<0.001*	
Personalisation	0.49 (0.293 to 0.686)	*<0.001*	
Retention rate in the intervention	0.022 (0.009 to 0.036)	*0.001*	
Studies where the app or tracker was the only difference between intervention and control	0.374 (-0.005 to 0.752)	0.053	

Multivariate metaregression models with statistically significant moderators identified in subgroup analyses, a dichotomous variable representing studies where the app or tracker was the only difference between intervention and control, and continuous moderators (number of BCTs in the intervention, retention rate and study duration). Statistically significant moderators were kept in successive models. R^2 was calculated to determine the proportion of total between-study variance explained by the model.
Italicised numbers correspond to statistically significant p values.
*Goals and planning: studies where the intervention includes BCTs in this category.
†Text messaging: studies where the intervention includes text messaging.
‡Personalisation: studies mentioning personalisation in the intervention.
§Conflicts of interest: studies where the authors mention conflicts of interest.
¶Graded tasks: studies where the intervention included this BCT.
**Behaviour change theories: studies mentioning use of behaviour change theories.
††Reference for all dichotomous variables: remaining studies.
‡‡Retention rate: retention rate in the intervention group (continuous variable).
BCT, behaviour change technique.

most commonly mentioned theory in our study and related reviews.[24] The higher prevalence of social cognitive theory and self-regulation techniques in our review may also explain our finding that interventions mentioning (ie, being based on) behaviour change theories were more effective, with previous meta-analyses suggesting that effectiveness may be more influenced by the specific BCTs used in an intervention than merely by the stated use of theory.[74]

As in other reviews, we found higher effectiveness of interventions including text messaging,[75] suggesting that this long-standing delivery mode continues to play an important role in behavioural informatics. Text messaging allows the delivery of prompts and cues, a BCT associated with behaviour maintenance.[76] Future research should explore whether the effect of text messages can be explained by their higher intrusiveness when compared with smartphone notifications (which can be switched off more easily). Additional studies with a longer duration should also explore the role of different components and BCTs in promoting engagement[77] and intervention effectiveness in the long term.

Our study showed a higher average retention rate than the only other meta-analysis reporting this measure (90.5% vs 80%).[11] In our analysis, retention was associated with effectiveness, whereas study duration was not. Furthermore, four studies reported on engagement changes over time, showing progressively lower usage[43 44 51 55] despite their short duration—a phenomenon known as the law of attrition of health informatics interventions.[78] Only one of these studies found a statistically

significant improvement in physical activity at the end of the intervention,[55] which suggests the importance of continued engagement for effectiveness. It thus remains unclear what the right 'dose' of app or tracker usage may be, or how it might vary for different people and circumstances. Future studies should consistently report engagement measures to allow future evaluation of the dose–response relationship between app or tracker usage and effectiveness.

Personalisation seems promising in promoting effective engagement with behaviour change interventions.[73 79 80] Previous reviews of computer-tailored interventions to promote behaviour change have found higher effectiveness of interventions providing tailored content, that is, selecting communication content using data-driven decision rules.[81] Recent developments in artificial intelligence may help leverage the richness of data routinely collected by smartphones and build machine learning models that optimise intervention content, timing and delivery, based on users' preferences, behavioural patterns, and other individual and contextual data.[82–84] In the future, mobile physical activity interventions may be able to deliver a core set of universally effective BCTs (eg, self-regulation), with additional techniques and features being personalised. Future research should explore users' perspectives on personalisation and the potential downsides resulting from sharing large volumes of personal data for that purpose.

Strengths and limitations

Our study has several strengths. Our search strategy included peer-reviewed and grey literature. There was substantial agreement in full-text screening. Given that data extraction was hampered by incomplete intervention descriptions, with most studies not adhering to reporting guidelines, we complemented data extraction with information from protocol papers, registrations and emails to authors, as well as known basic features of commercial trackers and mobile apps. Data extraction was extensive and included coding of BCTs by three trained investigators, following the BCT taxonomy.[8] Several sensitivity analyses were consistent with our main results. Our reporting of retention and engagement metrics and our analysis of the effectiveness of different features within the interventions are the most comprehensive to date.

Our review also has some limitations: (1) the search strategy was not peer reviewed; (2) data extraction and coding were not conducted independently and we could not measure intercoder agreement; (3) our coding of personalisation features was based on authors' mention of this term or synonyms; (4) subgroup analyses and meta-regression should be interpreted as exploratory findings due to the possibility of mass significance and uncontrolled confounding; (5) there was considerable heterogeneity, which was partially explained by differences in intervention components and population; (6) there were changes from the protocol, which are acknowledged in the methods and supplements; (7) generalisation of our results to the female population is limited, given that only 28% of participants were women (due to the inclusion of a few large-scale studies targeting only men).

What is already known

- Waist-worn pedometers can increase physical activity in the short term but are burdensome to use. Reviews of apps and trackers have shown inconsistent results, with high heterogeneity. Existing reviews of apps and trackers have not yet focused on healthy adults and on state-of-the-art technology, enabling automated and continuous self-monitoring and feedback.

What are the new findings

- Interventions using contemporary mobile apps or physical activity trackers are effective in promoting physical activity, with a statistically significant effect size of public health relevance. These interventions were more effective when including text-messaging or personalisation features. These results are valuable to clinicians, who may prescribe apps and trackers as part of a shared decision-making process to individuals who seem ready to make behavioural changes.

Implications

Interventions using smartphone apps or activity trackers seem promising from a clinical and public health perspective, promoting a significant step count increase of 1850 steps/day. These results are of public health importance according to recent evidence showing that any physical activity, regardless of intensity, is associated with lower mortality risk in a dose–response manner[85] and that an increase of 1700 steps/day is significantly associated with lower mortality rates.[86]

Apps and trackers are becoming ubiquitous in people's daily lives, with smartphone ownership surpassing three-quarters of the population and activity trackers being used by one-third of adults in the USA and UK.[87 88] Despite growing access to these technologies, it is important to ensure that the needs of diverse groups are being met by closing the digital divide, promoting digital health literacy and fostering inclusive design strategies.[89] Wide reach to different population groups is key to guaranteeing that improvements in physical activity from these interventions generate large effects at the population level, without worsening health inequities.

Enhancing the value of these interventions to consumers may boost long-term engagement and effectiveness, further increasing their impact. Promoting engagement beyond the initial 'novelty phase' is dependent on user experience, overall utility, and the ability to integrate with other devices and services.[14] Integrating sensor data from apps and trackers with electronic health record data are also likely to be useful for patients and clinicians. This is now possible with the Apple Health app, which is able to pull in health data from healthcare institutions,[12] operating as a personal health record. Such innovations, adding value to consumers, have the potential to spark a new generation of precision public health interventions.

The prescription of smartphone apps or activity trackers by clinicians to promote physical activity may extend the benefits of these interventions beyond the 'worried well' early adopters.[90 91] Primary care behaviour counselling interventions to promote physical activity are known to consistently improve important intermediate health outcomes, with evidence of a dose–response.[92] Given increasing time constraints in clinical practice, a brief intervention during the consultation may consist of prescribing an app or tracker, as part of a shared decision-making process, to individuals who seem ready to make behavioural changes.

CONCLUSION

We performed a systematic review and meta-analysis of RCTs and found that interventions using smartphone apps or physical activity trackers have a significant small-to-moderate effect in increasing physical activity (1850 steps daily). These interventions were more effective when including text-messaging or personalisation features. Given the wide and increasing reach of smartphones, even modest improvements in physical activity can produce large effects at the population level. Longer-duration studies with more diverse populations should explore long-term effectiveness and sustained engagement.

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Supplementary Online Content

Laranjo L, *et al. Br J Sports Med* 2020;0:1–13. doi: 10.1136/bjsports-2020-102892

Supplement 24: eFigure 3: Forest plot of effect sizes and 95% confidence intervals by ascending order of study duration representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)

Supplement 25: eFigure 4: Forest plot of effect sizes and 95% confidence intervals by decreasing order of number of low risk of bias categories (out of 6 categories in the Cochrane risk of bias tool) representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)

Supplement 26: eFigure 5. Forest plot of effect sizes and 95% confidence intervals by subgroup of studies where the intervention included behaviour change techniques in the 'goals and planning' category, representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)

Supplement 27: eFigure 6. Forest plot of effect sizes and 95% confidence intervals by subgroup of studies where the intervention included text-messaging, representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)

Supplement 28: eFigure 7. Forest plot of effect sizes and 95% confidence intervals by subgroup of studies mentioning personalisation features, representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)

Supplement 29: eFigure 8. Forest plot of effect sizes and 95% confidence intervals by subgroup of studies where authors mentioned conflicts of interest, representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)

Supplement 30: eFigure 9. Forest plot of effect sizes and 95% confidence intervals by subgroup of studies where the intervention included the behaviour change technique 'graded tasks', representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)

Supplement 31: eFigure 10. Forest plot of effect sizes and 95% confidence intervals by subgroup of studies mentioning a behaviour change theory, representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)

Supplement 32: eTable 15. Subgroup analyses

Supplement 1: eMethods 1. Search Strategy

Search strategy defined in collaboration with a medical librarian.

1.1. Search strategy for MEDLINE (via PubMED interface)
URL: https://www.ncbi.nlm.nih.gov/pubmed/
Limits: last 10 years

#1 "Mobile applications"[MeSH] OR "Smartphone"[MeSH] OR tablet computer*[tiab] OR wearable device*[tiab] OR accelerometer*[tiab] OR activity monitor*[tiab] OR "Fitness trackers"[MeSH] OR fitbit*[tiab] OR armband*[tiab] OR arm band*[tiab] OR fitness watch*[tiab] OR pedomet*[tiab] OR wearable technolog*[tiab] OR wearable system*[tiab] OR wearable sensor*[tiab] OR fitness monitor*[tiab] OR garmin[tiab] OR bodymedia[tiab] OR nike fuelband[tiab] OR jawbone[tiab] OR step count[tiab] OR smartwatch*[tiab] OR smart watch*[tiab] OR sports watch*[tiab] OR wristband*[tiab] OR wrist band*[tiab] OR MyFitnessPal [tiab]

#2 "Sedentary Lifestyle"[MeSH] OR "Obesity"[MeSH] OR "Weight Loss"[Mesh:NoExp] OR "Weight Reduction Programs"[MeSH] OR "Exercise"[MeSH] OR "Overweight"[MeSH] OR "Healthy LifeStyle"[MeSH] OR "Caloric Restriction"[MeSH] OR "Diet, Diabetic"[MeSH] OR "Diet, Mediterranean"[MeSH] OR "Diet, Reducing"[MeSH]

#3 #1 AND #2

1.2. Search strategy for EMBASE
URL: Macquarie University Library (via OVID interface)
Limits: last 10 years

#1 Mobile Application/ or Smartphone/ or pedometer/ or ("tablet computer" or "wearable device*" or "activity track*" or fitbit* or "fitness track*" or "fitness watch*" or "wearable system*" or "fitness monitor*" or garmin or bodymedia or "nike fuelband" or jawbone or "step count*" or smartwatch* or "smart watch*" or "sports watch*" or wristband* or "wrist band*").mp

#2 Weight reduction/ or lifestyle modification/ or "healthy lifestyle".mp or physical activity/ or diet/ or diet restriction/

#3 #2 and #3

1.3. Search strategy for PsychINFO
URL: Macquarie University Library (via OVID interface)
Limits: last 10 years
[mp=title, abstract, heading word, table of contents, key concepts, original title, tests & measures]

#1 ("mobile application*" or smartphone* or "tablet computer*" or pedomet* or "wearable device*" or accelerometer* or "activity track*" or fitbit* or "fitness track*" or "wearable system*" or "wearable technolog*" or "fitness monitor*" or garmin or bodymedia or "nike fuelband" or jawbone or "step count*" or smartwatch* or "smart watch*" or "sports watch*" or wristband* or "wrist band*" or armband* or "arm band*").mp

#2 ("weight loss" or "weight maintenance" or "weight reduction" or diet or "physical activity" or walking or exercise or "healthy lifestyle").mp

#3 #1 AND #2

1.4. Search strategy for CINAHL
URL: Macquarie University Library (via EBSCO Publishing)

#1 “mobile application*” OR smartphone* OR “tablet computer*” OR pedomet* OR "wearable device*" OR "activity track*" OR fitbit* OR "fitness tracker*" OR "fitness watch*" OR "wearable system*" OR "fitness monitor*" OR "wearable technolog*" OR garmin OR bodymedia OR "nike fuelband" OR jawbone OR "step count*" OR smartwatch* OR "smart watch*" OR "sports watch*" OR wristband OR "wrist band*" OR armband* OR "arm band*"

#2 “weight loss” OR “weight maintenance” OR “weight reduction” OR diet OR “physical activity” OR walking OR exercise OR “healthy lifestyle”

#3 #1 AND #2

1.5. Search strategy for ACM Digital Library
URL: Macquarie University Library (via EBSCO Publishing)
[ACM Digital does not allow the use of boolean operators]

Fitbit; mhealth; "activity tracker"; "mobile health"; "fitness tracker"; armband; wristband; pedomet*

1.6. Search strategy for SciELO (Scientific Electronic Library Online)
URL: www.scielo.org

[SciELO does not allow the use of boolean operators]
Filters: Health Sciences

Wearable*; Fitbit; pedomet*; acceleromet*; smartphone*; “Mobile application*”

1.7. Search strategy for ClinicalTrials.gov
URL: https://clinicaltrials.gov/ct2/search/advanced
Filters:
Study type: Interventional studies
Age group: adult
Condition: Body Weight OR Body Weight Changes OR Obesity OR Overweight OR Weight Loss OR Physical Activity OR Sedentary OR Diet OR Diet Modification OR Dietary intervention OR Healthy Lifestyle Behaviors OR Dietary habits OR Sedentary Lifestyle

#1 Mobile application* OR Smartphone* OR tablet computer* OR wearable device* OR activity monitor* OR Fitness tracker* OR fitbit* OR pedomet* OR wearable system* OR fitness monitor* OR wrist band* OR MyFitnessPal

1.8. Cochrane Central Register of Controlled Trials
URL: http://onlinelibrary.wiley.com/cochranelibrary/search/
Title, Abstract, Keywords
Publication Year from 2006 to 2017
Filter: Trials

#1 “Mobile application*” OR Smartphone* OR “tablet computer*” OR “wearable device*” OR “activity monitor*” OR “fitness tracker*” OR fitbit* OR pedomet* OR “wearable system*” OR “fitness monitor*” OR “wrist band*” OR MyFitnessPal

#2 “weight loss” OR “weight maintenance” OR “weight reduction” OR diet OR “physical activity” OR walking OR exercise OR “healthy lifestyle”

#3 #1 AND #2

Supplement 2: eTable 1. Inclusion and exclusion criteria

	Inclusion	Exclusion
Population	Adults (18-65) without chronic illness: healthy adults with any BMI. For studies including individuals up to 2 years outside of these boundaries, they were included if the mean age of study sample was above 18 and below 65. For studies including children and/or the elderly, they were only included if results for adults (18-65) were reported separately.	Studies focusing on: ● Elderly people (65 or plus years old); e.g. mean age of study sample >65 ● Athletes, military ● Patients with disabilities or chronic conditions, defined as a persistent (or otherwise long-lasting) condition that requires self-management and often requires therapy. ● Patients with psychiatric conditions or mental disability ● Pregnant women
Intervention	Includes a mobile application or a physical activity tracker enabling automated self-monitoring and feedback on physical activity measures in real-time, facilitating seamless ongoing access to tracked measures throughout time (either via the tracker's display or by wirelessly syncing with an app). The mobile application or tracker can be either isolated or delivered as part of a multi-component intervention.	Static pedometers or activity trackers not allowing for seamless ongoing access to tracked measures throughout time (either via the tracker's display or by wirelessly syncing with an app). Activity trackers requiring a USB connection to sync to a computer (not wireless) such as "Gruve" (MUVE, Inc) and the Personal Activity Monitor (PAM). Mobile applications not enabling automated self-monitoring (i.e. not collecting smartphone accelerometer data nor syncing with a tracker, instead requiring users to manually self-report their physical activity).
Comparison	Either 'no intervention' (e.g. usual care, waiting list) or active controls (receiving an intervention with or without mhealth components).	
Outcome	Any measure related to physical activity (e.g. step count).	Exclude studies that only report cognitive outcomes (e.g. intention to exercise), motivational outcomes or other subjective psychological measures.
Study type	Randomized controlled trials.	

Supplement 3: eMethods 2. Differences between protocol and review

Intervention
Intervention as defined in the protocol:

> 'Smart' mobile health intervention, either isolated or as part of a multi-component intervention. For this study, we defined "smart mobile health interventions" as health interventions involving the use of either: a smartphone; a tablet computer; a mobile application (app); or a monitoring device for automatic data collection of physical activity, diet or weight-related data (e.g. fitness tracker, wireless weight scale) with a consumer interface (e.g. app, web-based platform) enabling ongoing access to tracked measures throughout time (with data transmission occurring either wirelessly or through a hardware connection). We will exclude studies focusing on: MP3 players, podcast-only interventions, SMS-only interventions, personal digital assistant (PDA) or equivalent (e.g. handheld personal computer), web-only interventions (e.g. web-based application instead of a mobile application), telephone-only interventions (e.g. telephone coaching), telemonitoring and telemedicine interventions (e.g. remote management by healthcare providers), static pedometers (i.e. not able to transmit data to a consumer interface).

With the purpose of eliminating ambiguity and reflecting the rapid life cycle of consumer health technology, we updated the intervention definition and criteria at the start of the data extraction phase. The new definition does not include the ambiguous term "smart mhealth technology", specifically focusing on smartphone applications and/or activity trackers.
It is now also clearer in the definition that the technology has to enable *automated and continuous self-monitoring and feedback* on physical activity measures in *real-time*, meaning that the technology needs to show current measures of physical activity at any time (either via the tracker's display or by wirelessly syncing with an app). In addition, the technology also has to enable *seamless ongoing access to tracked measures throughout time* (either via the tracker's display or by wirelessly syncing with an app), which now excludes devices where data transmission occurs via USB connection, in line with the majority of trackers currently available on the market.

Outcome
Outcome as defined in the protocol:

> Weight, body mass index and any measure related to physical fitness, physical activity (e.g. step count), and dietary behaviours. We will exclude studies that only report cognitive outcomes (e.g. intention to exercise), motivational outcomes or other subjective psychological measures.

The present manuscript focuses on physical activity (for homogeneity and conciseness purposes); papers focusing on weight loss and diet were excluded at the full-text screening stage and will be analysed in a separate publication.

Data extraction
In the protocol we mentioned we would extract info regarding "compliance with the mHealth evidence reporting and assessment (mERA) guidelines".
In the present manuscript we broadened this extraction to "adherence to reporting guidelines".

Laranjo L, *et al. Br J Sports Med* 2020;0:1–13. doi: 10.1136/bjsports-2020-102892

Supplement 4: eMethods 3. Strategy for data synthesis in studies reporting several arms or outcomes

Whenever a single study reported several arms or outcomes, the arm and outcome to be included in the meta-analysis was selected through consensus among the authors with the aim of minimising bias, favouring:

1) primary outcomes and outcomes from intention-to-treat analysis;

2) smallest attrition;

3) continuous outcomes;

4) post-intervention (i.e. immediately after the end of the intervention period, instead of mid-study or post-study follow-up);

5) the most person-centred outcome (i.e. meaningful to lay consumers; e.g. step count).

Supplement 5: eMethods 4. Calculating effect sizes as daily step counts from standardized difference in means

1) Conducting a meta-analysis including only the 21 studies with daily step counts as an outcome, in order to obtain the standard error of the effect size (SE)

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Wyke, 2019	1208.000	172.483	29750.458	869.939	1546.061	7.004	0.000
Pope, 2018	-191.843	688.122	473511.554	-1540.536	1156.851	-0.279	0.780
Ashton, 2017	1012.700	755.433	570679.133	-467.922	2493.322	1.341	0.180
Brakenridge, 2016	60.100	334.169	111668.667	-594.858	715.058	0.180	0.857
Poirier, 2016	845.000	194.058	37658.548	464.653	1225.347	4.354	0.000
Ashe, 2015	3013.000	1354.860	1835646.774	357.522	5668.478	2.224	0.026
Martin, 2015	3376.000	697.752	486858.065	2008.431	4743.569	4.838	0.000
Thorndike, 2014	306.000	216.113	46704.774	-117.573	729.573	1.416	0.157
Patel, 2019	920.000	207.070	42878.154	514.149	1325.851	4.443	0.000
Ellingson, 2019	375.300	578.313	334445.463	-758.172	1508.772	0.649	0.516
Zhang, 2019	75.350	502.353	252358.683	-909.244	1059.944	0.150	0.881
Patel, 2018	742.000	486.788	236962.343	-212.087	1696.087	1.524	0.127
Robinson, 2018	2790.890	841.228	707663.956	1142.114	4439.666	3.318	0.001
Patel, 2017	953.000	227.179	51610.077	507.738	1398.262	4.195	0.000
John, 2016	367.060	105.710	11174.604	159.872	574.248	3.472	0.001
Melton, 2016	-1382.000	521.270	271721.907	-2403.669	-360.331	-2.651	0.008
Patel, 2016 a	1446.000	504.972	254997.120	456.272	2435.728	2.864	0.004
Patel, 2016 b	374.000	546.914	299115.084	-697.932	1445.932	0.684	0.494
Walsh, 2016	1292.000	623.097	388249.636	70.753	2513.247	2.074	0.038
Wang, 2015	457.000	352.974	124590.820	-234.817	1148.817	1.295	0.195
Glynn, 2014	2017.000	879.222	773031.290	293.757	3740.243	2.294	0.022
	753.169	149.522	22356.745	460.112	1046.226	5.037	0.000

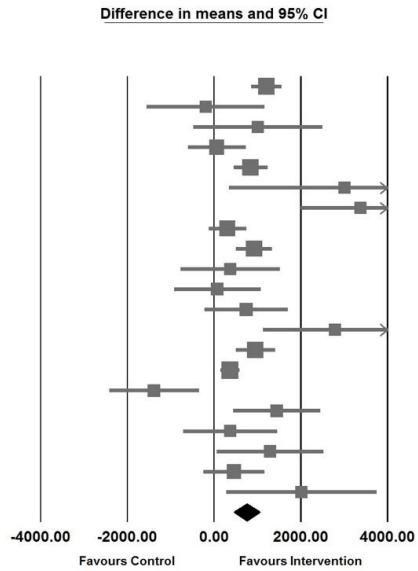

Figure 1: Forest plot of difference in means and 95% confidence intervals for the subgroup of 21 studies reporting step counts (random effects model)

SE=149.522

2) Using the standard error of the difference in means (SE) to calculate the standard deviation (SD) of the effect size of the 21 studies with daily step counts as an outcome

Estimated SD calculation:

$$SD = \frac{SE}{\sqrt{\frac{1}{Total\ sample\ size\ in\ intervention\ groups} + \frac{1}{Total\ sample\ size\ in\ congrol\ groups}}}$$

Total sample size in intervention groups=2451
Total sample size in control groups=2547

SD=5284.3686

Table 1: Sample size in intervention and control groups for the 21 studies with daily step counts as an outcome

First author, year	Sample size (intervention)	Sample size (control)
Wyke, 2019	464	471
Pope, 2018	19	19
Ashton, 2017	24	23
Brakenridge, 2016	66	87
Poirier, 2016	107	110
Ashe, 2015	13	12
Martin, 2015	16	16
Thorndike, 2014	50	49
Patel, 2019	150	151
Ellingson, 2019	45	46
Zhang, 2019	44	47
Patel, 2018	44	65
Robinson, 2018	14	11
Patel, 2017	98	102
John, 2016	1027	1028
Melton, 2016	28	41
Patel, 2016 I	80	68
Patel, 2016 II	64	100
Walsh, 2016	28	27
Wang, 2015	33	34
Glynn, 2014	37	40
Total sample size	2451	2547

3) Using the SD to extrapolate the difference in means in the 28 studies from the standardized difference in means

Standardized difference in means= Difference in means/SD
Difference in means= Standardized difference in means*SD
Difference in means=0.35*5284.3686
Difference in means=1849.53 steps/day

Supplement 6: eMethods 5. Sensitivity analyses conducted

Seven sensitivity analyses were conducted:
1) a sensitivity analysis excluding studies with a sample size lower than the median of 99 participants;
2) an analysis including only studies with 4 or more low risk of bias categories from Cochrane's risk of bias tool;
3) an analysis including only primary outcomes;
4) a) an analysis based on outcome type according to the outcomes in the main analysis [daily step count, moderate-to-vigorous physical activity (MVPA), or other];
4) b) an analysis based on outcome type for all studies reporting a given outcome (outcomes reported in at least 5 studies)
5) an analysis based on outcome measurement (research-grade accelerometer; tracker or mobile app; self-reported);
6) an analysis including the longest follow-up available, where the mean duration of the 28 studies increased to 18 weeks (4.5 months);
7) an analysis including studies with a true control (no smartphone app or tracker component)

Laranjo L, *et al. Br J Sports Med* 2020;0:1–13. doi: 10.1136/bjsports-2020-102892

Supplement 7: eMethods 6. Subgroup analyses and meta-regression, with differences from protocol

Planned subgroup analyses included: type of comparator (with or without a mobile app or an activity tracker); technology components (e.g. app, tracker, text-messaging); behaviour change techniques (according to the BCT taxonomy v1 of 93 BCTs); type of outcome included in the meta-analysis (defined by the authors as the primary outcome or not); measurement of outcome (self-reported versus objective measurement); study duration; and risk of bias.

Subgroup analyses as pre-specified in the protocol:

> "We will explore the cause of any observed statistical heterogeneity using subgroup analysis. Planned subgroup analysis include: type of outcome (physical activity, diet, weight), measurement of outcome (self-reported versus objective measurement), intention-to-treat versus per protocol analysis, type of mobile technology (e.g. smartphone, tablet, mobile application, monitoring device), study duration, behaviour change techniques (according to the Behaviour Change Technique (BCT) taxonomy v1 of 93 BCTs), risk of bias (low versus high), and type of comparator ['no intervention' versus active control (meeting criteria for 'smart mobile health intervention' or not)]."

Post-hoc subgroup analyses included: target population (physically inactive or sedentary; overweight or obese); personalisation features [explicitly mentioned by the authors using the term personalisation or related words and synonyms (e.g. tailoring, customisation, individualisation, adaptive intervention)]; human involvement in the intervention (i.e. face-to-face and phone call components); presence of an online social network[1]; and gamification (i.e. the use of game design elements in non-game contexts[2]). We conducted subgroup analysis for categorical variables where each subgroup had at least 5 studies; overall, 27 subgroup analyses were conducted.

Although this study contained no direct consumer involvement, post-hoc subgroup analyses were informed by previous work where consumer perspectives and needs in a physical activity intervention were explored[3].

1. Laranjo L, Arguel A, Neves AL, et al. The influence of social networking sites on health behavior change: a systematic review and meta-analysis. *J Am Med Inform Assoc* 2015;22(1):243-56.
2. Deterding S, Dixon D, Khaled R, et al. From game design elements to gamefulness: defining "gamification". Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments. Tampere, Finland: ACM, 2011:9-15.
3. Tong HL, Coiera E, Laranjo L. Using a Mobile Social Networking App to Promote Physical Activity: A Qualitative Study of Users' Perspectives. *J Med Internet Res* 2018;20(12):e11439.

Supplement 8: eResults 1. List of articles excluded after full-text review for not meeting inclusion criteria regarding the population, intervention, outcome or study design

Population:

1. Krein SL, Abdul-Wahab Y, Kadri R, Richardson CR. Adverse events experienced by participants in a back pain walking intervention: A descriptive study. Chronic illness. 2016;12(1):71-80.
2. Krein SL. Opioid use and walking among patients with chronic low back pain. Journal of Rehabilitation Research & Development. 2016;53(1).
3. Krein SL, Kadri R, Hughes M, Kerr EA, Piette JD, Holleman R, et al. Pedometer-based internet-mediated intervention for adults with chronic low back pain: randomized controlled trial. Journal of medical Internet research. 2013;15(8).
4. Krein SL, Metreger T, Kadri R, Hughes M, Kerr EA, Piette JD, et al. Veterans walk to beat back pain: study rationale, design and protocol of a randomized trial of a pedometer-based internet mediated intervention for patients with chronic low back pain. BMC musculoskeletal disorders. 2010;11(1):205.
5. Neil Thomas G, Macfarlane DJ, Guo B, Cheung BM, McGhee SM, Chou K-L, et al. Health promotion in older Chinese: A 12-month cluster randomized controlled trial of pedometry and peer support. Medicine and science in sports and exercise. 2012.
6. Richardson CR, Buis LR, Janney AW, Goodrich DE, Sen A, Hess ML, et al. An online community improves adherence in an internet-mediated walking program. Part 1: results of a randomized controlled trial. Journal of medical Internet research. 2010;12(4).
7. Ma J, Yank V, Lv N, Goldhaber-Fiebert JD, Lewis MA, Kramer MK, et al. Research aimed at improving both mood and weight (RAINBOW) in primary care: A type 1 hybrid design randomized controlled trial. Contemporary clinical trials. 2015;43:260-78.
8. Garcia-Ortiz L, Recio-Rodriguez JI, Agudo-Conde C, Patino-Alonso MC, Maderuelo-Fernandez JA, Gento IR, Puig EP, Gonzalez-Viejo N, Arietaleanizbeaskoa MS, Schmolling-Guinovart Y, Gomez-Marcos MA. Long-term effectiveness of a smartphone app for improving healthy lifestyles in general population in primary care: randomized controlled trial (Evident II study). JMIR mHealth and uHealth. 2018;6(4):e107.
9. Direito A, Jiang Y, Whittaker R, Maddison R. Apps for IMproving FITness and increasing physical activity among young people: the AIMFIT pragmatic randomized controlled trial. Journal of medical Internet research. 2015;17(8):e210.

Intervention:

10. Forman EM, Shaw JA, Goldstein SP, Butryn ML, Martin LM, Meiran N, et al. Mindful decision making and inhibitory control training as complementary means to decrease snack consumption. Appetite. 2016;103:176-83.
11. Kerr DA, Harray AJ, Pollard CM, Dhaliwal SS, Delp EJ, Howat PA, et al. The connecting health and technology study: a 6-month randomized controlled trial to improve nutrition behaviours using a mobile food record and text messaging support in young adults. International Journal of Behavioral Nutrition and Physical Activity. 2016;13(1):52.
12. Nishiwaki M, Kuriyama A, Ikegami Y, Nakashima N, Matsumoto N. A pilot crossover study: effects of an intervention using an activity monitor with computerized game functions on physical activity and body composition. Journal of physiological anthropology. 2014;33(1):35.
13. Naimark JS, Madar Z, Shahar DR. The impact of a Web-based app (eBalance) in promoting healthy lifestyles: randomized controlled trial. Journal of medical Internet research. 2015;17(3).
14. Vitamin K. Patient-oriented evidence that matters. Fam Med. 2008;6(1):69-77.
15. Adams MA, Sallis JF, Norman GJ, Hovell MF, Hekler EB, Perata E. An adaptive physical activity intervention for overweight adults: a randomized controlled trial. PloS one. 2013;8(12):e82901.

16. Aittasalo M, Miilunpalo S, Kukkonen-Harjula K, Pasanen M. A randomized intervention of physical activity promotion and patient self-monitoring in primary health care. Preventive Medicine. 2006;42(1):40-6.

17. Aittasalo M, Rinne M, Pasanen M, Kukkonen-Harjula K, Vasankari T. Promoting walking among office employees—evaluation of a randomized controlled intervention with pedometers and e-mail messages. BMC Public Health. 2012;12(1):403.

18. Andrade LF, Barry D, Litt MD, Petry NM. Maintaining high activity levels in sedentary adults with a reinforcement-thinning schedule. Journal of applied behavior analysis. 2014;47(3):523-36.

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Study design:

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Supplement 9: eTable 2. Kappa score for pairs of investigators in title and abstract screening and full-text screening

Cohen's kappa	Title and abstract screening	Full-text screening
Group 1	0.56 (n=5548)	0.89 (n=113)
Group 2	0.59 (n=1000)	0.82 (n=27)
Group 3	0.53 (n=1000)	0.73 (n=19)
Group 4	0.45 (n=1000)	0.51 (n=22)
Group 5	0.57 (n=1000)	0.5 (n=20)
Group 6	0.62 (n=1000)	-
Average kappa score	0.57	0.78

Supplement 10: eTable 3. Characteristics of studies not included in the meta-analysis

First author, year, country[a]	Self-monitoring mHealth[a]	Participants	N (I;C) [b]; N women	Study duration	Study arms description	Reason for exclusion from meta-analysis
Kitagawa, 2019, Japan	Jawbone UP (tracker+app)	Women, 20-50y	3-arm N 48 (16;16); 48	2 weeks	I: Tracker + app + tailored session; C: educational leaflet	Not enough data to calculate effect size[c]
Simons, 2018, Belgium	Tracker + app (Fitbit + Active Coach app)	Inactive; 18-30y; lower education	130 (60;70); 67	9 weeks	I: Fitbit tracker + Active Coach app; C: educational leaflet	Not enough data to calculate effect size[d]
Finkelstein, 2015, US	Tracker + app (Fitbit One)	Women; sedentary; BMI≥30	30	2 M	I: Fitbit + inactivity reminders (4 weeks); C: Fitbit alone (4 weeks)	Crossover design
Harries, 2016, UK	App (bActive)	Male adults	110 (55;55); 0 [3-arm N 165]	1.5 M	I: App + social and individual feedback; C: Blinded app	Not enough data to calculate effect size[e]
Rabbi, 2015, US	App (MyBehaviour)	18-60y	18 (9;8); 8	3 weeks	I: App with personalisation; C: App without personalisation	Not enough data to calculate effect size[f]
Koyle, 2013, US	App (Adidas miCoach)	Women; inactive[c]; 35-64y; employees	73 (36; 37); 73	1.5 M	I: App + SMS (tailored to promote self-efficacy) + walking plan + educational leaflets; C: App + walking plan + educational leaflets	Not enough data to calculate effect size[g]
Thompson, 2012, US	Tracker ("Gruve"; MUVE, Inc)	Physicians	20 (10;10); 3	8 M	Crossover trial; A: exercise counseling + accelerometer feedback + treadmill desk (12 weeks); B: accelerometer-only without feedback (12 weeks)	Crossover design

[a]Grouped by type of technology (tracker + app, app-only, tracker-only), from most to least recent year of publication (based on information provided by the authors and commercially available information for each tracker; interventions involving Fitbit, Jawbone and Polar M400 were considered to include tracker + application components even if the application was not mention by the authors, given their availability for download by participants from any app store for the setup of the tracker); [b] In studies with more than 2 arms, the intervention of interest and control groups were selected as per defined in the methods; [c]Author could not provide the p-value or confidence interval (CI) for the difference in the average daily number of steps after the intervention between control

and tailored feedback groups; [d]Author did not reply to our request to provide p-value (or CI) for the difference in steps post-intervention (9 weeks) between the 2 groups; [e]Author did not reply to our request to provide the average daily step count for the social + individual feedback group and for the control group at the end of the 6-week study (with CI or p-value); [f]Author did not reply to our request to provide the average daily walking minutes for the intervention and for the control groups at the end of the 3-week study (with CI or p-value); [g]Unable to contact author to provide p-value or CI for the difference in means. Abbreviations: App: smartphone application; C: control; I: intervention; M: months; SMS, Short Message Service; UK: United Kingdom; US: United States of America; y: years.

Supplement 11. eTable 4. Studies not included in the meta-analysis: Components and behaviour change techniques of intervention and control groups, as well as theories, incentives, and study retention rates

Author, year, country	Characteristics and BCTs of the intervention		Characteristics and BCTs of the control	Theories and models of behaviour change mentioned	Incentives to assessment compliance and study completion	Retention rates Intervention; Control N (%)
	"Smart" mHealth technology	Other components of the intervention				
Kitagawa, 2019, Japan	**Tracker + app (Jawbone UP)** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2, 2.3 The application displayed the number of steps, total physical activity time, longest activity time, longest prolonged sitting time, calorie consumption (total, active, inactive), and activity amount per time zone.]	**Tailored face-to-face session + educational leaflet** 2.2 Feedback on behaviour 4.1 Instruction on how to perform the behaviour 5.1 Information about health consequences -- [2.2, 4.1 advised the participants on effective methods for shortening sitting time specific to each participant's lifestyle; 5.1 same as control]	**Educational leaflet** 5.1 Information about health consequences -- [5.1 "pamphlet used graphs and pictures to show that long periods of sitting lead to mortality and lifestyle diseases, including diabetes, obesity, cardiovascular disease, and cancer"]	NR	NR	I: 16/16 (100); C: 16/16 (100)
Simons, 2018, Belgium	**Fitbit + Active Coach app** 1.1 Goal setting (behaviour) 1.2 Problem solving 1.5 Review behaviour goal 1.6 Discrepancy between current behaviour and goal 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 4.1 Instruction on how to perform the behaviour 7.1 Prompts/cues	**None**	**Educational leaflet** 4.1 Instruction on how to perform the behaviour -- [4.1 "tips about a physically active lifestyle"]	Attitude-social influence-self-efficacy model; Behavior Change Techniques	NR	I: 55/60 (92); C: 63/70 (90)

Author, year, country	Characteristics and BCTs of the intervention		Characteristics and BCTs of the control	Theories and models of behaviour change mentioned	Incentives to assessment compliance and study completion	Retention rates Intervention; Control N (%)
	"Smart" mHealth technology	**Other components of the intervention**				
	8.7 Graded tasks **--** [1.1, 8.7 "a personal goal dependent on the baseline level of the chosen behaviour (overall physical activity or active transport) was set by the app for the following week"; 1.2 "users were asked why they did not achieve their goal to determine their perceived barriers"; 1.5 "If they achieved their goal, they could increase it or maintain the same goal for the next week"; 1.6, 7.1 "Every day during the following 8 weeks, users received a notification on whether or not they had achieved their daily goal"; 4.1 "notification with a practical tip"]					
Finkelstein, 2015, US	**Fitbit** 2.3. Self-monitoring of behaviour -- 2.3 "For inactivity monitoring we employed a physical activity tracking device (Fitbit)"	**Android smartphone with digital data plan** 2.2. Feedback on behaviour 3. Social support 7.1. Prompts/cues -- [2.2. "allowed to see all the measurements of	**In "control" periods, participants are under the same conditions, but do not receive the messages** 2.3. Self-monitoring of behaviour 2.2. Feedback on behaviour	-	NR	27/30 (total; retention rates per arm not reported)

Author, year, country	Characteristics and BCTs of the intervention		Characteristics and BCTs of the control	Theories and models of behaviour change mentioned	Incentives to assessment compliance and study completion	Retention rates Intervention; Control N (%)
	"Smart" mHealth technology	Other components of the intervention				
		activity that are routinely captured and displayed by the commercial Fitbit website"; 3. "Text tailored motivational message"; 7.1 "checks to see if there have been less than 15 steps in the past hour (...) [and] it will send a tailored text message to the user's phone informing that sedentary period exceeded healthy limits, and encourages the user to take a break from the sedentary position"]				
Harries, 2016, UK	bActive app 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 6.2. Social comparison 2.2 "feedback on the participant's own steps"; 2.3 (app measures activity continually); 6.2 "average steps taken by others in their group"	Automated emails + weekly SMS 1.1 Goal setting (behaviour) 7.1 Prompts/cues 1.1 "self-generated, informal targets"; 7.1 "weekly messages to encourage them to walk more"	Disabled bActive app (no data; monitoring purposes-only) + SMS every 2 weeks to remind participants to carry their phone	NR	Mobile phone provided at beginning of the study could be kept at the end	I: 50/55 (91); C: 49/55 (89)
Rabbi, 2015, US	**MyBehaviour app** 2.2 Feedback on behaviour	None	**MyBehaviour app** 2.2 Feedback on behaviour	Learning theory, social	NR	I: 9/9 (100); C: 8/8 (100)

Author, year, country	Characteristics and BCTs of the intervention		Characteristics and BCTs of the control	Theories and models of behaviour change mentioned	Incentives to assessment compliance and study completion	Retention rates Intervention; Control N (%)
	"Smart" mHealth technology	Other components of the intervention				
	2.3 Self-monitoring of behaviour 4.1 Instruction on how to perform the behaviour 7.1 Prompts/cues 8.1 Behavioural practice/rehearsal 8.3 Habit formation -- [2.2 Figure 4 "Nearly 7 hours sedentary everyday"; 2.3 "MyBehavior uses the accelerometer and the Global Positioning System (GPS) sensor inside the mobile phone to continuously keep track of an individual's physical activities"; 4.1 "personalised context-sensitive suggestions", "suggestions that encourage the user to either continue positive activities (ie,walking, or exercise), make small changes in some situations (ie, stationary activities)"; 7.1 "MyBehavior suggests (ie, cues or triggers) a frequent behaviour"; 8.1, 8.3 "MyBehavior suggests (ie, cues or triggers) a frequent		2.3 Self-monitoring of behaviour 4.1 Instruction on how to perform the behaviour 7.1 Prompts/cues -- [2.2, 2.3, 7.1 Same as intervention; 4.1 "generic prescriptive recommendations"]	cognitive theory, the Fogg Behavior Model		

Author, year, country	Characteristics and BCTs of the intervention		Characteristics and BCTs of the control	Theories and models of behaviour change mentioned	Incentives to assessment compliance and study completion	Retention rates Intervention; Control N (%)
	"Smart" mHealth technology	Other components of the intervention				
	behaviour (eg, a particular walk) that the person often does in a particular life context. This small, low-effort change simply increases the frequency of a behaviour that the person already does."]					
Koyle, 2013, US	**App (Adidas miCoach)** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2, 2.3 Same as control]	**Weekly SMS + walking plan + education** 1.1 Goal setting (behaviour) 2.2 Feedback on behaviour 4.1 Instruction on how to perform the behaviour 15.1 Verbal persuasion about capability -- [1.1 Same as control; 2.2 text messages: "your overall pacing is steadily increasing"; 15.1 "The messages were individually tailored based upon the participant's walking logs for the previous week(s). An example of a message is, "Holly, your overall pacing is steadily increasing," and "Stacey, great pacing on	**App (Adidas miCoach) + walking plan + education** 1.1 Goal setting (behaviour) 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 4.1 Instruction on how to perform the behaviour -- [1.1 "aiming for at least 30 minutes walking per day"; 2.2, 2.3 "Walking distance and duration logs. These logs were collected by the smartphone exercise app (using the accelerometer feature of the smartphone) each time a walking for exercise activity was initiated."; 4.1 walking plan]	Social Cognitive Theory (Self-efficacy)	Those who completed the study had their names added to a drawing for one of five $50 gift-cards of their choice as well as all receiving a pair of athletic-style elastic shoelaces.	I: 30/36 (83); C: 33/37 (89)

Author, year, country	Characteristics and BCTs of the intervention		Characteristics and BCTs of the control	Theories and models of behaviour change mentioned	Incentives to assessment compliance and study completion	Retention rates Intervention; Control N (%)
	"Smart" mHealth technology	**Other components of the intervention**				
		your walk."]				
Thompson, 2012, US	**Tracker (Gruve)** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2. 2.3 "Feedback about activity was provided by the accelerometer"]	**20-min weekly exercise counselling session** + treadmill desk + website 4.1. Instruction on how to perform behaviour 12.5 Adding objects to the environment -- [4.1 "20 minute weekly counseling sessions on how to increase physical activity"; 12.5 treadmill"]	**Tracker without feedback** 2.3 Self-monitoring of behaviour	NR	NR	I: 8/10; C: 9/10

Abbreviations: App: smartphone application; BCT: behaviour change techniques; C: control; I: intervention; NR: not reported; SMS, Short Message Service; UK: United Kingdom; US: United States of America.

Supplement 12: eTable 5. Risk of bias of studies not included in the meta-analysis

Author, year, country	Random sequence allocation[a]	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting[b]
Kitagawa, 2019, Japan	High	Unclear	High	Low	Low	Unclear
Simons, 2018, Belgium	Unclear	Unclear	High	Low	Low	High
Finkelstein, 2015, US	Unclear	Unclear	High	Low	Unclear	Unclear
Harries, 2016, UK	High	Unclear	Unclear	Low	Low	Unclear
Rabbi, 2015, US	Unclear	Unclear	High	Low	Low	Low
Koyle, 2013, US	Low	Unclear	High	Unclear	Unclear	Unclear
Thompson, 2012, US	Unclear	Unclear	High	Low	High	Unclear

Legend: Low risk of bias; High risk of bias; Unclear risk of bias. [a]High: no random component or, in the case of trials with small sample sizes (N<50 per arm), when there are clear imbalances in baseline characteristics between groups; [b]Unclear: when a registered protocol was not found; High: in multiple-arm trials when the authors did not pre-specify which arm was considered superior and which was considered the "control". Abbreviations: UK: United Kingdom; US: United States of America.

Supplement 13: eTable 6. Risk of bias of studies included in the meta-analysis

Author, year	Random sequence allocation[a]	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment[b]	Incomplete outcome data	Selective reporting[c]
Wyke, 2019	Low	Low	High	Low	Low	Low
Donoghue, 2018	Unclear	Unclear	High	High	Low	Low
Pope, 2018	Low	Unclear	High	Low	Low	Low
Vandelanotte, 2018	Low	Unclear	High	High	High	Low
Ashton, 2017	Low	Low	High	Low	Low	Low
Brakenridge, 2016	Low	Unclear	High	Low	Low	Low
Finkelstein, 2016	Low	Low	High	Low	Low	Low
Poirier, 2016	Low	Unclear	High	Low	Low	Low
Ashe, 2015	High	Low	High	Low	High	Low
Cadmus, 2015	Low	Unclear	High	Low	Low	Unclear
Martin S, 2015	High	Low	High	Low	Low	Low
Thorndike, 2014	Low	High	High	Low	Low	Low
Patel, 2019	Low	Unclear	High	Low	Low	Low
Ellingson, 2019	Unclear	Unclear	High	Low	Unclear	Unclear
Zhang, 2019	Low	Unclear	Low	Low	Low	Low
Patel, 2018	Low	Unclear	High	Low	Low	Low
Robinson, 2018	High	Unclear	Low	Low	Low	Unclear
Fanning, 2017	High	Unclear	High	Low	Low	Low
Patel, 2017	Low	Low	High	Low	Low	Low
John, 2016	Unclear	Unclear	Unclear	Low	Low	Unclear
King, 2016	Low	Low	High	Low	Low	High

Author, year	Random sequence allocation[a]	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment[b]	Incomplete outcome data	Selective reporting[c]
Melton, 2016	Low	Unclear	High	Low	Low	Unclear
Patel, 2016 I	Low	Unclear	High	Low	Low	Low
Patel, 2016 II	Low	Unclear	High	Low	Low	Low
Walsh, 2016	High	Unclear	High	Low	Low	Unclear
Cowdery, 2015	Low	Unclear	High	High	Low	Unclear
Wang, 2015	Low	Low	High	Low	Low	Low
Glynn, 2014	Low	Low	High	Low	Low	Low

Legend: Low risk of bias; High risk of bias; Unclear risk of bias [a]High: no random component or, in the case of trials with small sample sizes (N<50 per arm), when there were clear imbalances in baseline characteristics between groups; [b]Outcome-related domains were assessed considering the outcomes mentioned in Table 1; [c]Unclear: when a registered protocol was not found; High: in multiple-arm trials when the authors did not pre-specify which arm was considered superior and which was considered the "control".

Supplement 14: eTable 7. Conflict of interests, funding sources, and adherence to reporting guidelines in included studies

Author, year	Conflict of interest declaration	Funding	Adherence to reporting guidelines
Wyke, 2019	AM is a paid statistical advisor for PLOS Medicine. AM's institution received funding from the European Union FP7 funding programme, covering salaries of staff within the Robertson Centre for Biostatistics who provided statistical and data management support to the study. DJM and DWL work for PAL Technologies Ltd., a manufacturer of the activPAL and SitFIT, and a partner in EuroFIT.	This project has received funding from the European Union's Seventh Framework Program for research, technological development, and demonstration under grant agreement number 602170. The Health Services Research Unit, University of Aberdeen, receives core funding from the Chief Scientist Office of the Scottish Government Health Directorates.	NR
Donoghue, 2018	The authors have no professional relationships with companies or manufacturers who will benefit from the results of the present study.	This project was funded by an in-house New York Institute of Technology College of Osteopathic Medicine grant.	NR
Pope, 2018	NR	NR	CONSORT
Vandelanotte, 2018	None declared.	The study was funded through a Central Queensland University infrastructure grant and through support funds as part of a National Heart Foundation of Australia Future Leader Fellowship (ID 100427). CV (ID 100427), MJD (ID 100029), and SS (ID 101240) were supported by National Heart Foundation of Australia Fellowships. CAM (ID 1125913), ALR (ID 1105926), SS (ID GNT1125586), and CES (ID 1090517) were supported by National Health and Medical Research Council Fellowships. Study and fellowship funders had no role in any part of this study.	CONSORT-EHEALTH
Ashton, 2017	The authors declare that they have no competing interests.	The research was funded by a project grant from the Hunter Medical Research Institute (HMRI) (14–30). HMRI did not have any influence on the performance of the trial, analysis of the data, writing, or the publication of the results. CEC is supported by an NHMRC Senior Research Fellowship.	CONSORT
Brakenridge, 2016	None declared.	This work is supported by a Vanguard Grant (Award ID: 100216) from the National Heart	CONSORT

Author, year	Conflict of interest declaration	Funding	Adherence to reporting guidelines
		Foundation of Australia. The authors would also like to acknowledge Lendlease for providing additional support for this work and for the Office Ergonomics Research Committee (OERC) for providing funding to conduct the 12-month follow-up. The National Health and Medical Research Council (NHMRC) of Australia through a Centre of Research Excellence Grant (#1057608) to GNH and DWD, provides salary support to EAHW, and a top up scholarship to CLB. CLB is also supported by an Australian Postgraduate Award. DWD is supported by an NHMRC Senior Research Fellowship (#1078360). LMS is supported by an NHMRC Australia Senior Research Fellowship (#1019980). GNH is supported by a Heart Foundation Postdoctoral Fellowship (#PH 12B 7054) and NHMRC Career Development Fellowship (#108029).	
Finkelstein, 2016	We declare no competing interests.	This study was supported by a Health Services Research Competitive Research Grant (HSRG/0022/2012) from the Ministry of Health, Singapore. The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.	NR
Poirier, 2016	JP and NC are full-time employees of MeYou Health and own stock in Healthways Inc, the parent company of MeYou Health. WB, ML, GJ, H-CY, JC, and NS are faculty or employees of the Johns Hopkins University and were paid through an institutional consulting agreement with Healthways for work in designing the study and analyzing the data.	We thank Human Resources at Healthways and the MeYou Health Walkadoo team. The work was fully funded by MeYou Health LLC.	NR
Ashe, 2015	The authors declare that they have no competing interests.	We also acknowledge Canadian Institutes of Health Research (CIHR) for operation funds for this	NR

Author, year	Conflict of interest declaration	Funding	Adherence to reporting guidelines
		project (funding reference number AAM-108607). We acknowledge career award support for Dr. Ashe and Dr. Sims-Gould from CIHR (New Investigator Award) and the Michael Smith Foundation for Health Research (MSFHR) Scholar Award. Dr. Hoppmann is supported by career awards from MSFHR and the Canada Research Chairs Program. Dr. Gardiner is supported by an Australian National Health and Medical Research Council Centre of Research Excellence (Grant No. 1000986). Dr. Giangregorio is the recipient of a CIHR New Investigator Award and an Early Researcher Award from the Ontario Ministry of Research and Innovation. The sponsor had no role in the study design; collection, analysis, and interpretation of data; writing the report; and the decision to submit the report for publication.	
Cadmus-Bertram, 2015	The authors have no conflicts of interest to report.	This study was funded by NIH (1R03CA168450) and recruitment supported by the Athena Breast Health Network. This research was supported by the National Cancer Institute (1R03CA168450).	NR
Martin, 2015	Digital physical activity tracking devices were provided in kind by Fitbug, a private for-profit company. This trial was investigator initiated and Fitbug did not provide cash payments for the research or writing of the manuscript. Fitbug did not participate in the analysis of the data or influence the conclusions.	This trial was funded, in part, by an unrestricted grant to Blaha from the PJ Schafer Cardiovascular Research Fund, a 501(c) (3) nonprofit organization. Martin was supported by a National Institutes of Health training grant (T32HL07024) for which Coresh served as the PI. Martin received additional support from the Pollin Cardiovascular Prevention Fellowship and the Marie-Josee and Henry R Kravis Endowed Fellowship. Furthermore, Martin received a modest monetary award in conjunction with the Howard C. Silverman prize for originality and creativity in medical research, which was awarded by the Johns Hopkins Division of Cardiology based on the preliminary design of the mActive trial. He also received a modest monetary award from the	CONSORT-EHEALTH

Author, year	Conflict of interest declaration	Funding	Adherence to reporting guidelines
		American Heart Association's Council on Lifestyle and Cardiometabolic Health with the Steven N. Blair Award for Excellence in Physical Activity Research. Long-term follow-up of mActive trial participants is being supported by the Aetna Foundation. Blumenthal was supported by the Kenneth Jay Pollin Professorship in Cardiology.	
Thorndike, 2014	The authors have declared that no competing interests exist.	Dr. Thorndike is supported by the grant K23 HL93221 from the National Institutes of Health/National Heart Lung and Blood Institute. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.	CONSORT
Patel, 2019	Dr Patel reported receiving personal fees as the owner of Catalyst Health LLC, stock options from LifeVest Health, personal fees and stock options from HealthMine, Inc, personal fees from Holistic Industries, and personal fees from Deloitte Consulting LLP outside the submitted work. Dr Reh reported receiving personal fees from Deloitte Consulting LLP during the conduct of the study and outside the submitted work and having a patent planned outside the submitted work. Dr Szwartz reported being employed by Deloitte Consulting LLP. Dr Guszcza reported receiving personal fees from Deloitte Consulting LLP during the conduct of the study and outside the submitted work. Dr Steier reported receiving personal fees from Deloitte Consulting LLP during the conduct of the study and outside the submitted work and having a patent planned outside the submitted work. Dr Kalra reported receiving personal fees from Deloitte Consulting LLP during the conduct of the study and outside the submitted work. No	This study was supported by Deloitte Consulting LLP and the University of Pennsylvania Health System through the Penn Medicine Nudge Unit (Dr Patel).	NR

Author, year	Conflict of interest declaration	Funding	Adherence to reporting guidelines
	other disclosures were reported.		
Ellingson, 2019	None declared.	NR	NR
Zhang, 2019	The authors declare that they have no conflict of interest.	NR	NR
Patel, 2018	The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Dr. Patel is supported by career development awards from the Department of Veterans Affairs HSR&D and the Doris Duke Charitable Foundation. Dr. Patel is also founder of Catalyst Health, a technology and behavior change consulting firm. Dr. Patel also has received research funding from Deloitte, which is not related to the work described in this manuscript. Dr. Volpp and Dr. Asch are principals at VAL Health, a behavioral economics consulting firm. Dr. Volpp also has received consulting income from CVS Caremark and research funding from Humana, CVS Caremark, Discovery (South Africa), Hawaii Medical Services Association, Oscar, and Merck, none of which are related to the work described in this manuscript.	The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was funded by the National Institute on Aging (RC4 AG039114) to Drs. Asch and Volpp.	NR
Robinson, 2018	The authors have no conflict of interest and no financial interest or benefit.	This work was supported by the National Institutes of Aging under Grants P30 AG048785 and 5T32AG000204.	NR
Fanning, 2017	Jason Fanning, Sarah Roberts, Charles H. Hillman, Sean P. Mullen, Lee Ritterband, and Edward McAuley declares that they have no conflict of interest.	NR	NR
Patel, 2017	Dr Patel reported being supported by career development awards from the Department of Veterans Affairs Health Services Research and Development Service and the Doris Duke Charitable Foundation and reported being a principal at Catalyst Health, a technology and behavior change consulting firm. Dr	This study was funded by grants 1R01HL128914, 2R01HL092577, and P30AG034546 from the National Heart, Lung, and Blood Institute Division of Intramural Research. The Framingham Heart Study is funded by contracts N01-HC-25195 and HHSN268201500001I from the National Institutes of Health.	NR

Author, year	Conflict of interest declaration	Funding	Adherence to reporting guidelines
	Volpp reported being a principal at VAL Health, a behavioral economics consulting firm, and reported receiving consulting income from CVS Caremark and research funding from Humana, CVS Caremark, Discovery (South Africa), Hawaii Medical Services Association, and Merck, none of which are related to the work described in this article. Dr Fox reported becoming an employee of Merck Research Laboratories in December 2015. No other disclosures were reported.		
John, 2016	NR	NR	NR
King, 2016	The authors have declared that no competing interests exist.	This work was supported by US Public Health Service grant #RC1 HL099340 from the National Heart, Lung, & Blood Institute of the National Institutes of Health (NIH) awarded to Dr. King; US Public Health Service Grant 1U54EB020405 supporting The National Center for Mobility Data Integration and Insight; and US Public Health Service grant #5T32L007034 from the National Heart, Lung, & Blood Institute. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.	CONSORT
Melton, 2016	The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.	The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Office Research and Sponsored Services at Georgia Southern University which provided seed funding for this project (H13451).	NR
Patel, 2016 I	Dr. Volpp and Dr. Asch are principals at the behavioral economics consulting firm, VAL Health. Dr. Volpp also has received consulting income from CVS Caremark and research funding from Humana, CVS Caremark, Discovery (South Africa), and Merck, none of which are related to the work described in this manuscript. The authors declare no other conflicts of	This work was funded by the National Institute on Aging (RC4 AG039114) to Drs. Asch and Volpp. Drs. Patel, Asch and Volpp were supported in part by the Department of Veteran Affairs and Drs. Patel and Asch were supported in part by the Robert Wood Johnson Foundation. The funding sources had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; and	NR

Author, year	Conflict of interest declaration	Funding	Adherence to reporting guidelines
	interest.	preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication. Dr. Patel had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.	
Patel, 2016 II	The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.	The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was funded by the National Institute on Aging (RC4 AG039114) to Drs Asch and Volpp. Dr Patel was supported in part by the Department of Veteran Affairs and the Robert Wood Johnson Foundation. Dr. Volpp also has received consulting income from CVS Caremark and research funding from Humana, CVS Caremark, Discovery (South Africa), and Merck, none of which are related to the work described in this manuscript.	NR
Walsh, 2016	None declared.	NR	NR
Cowdery, 2015	NR	NR	NR
Wang, 2015	No competing financial interests exist.	This research was supported by a gift from the Carol Vassiliadis family and in part by grant CA-113710 from the National Cancer Institute.	NR
Glynn, 2014	The authors have declared no competing interests.	Funding was awarded by the European Union's Northern Periphery Programme 2007–2013, through the Implementing Transnational Telemedicine Solutions project (reference number: 7.13). The funder had no role in: the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.	CONSORT

Abbreviations: CONSORT: Consolidated Standards of Reporting Trials; NR: not reported

Supplement 15: eTable 8. Information about outcomes from each study included in the meta-analysis

First author, year[a]	Outcome included in meta-analysis	Outcome measurement [a]
Wyke, 2019	Daily step count *	Accelerometer (ActivPal)
Donoghue, 2018	Weekly days exercised[b]	Self-reported
Pope, 2018	Daily step count*	Accelerometer (ActiGraph)
Vandelanotte, 2018	Total physical activity (min/week) *	Survey (8-item Active Australia Survey)
Ashton, 2017	Daily step count *	Pedometer (Yamax digiwalker)
Brakenridge, 2016	Daily step count[c]	Accelerometer (ActivPal)
Finkelstein, 2016	MVPA (bout min/week) *	Accelerometer (ActiGraph)
Poirier, 2016	Daily step count *	Tracker (Pebble+)
Ashe, 2015	Daily step count[d]	Accelerometer (ActiGraph)
Cadmus-Bertram, 2015	MVPA (min/week) *	Accelerometer (ActiGraph)
Martin, 2015	Daily step count *	Tracker (Fitbug)
Thorndike, 2014	Daily step count *	Tracker (Fitbit)
Patel, 2019	Daily step count *	Tracker (Withings Activité Steel)
Ellingson, 2019	Daily step count *	Accelerometer (ActiGraph)
Zhang, 2019	Daily step count[e]	Tracker (Fitbit)
Patel, 2018	Daily step count[f]	App (Moves)
Robinson, 2018	Daily step count *	Tracker (Fitbit)
Fanning, 2017	MVPA (min/week) *	Accelerometer (ActiGraph)
Patel, 2017	Daily step count[g]	App (Moves) and tracker (Fitbit)
John, 2016	Daily step count *	Tracker (Fitbit)
King, 2016	MVPA (min/week) *	Study app
Melton, 2016	Daily step count *	Accelerometer (ActiGraph)
Patel, 2016 I	Daily step count[f]	App (Moves)
Patel, 2016 II	Daily step count[f]	App (Moves)
Walsh, 2016	Daily step count *	App (Accupedo-Pro)
Cowdery, 2015	MET (/week) *	Survey (IPAQ 7-item)
Wang, 2015	Daily step count *	Accelerometer (ActiGraph)
Glynn, 2014	Daily step count *	App (Accupedo-Pro)

[a]Accelerometers and pedometers (research-grade devices) are distinguished from trackers because the latter are consumer-grade devices; [b]Not possible to use the primary outcome—daily step count—because it was not measured in the control group; [c]The primary outcome was average time per day spent sitting during work hours and overall—for consistency with outcomes extracted from other studies we included daily step count in the meta-analysis; [d]The authors defined their primary outcome as "recruitment and retention rates"; [e]The primary outcome was "meeting the goal of engaging in at least 90 min/day of light physical activity during the 3-month study period"—for consistency we included daily step count in the meta-analysis instead of the odds ratio for the primary outcome; [f]The primary outcome was the "mean proportion of participant-days that the 7000-step goal was achieved during the intervention period"— for consistency we included daily step count in the meta-analysis; [g] The primary outcome was the "proportion of participant-days that step goals were achieved during the intervention period"— for consistency we included daily step count in the meta-analysis. * indicates primary outcomes. Abbreviations: App: smartphone application; AQuAA: Activity questionnaire for adolescents and adults; h: hours; IPAQ: International Physical Activity Questionnaire; min: minutes; MET: metabolic equivalent; MVPA: moderate to vigorous physical activity; SLIPA: Sedentary and Light Intensity Physical Activity Log. MVPA bouts are defined as the total number of minutes during each one-week assessment period in which moderate or vigorous activity of at least eight of 10 consecutive minutes are reached.

Supplement 16: eTable 9. Engagement with the intervention and retention rates in included studies

Author, year	Engagement with the intervention (article quotes)	Metrics	Retention rates N (%)
Wyke, 2019	"65.1% of intervention participants reported they used the SitFIT 'a great deal' (score 4 on a scale of 0–4) and 36.8% reported they used MatchFIT 'a great deal'"	-Self-reported usage score (scale of 0 to 4)	I: 492/560 (88); C: 508/553 (92)
Donoghue, 2018	"six participants were not compliant wearing the activity tracker (if they did not sync the tracker for over 1 month). It is worth noting that 18 (23%) of the activity Fitbits were lost throughout the study and were replaced by the institution conducting the study."	-Participants not syncing the tracker for over 1 month -Trackers lost	I: 35/40 (88); C: 40/40 (100)
Pope, 2018	"Combined, both groups demonstrated high adherence to Facebook-delivered health education intervention: 87.1 ± 21.9%. When stratified by group, it was found that the comparison group demonstrated lower adherence (84.4 ± 22.3%) to the health education intervention than the experimental group (89.8 ± 21.8%)."; "experimental group participants reported the Polar M400 to be "somewhat useful" to "useful" for assisting them in becoming more active and stated the smartwatch to be "somewhat easy" to use, with the most frequently reported positive and negative features of the device reported as the "exercise bar" on the main screen and the difficult smartphone syncing process, respectively."	-Adherence to Facebook-delivered education (combined measure using "likes" and "seen by") -User perspectives (Usefulness, ease-of-use, positive and negative features)	I: 16/19 (84); C: 19/19 (100)
Vandelanotte, 2018	"73.1 % participants said they "wore the Fitbit every day during the study."	-Self-reported daily usage (%)	I: 78/121 (64); C: 46/122 (38)
Ashton, 2017	"Jawbone™ wearable physical activity tracker and UP app: Data from the process evaluation questionnaire showed that most participants (95.8%, n = 23) reported using the Jawbone™ and UP app, and 58.3% (n = 14) reported meeting the recommended frequency of use (daily). Objective data from the Jawbone UP app was available for 21 of the 24 retained participants (log in details had been changed for three participants, so sign in was not possible to access data). Additionally, an error occurred within Jawbone, which meant that no data was recorded for the final 19 days of the intervention, hence data was only available for 65 out of the 84 days. Objective data for the 21 participants indicates that all of these participants used the Jawbone UP during the intervention. Step counts were uploaded for an average of 48 (SD 19) out of the available	-Any usage -Self-reported daily usage (%) -Average number of days with valid step counts -Facebook interaction (e.g. "likes")	I: 24/26 (92); C: 23/24 (96)

Author, year	Engagement with the intervention (article quotes)	Metrics	Retention rates N (%)
	65 days (range of 10–65 days/participant).”; “All participants (100%, n=24) joined the program Facebook group, with a total of 23 posts, including 22 posts by the moderator. There was an average of 20 views and 1.8 ‘likes’ per post. In total, 75% (n=18) reported meeting the recommended frequency of use (reading weekly Facebook posts).”		
Brakenridge, 2016	“LUMOback usage had ceased by 12 months in all study completers. Reasons for non-use included technical difficulties and having no time to set up.”; “Use of LUMOback at least once in first 3 months: n=43/61”; “18 participants did not uptake the LUMOback”; “Any use of LUMOback in study completers at 12 months: n=0/25”.	-Usage at least once in the first 3 months -Participants with no uptake -Study completers showing any use of LUMOback at 12 months	I: 68/87 (78); C: 41/66 (62)
Finkelstein, 2016	“By 6 months <65% of participants in the Fitbit group were still wearing the device at least once/week.”	-Participants using the tracker once/week at 6 months (%)	I: 186/203 (92); C: 189/201 (94)
Poirier, 2016	“Participants wore their activity tracker on 78.6% (33/42) of days and visited the website every 3.6 days on average (11.8/42 days).”	-Daily usage (%)	I: 107/133 (80); C: 110/132 (83)
Ashe, 2015	NR	NR	I: 12/13 (92); C: 8/12 (67)
Cadmus-Bertram, 2015	“Intervention participants reported using the tracker on 95% of study days”	-Self-reported daily usage (%)	I: 25/25 (100); C: 24/26 (92)
Martin S, 2015	“Daily activity data capture was 97.4%.”	-Daily usage (%)	I: 16/16 (100); C: 15/16 (94)
Thorndike, 2014	“Daily usage of the tracker: 77% in both groups”	-Daily usage (%)	I: 50/52 (96); C: 49/52 (94)
Patel, 2019	Missing data from the tracker in the control group was 28.8% and in the intervention (gamification with competition) was 18.8%.	-Missing data (%)	I: 143/150 (95); C: 150/151 (99)
Elingson, 2019	“Across the 12 weeks of the study, participants in both groups decreased the number of days/week the Fitbit was worn, with more notable declines in the final weeks (average 6.5 days/week in week 1 to average 4.5 days/week in week 12)”	-Average number of days/week the tracker was used	I: NR/45 (NR); C: NR/46 (NR)
Zhang, 2019	“The total percentage of participant days on which Fitbit tracked behavior data were missing during the 90-day intervention was 16%. The mean number of logins to the app per day during the 90-day study period was 2.4 (SD=4.4) in the intervention and 1.1 (SD=2.8) in the control condition.”	-Missing data (%) -Average number of app logins during study	I: 43/44 (98); C: 47/47 (100)
Patel, 2018	NR	NR	I: 136/144 (94);

Author, year	Engagement with the intervention (article quotes)	Metrics	Retention rates N (%)
			C: 60/65 (92)
Robinson, 2018	NR	NR	I: 29/31 (94); C: 30/32 (94)
Fanning, 2017	"The random linear effect for time was significant, indicating that use decreased across the intervention period. The fixed effect for the goal setting module was also significant, as was the fixed effect for the points module, indicating the addition of either module was related to higher levels of usage."	-Usage time -Modules used	I: 26/29 (89); C: 27/30 (90)
Patel, 2017	NR	NR	I: 98/102 (96); C: 102/104 (98)
John, 2016	The percentage of individuals with missing fitbit data on at least one day was 72.74% in the intervention and 69.16% in the control.	-Missing data (%)	I: 1027/1027 (100); C: 1028/1028 (100)
King, 2016	"During the study period, 91.3% of social app participants used the message board, with a total of 775 messages posted."	-Participants using the app message board (%)	I: 22/22 (100); C: 24/27 (89)
Melton, 2016	NR	NR	I: 17/28 (61); C: 33/41(80)
Patel, 2016 I	NR	NR	I: 78/80 (98); C: 64/68 (94)
Patel, 2016 II	NR	NR	I: 59/64 (92); C: 99/100 (99)
Walsh, 2016	NR	NR	I: 28/29 (97); C: 27/29 (93)
Cowdery, 2015	NR	NR	I: 20/20 (100); C: 19/20 (95)
Wang, 2015	"a greater proportion of comparison (versus intervention) participants reported that, on a typical day, they viewed their Fitbit trackers ''Very Often'' or ''Often'' for steps (90% versus 71%) and distance (70% versus 55%)."; "a common response among participants was that they had stopped reading them altogether when they noticed that the messages were ''automated.'' Other notable phrases were that the messages were ''inconvenient,'' ''annoying,'' and ''impersonal.''"	-Self-reported viewing of step counts in the tracker (Likert-type scale)	I: 31/33 (94); C: 30/34 (88)
Glynn, 2014	NR	NR	I: 37/45 (82); C: 40/45 (89)

Abbreviations: C: control; I: intervention; NR: not reported.

Supplement 17: eTable 10. Incentives for study compliance in included studies

Author, year	Incentives to study procedures compliance and study completion
Wyke, 2019	A club store voucher for the equivalent of €25 at post-programme and €75 at the 12-month measurements.
Donoghue, 2018	NR
Pope, 2018	Both groups received a $10 cash incentive after completion of each testing period (i.e., baseline testing and testing during the sixth and 12th weeks; $30 total).
Vandelanotte, 2018	Participants who complied with all study procedures received an $50 incentive for their participation; those in the Fitbit group were able to decline the incentive in exchange for keeping the Fitbit they received (informed about this option at the end of the study).
Ashton, 2017	Control participants received incentives for returning to the follow-up session (e.g. $10 voucher to cover travel expenses).
Brakenridge, 2016	NR
Finkelstein, 2016	Incentive to participants: 4$/week; 25$ supermarket voucher and a 1 in 10 chance of receiving a 50$ voucher for completing the 6-month assessment.
Poirier, 2016	All study participants were allowed to keep the activity tracker at the end of the study. Participants who completed follow-up also received a US $25 Amazon gift card.
Ashe, 2015	NR
Cadmus, 2015	Participants received $20 for study completion.
Martin S, 2015	NR
Thorndike, 2014	NR
Patel, 2019	All participants received $25 for enrolling in the trial, $50 for completing the 24-week intervention and surveys, and $50 for completing the 12-week follow-up and surveys.
Elingson, 2019	NR
Zhang, 2019	Participants received $15 at the baseline assessment, $35 at the 1-month assessment, $50 at the 3-month final assessment, and the Fitbit.
Patel, 2018	All participants received $25 for enrolling and $75 for completing the 13-week intervention period and a survey on their experience. There was no participation incentive for the 13-week follow-up period.
Robinson, 2018	Participants were given the Fitbit as compensation for their participation. If participants decided to stop participating in the study, or they decided they did not want to keep the Fitbit at the end, they received monetary compensation relative to their time in the study ($10 for pre-test assessment and $1 for each of the 35 study days, totalling to a possible $45 dollars).
Fanning, 2017	NR
Patel, 2017	Participants who received a wearable device were allowed to keep it; no other financial compensation was offered.
John, 2016	NR
King, 2016	Participants received a US $20 gift card for participating in the study.
Melton, 2016	Following the 6-week intervention, participants were given the Jawbone UP Band and encouraged to use the platform as an incentive for participation.
Patel, 2016 I	All participants received $25 for enrolling in the study and $75 for participating through the primary endpoint at 13 weeks.
Patel, 2016 II	NR
Walsh, 2016	NR
Cowdery, 2015	NR
Wang, 2015	NR
Glynn, 2014, UK	NR

Abbreviations: NR: not reported.

Supplement 18: eTable 11. Behaviour change techniques, theories, models, and constructs in included studies

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	Other components of the intervention		
Wyke, 2019	**Tracker (SitFIT) + App (MatchFIT)** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 3.1 Social support (unspecified) 6.2 Social comparison -- [2.2 "The SitFIT provided the wearer with feedback on their Physical Activity and Sedentary Behavior"; 2.3 "allow self-monitoring of sedentary and nonsedentary time, in addition to daily steps"; 3.1 "use of MatchFit as a means for participants to support one another"; 6.2 "MatchFIT allowed participants to contribute their weekly steps to their group's collective average step count and compare it with that of a virtual competitor team." MatchFIT also provided a "week by week summary of SitFIT data"] "the SitFIT was designed with a display to provide real-time visual feedback of stepping and sedentary/upright behaviors, a vibrotactile actuator to provide customisable haptic feedback of time spent sitting, and a Bluetooth SMART module to enable communication with external devices, such as smartphones, tablets, and PCs." DOI: 10.1249/MSS.0000000000001458	**12 weekly group training sessions (90 min) with coaches** 1.1 Goal setting 1.4 Action planning 1.5 Review behaviour goal(s) 1.7 Review outcome goal(s) 3 Social support 4.1 Instruction on how to perform the behaviour 5.1 Information about health consequences 5.6 Information about emotional consequences 8.1 Behavioural practice 8.7 Graded tasks 9.1 Credible sources 13.5 Identity associated with changed behaviour -- [1.1 "set weekly goals"; 1.4 "action planning"; 1.5, 1.7 "reviewing goals for behaviours and outcomes"; 3.1 "encouraging positive banter (…) promoting a 'team' environment"; 4.1 "tips to change diet or increase physical activity (…) Coaches taught participants to choose from a 'toolbox' of behaviour change techniques (including setting and reviewing goals for behaviours and	None	Behaviour Change Techniques, Self-Determination Theory, Achievement Goal Theory

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	Other components of the intervention		
		outcomes, action planning, self-monitoring, and information about health and emotional consequences of change) and to emphasise personally relevant benefits of behaviour change"; 5.1, 5.6 "information about health and emotional consequences of change"; 8.1 "graded group-based physical activity"; 8.7 "slowly increase the number of steps and time spent upright each week"; 9.1 "we developed detailed manuals for coaches and participants, and trained club coaches over 2 days to deliver programme content in an appropriate and accessible style"; 13.5 "support to change their behaviours that may challenge their masculine identities, but is not in conflict with them"]		
DiFranciso-Donoghue, 2018	**Arm: "Fitbit Plus" intervention**		None	NR
	Fitbit Flex tracker 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour [2.2, 2.3 Fitbit]	**Weekly emails + mentored weekly walk/runs** 1.1 Goal setting (behaviour) 2.2 Feedback on behaviour 6.2 Social comparison 8.1 Behaviour practice/rehearsal 8.2 Behaviour substitution		

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
		8.7 Graded tasks 12.1 Restructuring the physical environment -- [1.1 "The goal was to attain at least 10,000 steps daily"; 2.2 "feedback on step count"; 6.2 "These weekly emails provided feedback on group step count as a total compared with the other group."; 8.1 mentored weekly walk/runs; 8.2 "take the stairs in lieu of the elevators"; 8.7 "encourage and increase step count by 500 steps daily per week"; 12.1 "Participants were encouraged to park their cars as far as possible to add extra steps, and were urged to take the stairs in lieu of the elevators throughout the day."]		
Pope, 2018	**Tracker (Polar M400) + app** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.3 "track physical activity duration, steps per day, and energy expenditure."; "The Polar M400 can upload health metric data to an associated smartphone application (via bluetooth) and internet portal regarding the user's steps per day; time spent lying down, sitting, and standing; durations of moderate and vigorous physical activity; daily activity	**Twice weekly health education via Facebook group** 4.1 Instruction on how to perform the behaviour -- ["physical activity and nutritious eating health education tips"]	**Twice weekly health education via Facebook group** 4.1 Instruction on how to perform the behaviour -- ["physical activity and nutritious eating health education tips"]	Social cognitive theory, Self-determination theory

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	Other components of the intervention		
	time; energy expenditure; and sleep."]			
Vandelanotte, 2018	**Fitbit Flex tracker** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 10.3 Non-specific reward **--** [2.2, 2.3 Fitbit; 10.3 "1 LED illuminates for every 2000 steps taken"]	**Same as control** 1.1 Goal setting (behaviour) 1.2 Problem solving 1.4 Action planning 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 3.1 Social support (unspecified) 5.1 Information about health consequences	**Website (TaylorActive)** 1.1 Goal setting (behaviour) 1.2 Problem solving 1.4 Action planning 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 3.1 Social support (unspecified) 5.1 Information about health consequences -- [1.1, 1.2, 1.4, 2.3, 3.1 "training was provided on self-regulatory strategies to enhance the enactment of intentions into behaviour through effective goal-setting, action planning, use of social support, overcoming barriers, problem solving, decision making, relapse prevention, and self-monitoring"; 2.2 "On the basis of participant responses and using IF-THEN algorithms (eg, IF not meeting activity guideline, THEN provide advice to increase activity levels), relevant feedback is selected from a large database with all possible response options"; 5.1	Theory of Planned Behaviour, Self-determination theory, Social cognitive theory

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	Other components of the intervention		
			"Participants in both groups also had access to a Library with generic educational information about physical activity; a total of 19 brief articles were available about different aspects of physical activity and what to do to increase physical activity levels (eg, "Are you physically fit?," "Getting motivated," and "Making time to be active")."]	
Ashton, 2017	**Jawbone wearable tracker + app** 1.1 Goal setting (behaviour) 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [1.1 "goal setting"; 2.2 Jawbone app; 2.3 "self-monitoring of key health behaviours"]	**Private Facebook discussion group + website + 1-hour weekly face-to-face sessions with researchers (11 group-based + 1 individual) + gymstick resistance band + TEMPlate Dinner disc** 1.2 Problem solving 1.5 Review behaviour goal(s) 2.2 Feedback on behaviour 3.1 Social support (unspecified) 4.1 Instruction on how to perform the behaviour 6.1 Demonstration of the behaviour 8.1 Behaviour practice/rehearsal 8.3 Habit formation 9.1 Credible source 12.5 Adding objects to the environment -- [1.2 "problem solving strategies to	None	Social Cognitive Theory, Self Determination Theory

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	Other components of the intervention		
		address key issues apparent in young men"; 1.5, 2.2 "personalized feedback from a food and nutrient report (…), and from the Jawbone physical activity data. From this, personal tailored goals were set."; 3.1 "facilitate social support"; 4.1 "a 'resource library' housing relevant information and resources, including fact sheets from best practice guidelines, […] and recommended mobile applications for improving eating habits, physical activity, reducing alcohol intake or coping with stress"; 6.1 "support videos (e.g. short cooking videos and demonstration of Gymstick™ exercises)"; 8.1 "practical exercise activities focusing on aerobic (e.g., team based recreational games) and strength exercises (e.g., High Intensity Interval Training)"; 8.3 "Group based sessions took place on Thursday evenings (18:00–19:00 pm)"; 9.1. "Sessions were delivered by two male researchers from the same age demographic (one was a qualified P.E. teacher, undertaking a PhD in Education and the other was a PhD candidate in Nutrition and Dietetics)"; 12.5 "A Gymstick™ resistance band, for home-based		

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	Other components of the intervention		
		strength training"]		
Brakenridge, 2016	**LUMOback (tracker + app)** 2.3 Self-monitoring of behaviour 2.2. Feedback on behaviour -- [2.2, 2.3 "which provided feedback on sitting, standing, stepping, sitting breaks, posture and sleep"; "The LUMOback assesses activity by inertial sensors, which collect data at a constant 25 Hz, and is controlled through a mobile app via a Bluetooth connection that can be used by both iPhone operating system and Android platforms."]	**Same as control group**	**Educational booklet + emails + workplace champion** 2.2 Feedback on behaviour 4.1 Instruction on how to perform the behaviour 5.1 Information about health consequences 6.3 Information about others approval 7.1. Prompts/cues -- [2.2 "email that had a preliminary summary of the averaged activity monitor data from the baseline assessment"; 4.1 "Recommendations and tips to 'Stand Up, Sit Less and Move More"; 5.1 "booklet contained background information on sitting and health implications"; 6.3 "To visibly demonstrate support for the program and its messages, senior executives took part in the baseline assessment and received the five emails. Their participation in the study was communicated to participants by the champion." 7.1 emails]	NR

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	Other components of the intervention		
Finkelstein, 2016	**Arm: Fitbit tracker (without charity or cash incentives)**		**Educational booklets** 4.1 Instruction on how to perform the behaviour 5.1. Information about health consequences 9.1 Credible source -- [4.1, 5.1 "benefits of and strategies for increasing physical activity"; 9.1 "educational booklets, published by the Singapore Health Promotion Board"]	Economic theory, Theory of reasoned action
	Fitbit zip tracker 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2, 2.3 Fitbit]	**Fitbit website + control group** 1.1 Goal-setting (behaviour) 3.1 Social support 4.1 Instruction on how to perform the behaviour 5.1. Information about health consequences 6.2 Social comparison 9.1 Credible source 10.3 Non-specific reward -- [1.1 "the website allows participants to set step goals for themselves"; 3. "Motivating messages"; 4.1, 5.1, 9.1 Same as control; 6.2 "Competitions"; 10.3 "Badges]		
Poirier, 2016	**Tracker Pebble + (Fitlinxx Inc)** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2, 2.3 "Follow their progress through their activity tracker"; the pebble display indicates progress towards daily goal; "Walkadoo is a freely available, open access, Internet-based program that pairs with a range of activity trackers to increase walking behavior. Activity trackers wirelessly and automatically send data to the program (or a smartphone app)	**Website with SNS (Walkadoo) + daily emails + SMS** 1.1 Goal setting 2.2 Feedback on behaviour 3.1 Social support 6.2. Social comparison 7.1 Prompts/cues 8.7 Graded tasks 10.3 Non- specific reward -- [1.1 "Participants receive daily steps goals"; 2.2 "Participants can opt to	None [Kept the tracker throughout the study but had no visual feedback or access to Walkadoo. Plus, they were "instructed not to wear their tracker"]	"Principles of behavioural economics and operant shaping"

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
	throughout the day via sync points, or a Bluetooth connection and the Internet."]	receive up to 4 pre-scheduled SMSs per day: previous day's step count (...) and/or goal completion notification"; 3.1 "engaging socially with the community"; 6.2 "group competitions"; 7.1 "receive daily steps goals in the morning via email"; 8.7 " adaptive daily steps goals"; 10.3 "Participants receive virtual rewards (points, levels, and badges) for performing certain actions and reaching milestones"]		
Ashe, 2015	**Fitbit One tracker + app** 2.2 Feedback on the behaviour 2.3 Self-monitoring of the behaviour -- [2.2 "immediate feedback on activities including daily step counts, distance walked, and stairs climbed."; 2.3 "use of an activity monitor"]	**Group-based education and social support and individualized physical activity prescription (9 2-hour sessions) + public transportation tickets + Fitbit website** 1.1 Goal setting behaviour 1.2 Problem solving 1.4 Action planning 1.5 Review behaviour goals 3. Social support 4.1 Instruction on how to perform the behaviour 5.1. Information about health consequences 6.2 Social comparison 8.7 Graded tasks 12.5 Adding objects to the environment	**Monthly health-related education sessions** 4.1. Instruction on how to perform the behaviour -- [4.1 "We provided control participants with separate monthly education sessions (...) [on] falls prevention"	Social-ecological model and social cognitive theory

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
		-- [1.1 “set activity goals”; 1.2 “dealing with setbacks”; 1.4 “discuss their progress to date, goals, and individual walking (step count) prescription”(...) ”strategies to reduce sedentary behaviour”; 1.5 “Participants individually reviewed goals with exercise professionals at each session” ;3 “group-based education and social support“; 3, 6.2 “social networking and/or friendly competitions”; 4.1 “education topics included (...) gearing up for physical activity tips, tricks, and safety”; 5.1 “education topics included the following (...) the importance of exercise; 8.7 “increase their step counts by 5% at each visit”; 10.6 “given a booklet of 10 transit tickets to encourage use of public transportation”]		
Cadmus-Bertram, 2015	**Fitbit One tracker** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2, 2.3 “summary data shown on the tracker’s display”]	**Fitbit website + instructional session** 1.1 Goal setting 1.4 Action planning 1.5 Review behaviour goals 1.9 Commitment -- [1.1 “Individualized goals were set for the first 4 weeks of the study“;	**Pedometer + printed materials** 1.1. Goal setting (behaviour) 2.3. Self-monitoring of behaviour 4.1. Instruction on how to perform the behaviour -- [1.1 “completed a brief goal-setting process…”; 2.3 “Standard pedometer”; 4.1	Coventry, Aberdeen, and London—Refined (CALO-RE) framework

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
		1.5 “follow-up call at 4 weeks was used to evaluate progress and refine goals.”; 1.4 1.9 “participant committed to a specific plan”]	“printed materials with tips for increasing steps”]	
Martin, 2015	**Arm: tracker + SMS**		None [Blinded tracker (measurement-purposes only)]	“Feedback loops and habit formation”
	Tracker + app (Fitbug) 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2, 2.3 “Fitbug Orb, a wearable, display-free, triaxial accelerometer that pairs with low-energy Bluetooth with compatible smartphones.”]	**Website + SMS (3/day) + emails (baseline, day 3, then weekly)** 1.1 Goal setting behaviour 4.1 Instruction on how to perform the behaviour 7.1. Prompts/cues 8.3. Habit formation 9.1. Credible source 10.3 Non-specific reward -- [1.1 “goal of 10 000 steps/day”; 4.1 “practical tip that may help fit in more physical activity into one’s schedule”; 7.1 “booster messages, to motivate individuals when they were not tracking to surpass their step goal.”; 8.3 “content was written by the physician investigators and reflected behavioural change theories, particularly of feedback loops and habit formation”; 9.1 “texts aiming to leverage the physician-patient relationship, using the physician’s name in texts”; 10.3		

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
		"SMS sent when a participant (...) had already attained his or her goal"]		
Thorndike, 2014	**Fitbit tracker** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 10.3 Non-specific reward **--** [2.2, 2.3 "The monitor displayed steps, energy consumed, and distance travelled; 10.3 "displayed an activity ''avatar'' that would grow larger with increasing activity and smaller with more sedentary behaviour."]	**Fitbit website + same as control** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 7.1. Prompts/cues 8.1 Behavioural practice 12.5 Adding objects to the environment -- [2.2, 2.3 Fitbit website; 7.1, 8.1, 12.5 Same as control]	(Blinded Fitbit) **Free access to fitness centre + 1-hour personal training session/week + 2 nutrition sessions + weekly emails** 7.1. Prompts/cues 8.1 Behavioural practice 12.5 Adding objects to the environment -- [7.1 Weekly emails; 8.1 "1-hour personal training session"; 12.5 free gym access, free sessions]	NR
Patel, 2019	**Competition arm**		**Tracker (Withings Activité Steel) + app + SMS/emails** 1.1 Goal setting 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 7.1 Prompts/cues -- [1.1 "Each participant was informed of his or her baseline step count and then asked to choose a step goal increase";	Prospect theory, behavioural economics
	Tracker (Withings Activité Steel) + app 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour	**SMS/emails + gamification** 1.1 Goal setting 1.8 Behavioural contract 1.9 Commitment 5.5 Anticipated regret 6.2 Social comparison 7.1 Prompts/cues 7.5 Remove aversive stimulus 8.7 Graded tasks		

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	Other components of the intervention		
		10.3 Non-specific reward 10.6 Non-specific incentive 10.11 Future punishment 14.2 Punishment -- [1.1, 7.1 Same as control; 1.8, 1.9 participants in the gamification arms signed a pre-commitment pledge to strive to achieve their step goal during the 36-week study"; 5.5, 10.11, 14.2 "every Monday the participant received 70 points (10 for each day of the week). If the participant did not achieve their step goal on the prior day, they lost 10 points from their balance"; 6.2 "participants received an email with a leaderboard that ranked them on their cumulative points in the study thus far and displayed their level. This feedback may have helped induce"; 7.5 "A new component was added to help reengage participants who were struggling to meet their goals at weeks 8 and 16 (defined as being in the blue or bronze levels of the game). These participants were sent an email that stated that they would get a fresh start by being reset to the silver level and offered the opportunity to readjust their goals among the initial options"; 8.7	2.2, 2.3 tracker + app; 7.1 "Each participant selected whether to receive regular study communications by email, text message, or both"]	

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
		"ramp-up period during the first 4 weeks in which daily step goal targets increased by 25% per week from baseline to the goal."; 10.3, 10.6 "entered into a game with points and levels that was run automatically (participants did not have to actively play the game, just strive for step goals) and provided a daily notification of their progress"; "participants could move up or down levels (from lowest to highest: blue, bronze, silver, gold, or platinum)","Participants needed 40 points to advance a level"]		
Ellingson, 2019	**Tracker + app (Fitbit Charge)** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2, 2.3 Fitbit]	**Coach-provided motivational interviewing and habit education (meetings + phone)** 1.1 Goal setting 1.2 Problem solving 3 Social support 4.1 Instruction on how to perform the behaviour 7.1 Prompts/cues 8.3 Habit formation -- [1.1, 8.3, 4.1 "discussed their self-determined goals regarding PA and principles of habit formation with a trained staff member"; 1.2 "discuss their perceived benefits and barriers	**Tracker + app (Fitbit Charge)** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2, 2.3 Fitbit]	Motivational interviewing; habit formation

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
		of becoming more physically active"; 3 "Motivational interviewing"; 7.1, 8.3 "brief definition of habits and their relevance for sustained behaviour change, followed by working with participants to determine salient cues to remember to wear their Fitbit and regularly check their data on the Fitbit itself and through the app at a time when PA was feasible"]		
Zhang, 2019	**Fitbit Zip tracker + PennFit app** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 3.1 Social support (unspecified) 6.2 Social comparison 7.1 Prompts/cues -- [2.2, 2.3 Same as control; 3.1 "An important feature designed to increase social support was the ability to send messages to their small group through an instant chatting tool."; 6.2 "use the PennFit app to see both their own profile and PA data and those of the three other women in their group"; 7.1 "system-generated notifications that reminded them to wear their Fitbit at 8am and to log their PA minutes at 9pm"]	None	**Fitbit Zip tracker + PennFit app** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 7.1 Prompts/cues -- [2.2, 2.3 "All participants then received, to wear daily during the 3-month study period, a Fitbit Zip, a small, wireless activity-tracking device that measures active minutes and steps", "use the PennFit app to monitor their behaviors by tracking daily steps and light-intensity PA objectively collected from Fitbit's application program interface. To increase awareness of exercise effort, we	Social Cognitive Theory

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
			encouraged participants to manually enter their exercise minutes for specific workouts involving moderate (e.g., walking briskly) or vigorous (e.g., jogging) aerobic PA or muscle-strengthening PA (e.g., push-ups)"; 7.1 Same as intervention]	
Patel, 2018	**Arm: Combined lottery incentives**		**App (Moves) + daily feedback on goal achievement (SMSs and/or emails)** 1.1 Goal setting 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2, 2.3 "For 26 weeks, all participants including those in the control group received daily feedback on whether or not they had achieved the 7000-step goal on the prior day."]	NR
	App (Moves) 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2, 2.3 "Step counts were tracked using the Moves smartphone application (ProtoGeo Oy), which uses accelerometers within the phone."]	**Financial incentives + daily feedback on goal achievement (SMSs and/or emails)** 1.1 Goal setting 2.2 Feedback on behaviour 5.5 Anticipated regret 10.1 Material incentive (behaviour) 10.2 Material reward (behaviour) 10.11 Future punishment -- [1.1, 2.2 Same as control; 5.5, 10.11 "Participants who won the lottery but did not achieve their goal were informed what they would have won had they been adherent, drawing on research showing that the desire to avoid regret can be motivating."; 10.1 "In all 3 incentive arms, participants were informed of		

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
		these amounts and probabilities at the beginning of the trial."; 10.2 "In the "combined" incentive arm, each participant had both an 18% chance (approximately 1 in 5 chance) of winning $5 and a 1% chance of winning $50."]		
Robinson, 2018	**Tracker (Fitbit Zip)** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2, 2.3 "Participants received a pedometer (Fitbit) to objectively measure activity."]	**Daily emails (+ incentive reminders) + online resources** 1.1 Goal setting (behaviour) 1.2 Problem solving 1.4 Action planning 2.2 Feedback on behaviour 4.1 Instruction on how to perform the behaviour 7.1 Prompts/cues 8.3 Habit formation 8.7 Graded tasks 11.2 Reduce negative emotions 13.2 Framing/reframing -- [1.1 "Participants were given a goal to increase the number of daily steps each week"; 1.2 "manage time-related barriers to exercise"; 1.4 "Implementation intentions were formed by specifying the when, where, and how they would add steps to their day. Specifically, after the baseline week, for 4 weeks, participants specified the 'when' by	**Tracker (Fitbit Zip) + Daily emails** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 7.1 Prompts/cues -- [2.2, 2.3 "Number of steps were recorded daily."; 7.1 daily emails: "request to wear the fitbit"]	Implementation intentions

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	Other components of the intervention		
		identifying time in their schedule that they could add steps and were asked to estimate approximately how many steps they would walk during each time point. The intervention condition was prompted with an email each evening to review their schedules for the following day and identify time slots where they could add activity. They were given instructions for providing a detailed calendar of appointments and open slots for the next day using a simple daily planner. To specify the 'where' of the implementation intention, participants were given customised maps near their home and work with specific information about distances, estimated time to walk between different points, and estimated number of steps based on the participants' walking pace for specific routes to help them in planning. To help with the 'how' component of the implementation intentions, participants in the intervention condition were given a list of strategies they could use to augment their step counts throughout the day."; 2.2 "Number of steps and goal achievement were		

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
		recorded daily."; 4.1 Supplement "Other ways to increase steps"; 7.1 same as control; 8.3 "Implementation intentions are utilised to establish habits – the specific habit for this study was the habit of identifying opportunities within a daily schedule to increase steps"; 8.7 "increments of 2,000 steps each week"; 11.2 "using cognitive restructuring to combat general worries and perceived barriers to exercising"; 13.2 "using cognitive restructuring to combat general worries and perceived barriers to exercising"]		
Fanning, 2017	**Arm: group A**		**App (without goal setting) + orientation session + weekly emails + weekly SMS + resources + printed workbook to record goals** 1.1 Goal setting (behaviour) 1.5 Review behaviour goals 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 4.1 Instruction on how to perform the behaviour 7.1 Prompts/cues 8.7 Graded tasks 9.1 Credible source --	Social Cognitive Theory
	App + goal setting and point-based feedback features (group A) 1.1 Goal setting (behaviour) 1.5 Review behaviour goal(s) 1.6 Discrepancy between current behaviour and goal 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 4.1 Instruction on how to perform the behaviour 10.3 Non-specific reward 10.6 Non-specific incentive	**Orientation session + weekly emails + weekly SMS + resources** 1.1 Goal setting (behaviour) 1.5 Review behaviour goals 2.2 Feedback on behaviour 7.1 Prompts/cues 8.7 Graded tasks 9.1 Credible source 10.3 Non-specific reward -- [1.1, 1.5, 2.2, 7.1, 8.7, 9.1, 10.3 Same as control]		

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	Other components of the intervention		
	-- [1.1 “goal setting module within the app”; 2.2, 2.3, 4.1 Same as control; 1.5, “Goal recommendations emphasized revision or progression as appropriate”; 1.6 “module displayed participant goal progress”; 8.7 “progression toward public health recommendations for PA over the course of the 12-week intervention.”; 10.3, 10.6 “points-based feedback module. This module was intended as a novel tool for delivering instant SCT feedback and incremental rewards, and did so using a system of ‘‘program points’’, ‘‘levels’’ and ‘‘badges’’.]		[1.1 “During the program orientation, staff provided all participants with counseling on a goal setting process; 1.5, 2.2 “Emails contained an opening paragraph that was tailored by position within the program, weekly educational content, and progress toward the previous weekly goal”; 2.2, 2.3 “All individuals received access to a base-level app containing four features (i.e., tracking, instant feedback, biweekly feedback, knowledge); 4.1 “Weekly educational modules covered central topics in social cognitive theory and health behaviour change”; 7.1 “Thursday text-messages provided a brief motivational quote and summary information for those who had tracked activity in the week, and a reminder to be active for those who had not”; 8.7 “Participant goals urged progression toward public health recommendations for PA over the course of the 12-week intervention“; 9.1 “several reputable exercise resources (e.g., the American Council on Exercise Activity Library;	

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
			American Council on Exercise) to facilitate ongoing goal setting."]	
Patel, 2017	**App (Moves) OR tracker (Fitbit Flex)** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2, 2.3 Same as control]	**SMSs and/or emails** 1.1 Goal setting 1.8 Behavioural contract 1.9 Commitment 2.2 Feedback on behaviour 3.1 Social support 5.5 Anticipated regret 8.7 Graded tasks 10.1 Material incentive (behaviour) 10.2 Material reward (behaviour) 10.3 Non-specific reward 10.6 Non-specific incentive 10.11 Future punishment -- [1.1 "After randomization but before participants learned of study arm assignment, each participant was informed of his or her baseline step count and was asked to select a step goal increase of 33%, 40%, or 50% or any goal at least 1000 steps greater than baseline."; 1.8, 1.9 "Participants electronically signed a commitment pledge to try their best to achieve their step goal."; 2.2 Same as control; 3.1 "seek help from a family member"; 8.7 "achievable goal gradients"; 10.1,	**App (Moves) OR tracker (Fitbit Flex) + SMSs and/or emails** 1.1 Goal setting 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2 "All participants (including those in the control arm) receive daily feedback on whether or not they had achieved their step goal on the prior day."; 2.3 "Eligible participants either downloaded a smartphone application (Moves or Fitbit) or were mailed a wrist-worn wearable device (Fitbit Flex) to track step counts."]	Behavioural economics

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
		10.2 “families were informed that if they finished the intervention period at the gold or platinum level they each would receive a coffee mug with the study logo as a reward.”; 5.5, 10.3, 10.6, 10.11 “every Monday, the family was endowed with 70 points (10 for each day of the upcoming week). Each day, the family was informed of the one member who was selected at random to represent their team. If that member achieved his or her step goal on the prior day, the family kept its points; otherwise, 10 points were lost.”]		
John, 2016	**App (AchieveMint) + Tracker (Fitbit)** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 10.1 Material incentive (behaviour) -- [2.2 Fitbit; 2.3 app that tracks pedometer use.” 10.1 “Every time an AchieveMint user takes 200 steps, he or she earns one point from the platform. Points are redeemable for cash rewards: after a user has taken 200,000 steps, he or she earns $1.00.”]	**Emails + monetary reward** 7.1 Prompts/cues 7.2 Cue signalling reward 10.2 Material reward (behaviour) -- [7.1 same as control; 7.2 “Users in the “salient” incentives condition received extra emails containing information about offered incentives.”; 10.1 “Users receive a check for every $25 earned.”]	**App (AchieveMint) + Tracker (Fitbit) + monetary reward + emails** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 7.1 Prompts/cues 10.1 Material incentive (behaviour) 10.2 Material reward (behaviour) -- [2.2 2.3 “The experiment’s participants were users of an app that tracks pedometer use.”; 7.1 “All participants were able to track their AchieveMint points	Incentive salience

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
			through the AchieveMint app, website, and through standard weekly update emails"; 10.1, 10.2 "Every time an AchieveMint user takes 200 steps, he or she earns one point from the platform. Points are redeemable for cash rewards: after a user has taken 200,000 steps, he or she earns $1.00."; 10.2 "Users receive a check for every $25 earned."]	
King, 2016	**Arm: socially-framed app**		**Dietary app (Calorific)** -- ["app that tracks dietary behaviours"]	Social Cognitive theory and social influence theory
	Social app 1.2 Problem solving 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 3.1 Social support 4.1 Instruction on how to perform the behaviour 6.2. Social comparison 7.1. Prompts/cues -- [1.2 "problem solving strategies"; 2.2, 2.3 "real-time customized feedback that was driven by the personal data being captured via the built-in accelerometer"; 6.2 "social normative feedback", current physical activity/sedentary behaviour levels of the participant and other	None		

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
	members of the "virtual team" to which he/she had been automatically assigned"; 3.1 "online message board"; 4.1 "information tips"; 7.1 "push" (notifications)]			
Melton, 2016	**Tracker + app (Jawbone)** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2 "accelerometer that links with a smartphone application and is able to provide participants feedback about physical activity"]	**Weekly emails** 7.1. Prompts/cues -- [7.1 "Weekly email reminders were sent with general health tips, reminders to use the band and application"]	**MyFitnessPal app + weekly emails** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 7.1. Prompts/cues -- [2.3 "tracking"; 7.1. Prompts/cues: "same schedule of weekly email reminders"]	NR
Patel, 2016 I	**Arm: combined incentive**		**App (Moves) + SMS / email / automated voice call** 1.1 Goal setting behaviour 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [1.1 "goal of at least 7000 steps"; 2.2 "Participants in all arms received daily individual performance feedback for 26 weeks on whether the goal of at least 7000 steps was achieved on the prior day (...) "choose whether to receive this feedback by email, text message, or automated voice call."]	NR
	App (Moves) 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.3 "Once the application was installed on their phones, participants were not required to ever re-open the application, although they could as often as they wished" (same as control)]	**Daily SMS / email / automated voice call + Individual incentives + team incentives** 1.1 Goal setting behaviour 2.2 Feedback on behaviour 6.2. Social comparison 10.1 Material incentive (behaviour) 10.2 Material reward (behaviour) 10.4 Social reward 10.5 Social incentive -- [1.1, 2.2 Same as control; 6.2 "participants received weekly feedback on team performance";		

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
		10.1, 10.2 Each person on the chosen team (randomly picked every other day) could collect $20 if he or she had at least 7000 steps on the prior day; 10.5, 10.6 "additional $10 for each team member who also had at least 7000 steps on the prior day"]		
Patel, 2016 II	**Arm: Weekly feedback on team performance compared to the 75th percentile (no incentive)**		**App (Moves) + weekly feedback on team performance compared to the 50th percentile (email and/or SMS)** 1.1 Goal setting (behaviour) 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 6.2. Social comparison -- [1.1 "All participants were given a goal of achieving at least 7000 steps per day"; 6.2 "told how their weekly average step count compared to the 50th percentile (median) in their arm (above or below, as well as average step count at that percentile)."]	NR
	App (Moves) 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2, 2.3 Moves application, same as control]	**Weekly feedback on team performance compared to the 75th percentile (email and/or SMS)** 1.1 Goal setting (behaviour) 2.2 Feedback on behaviour 6.2. Social comparison -- [1.1 Same as control; 2.2 all participants received "daily individual performance feedback"; 6.2 "told how their performance compared to the 75th percentile (top quartile)"]		
Walsh, 2016	**App (Accupedo-Pro Pedometer app) with widget (home screen)** 1.6 Discrepancy between current behaviour and goal	**Face-to-face session + educational content + goal-setting** 1.1 Goal setting	**App (Accupedo-Pro Pedometer app) without widget + face-to-face session + educational content + goal-**	COM-B model, Behaviour Change Wheel

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	**Other components of the intervention**		
	2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 7.1 Prompts/cues -- [1.6, 2.2, 2.3 “encouraged this group to use the app to monitor their steps and obtain feedback, in order to achieve their target goals.”; 7.1 app widget]	4.1 Instruction on how to perform the behaviour 5.1 Information about health consequences 6.1 Demonstration of the behaviour -- [1.1, 4.1, 5.1, 6.1 Same as control]	**setting** 1.1 Goal setting 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 4.1 Instruction on how to perform the behaviour 5.1 Information about health consequences 6.1 Demonstration of the behaviour -- [1.1 “given a goal of 30 minutes of walking per day over the following month”; 4.1 “Information related to daily recommended PA levels (ie, 30 minutes daily)”; 5.1 “information highlighting the benefits of walking regularly”; 6.1 “Demonstration of the behaviour”]	
Cowdery, 2015	**Exergame app + MOVES app** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 10.3 Non-specific reward 10.6 Non-specific incentive 12.4 Distraction -- [2.2, 2.3. MOVES app; 10.3, 10.6 “collect supplies and avoid being attacked by Zombies as they exercise”; 12.4 exergame]	**Weekly motivational emails** 3.1 Social support 4.1 Instruction on how to perform the behaviour 7.1 Prompts/cues -- [3.1, 7.1 “Participants in the intervention group also received weekly motivational emails”; 4.1 “Guidelines (...) recommend that	**MOVES app (for passive data collection)** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour	Self-determination theory

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	Other components of the intervention		
		adults get at least 150 minutes per week of moderate intensity activity"]		
Wang, 2015	**Tracker (Fitbit One) +/- Fitbit app** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [2.2, 2.3 Fitbit]	**SMSs (3/day) + Fitbit website + educational session** 1.1 Goal setting (behaviour) 1.2 Problem solving 7.1 Prompts/cues -- [1.1, 1.2 Same as control; 7.1 "three daily SMS-based physical activity prompts"]	**Tracker (Fitbit One) + Fitbit app and/or website + educational session** 1.1 Goal setting (behaviour) 1.2 Problem solving 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour -- [1.1, 1.2 "To set the physical activity agenda for all participants, study personnel provided participants with a brief 5-min intervention to review motivation, set goals (i.e., toward 10,000 steps/day), and plan for challenging situations; 2.2, 2.3 Fitbit]	NR
Glynn, 2014	**App (Accupedo-Pro Pedometer app) with widget (home screen)** 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 7.1 Prompts/cues -- [2.2, 2.3 Same as control; 7.1 app widget]	**Leaflet + SMS (weeks 1, 2 and 8) + phone call (week 1 session)** 1.1 Goal-setting 4.1 Instruction on how to perform the behaviour 5.1 Information about health consequences 7.1 Prompts/cues 9.1 Credible source -- [1.1 "given a physical activity goal	**Blinded app (Accupedo-Pro Pedometer app) without widget + leaflet + SMS (weeks 1, 2 and 8) + phone call (week 1 session)** 1.1 Goal-setting 2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour 4.1. Instruction on how to perform the behaviour 5.1 Information about health	NR

Author, year	Characteristics and BCTs of the intervention [abcd]		Characteristics and BCTs of the control[e]	Behaviour change theories, models or constructs mentioned
	Tracker and/or app	Other components of the intervention		
		of 10 000 steps per day"; 4.1, 5.1, 7.1, 9.1 same as control]	consequences 7.1 Prompts/cues 9.1 Credible source -- [1.1 "given similar physical activity goals"; 2.2, 2.3 "automatic feedback and tracking of step count and calories burnt"; 4.1, 9.1 "issued with the Irish Heart Foundation Be Active physical activity promotion brochure" 5.1 "information on the benefits of exercise"]	

[a]Interventions involving Fitbit, Jawbone and Polar were considered to include tracker + app components given the app's availability for download from any app store (these companies sometimes have an associated website similar to the mobile apps—we refer only to the apps in this table); [b]In studies with more than 2 arms, only the control and intervention of interest are described, selected as per defined in the methods; [c]The classification of BCTs was based on the information provided in the main manuscript, existing protocol papers or registrations, and on known basic features of commercial trackers and mobile apps (e.g. feedback on behaviour and self-monitoring of behaviour in Fitbit devices); [d]For apps focusing on more than one health behaviour, only BCTs related to physical activity were coded; [e]Blinded tracker: activity monitor which does not display any information monitored, nor it allows the participant to download or access those data (measurement tool for research-purposes only). Abbreviations: app: application; BCT: behaviour change technique; NR: not reported; SMS: Short Messaging Service (i.e. text messaging); SNS: Social Networking Site.

Supplement 19: eTable 12. Presence of gamification and games in included studies

Author, year	Gamification elements	Delivery platform	Quotes
Wyke, 2019	Competition	Tracker (MatchFit)	"MatchFIT allowed participants to contribute their weekly steps to their group's collective average step count and compare it with that of a virtual competitor team."
DiFranciso-Donoghue, 2018	Challenges	Email	"Weekly emails were sent to this group offering fitness challenges in an attempt to foster an increase in step count"; "Throughout the study the men and women in the Fitbit-Plus group were routinely encouraged to compete with each other in weekly challenges"
Pope, 2018	None	N/A	N/A
Vandelanotte, 2018	None	N/A	N/A
Ashton, 2017	None	N/A	N/A
Brakenridge, 2016	None	N/A	N/A
Finkelstein, 2016	Badges	Website (Fitbit)	"An additional feature of the website is a system of non-monetary rewards whereby participants could earn badges (visible to others in the support group) for meeting specific targets"
Poirier, 2016	Points, levels, badges	Website (Walkadoo)	"Participants receive virtual rewards (points, levels, and badges) for performing certain actions and reaching milestones such as completing a steps goal, achieving a personal best, and engaging socially with the community (eg, by encouraging other participants via "smiles" and comments, or by participating in group competitions)"
Ashe, 2015	Competition	Website	"social networking and/or friendly competitions"
Cadmus-Bertram, 2015	None	N/A	N/A
Martin S, 2015	None	N/A	N/A
Thorndike, 2014	Avatar	Tracker	"The monitor displayed steps, energy consumed, and distance travelled, and it also displayed an activity ''avatar'' that would grow larger with increasing activity and smaller with more sedentary behaviour"
Patel, 2019	Points, levels	SMS/email	"Participants in the intervention arms (support [n = 151], collaboration [n = 150], and competition [n = 150]) were entered into a game with points and levels that was run automatically (participants did not have to actively play the game, just strive for step goals) and provided a daily notification of their progress."; "Second, every Monday the participant received 70 points (10 for each day of the week). If the participant did not achieve their step goal on the prior day, they lost 10 points from their balance."; "at the end of each week, participants could move up or down levels (from lowest to highest: blue, bronze, silver, gold, or platinum)"

Author, year	Gamification elements	Delivery platform	Quotes
Ellingson, 2019	None	N/A	N/A
Zhang, 2019	None	N/A	N/A
Patel, 2018	Lottery	SMS/email	"lottery-based financial incentives"
Robinson, 2018	None	N/A	N/A
Fanning, 2017	Points, levels, badges	App (PennFit)	"Individuals randomly assigned to groups A or C also had access to a points-based feedback module. This module was intended as a novel tool for delivering instant SCT feedback and incremental rewards, and did so using a system of ''program points'' (pp, awarded for all in-app tasks; see ESM Table 1), ''levels'' (awarded for accumulated points), and ''badges'' (awarded for every two earned badges)"; "Watching the video in full unlocked a simple quiz question intended to reinforce the video content. Answering the quiz question unlocked ''support'' content that could be referenced at any time (e.g. strategies for overcoming common barriers to exercise)"; "Points were provided for all in-app tasks", "More points were provided for more important/challenging tasks (e.g., meeting goals)"; "Points accumulated to earn levels"; "Badges depicting an increasingly fit avatar were awarded every 5 levels"; "New titles (e.g., ''master exerciser'') were provided every 2 badges"
Patel, 2017	Points, levels	SMS and/or emails	"Participants in the gamification arm were entered into a game with their family for 12 weeks that was designed using insights from behavioural economics to address predictable barriers to behaviour change and to enhance social incentives. First, participants electronically signed a commitment pledge to try their best to achieve their step goal. […] Second, every Monday, the family was endowed with 70 points (10 for each day of the upcoming week). Each day, the family was informed of the one member who was selected at random to represent their team. If that member achieved his or her step goal on the prior day, the family kept its points; otherwise, 10 points were lost. […] Third, each individual had 5 lifelines to use on days when they were sick or activity was infeasible. This element allowed for some forgiveness and enabled individuals to seek help from a family member. Fourth, if the family had 50 points or more at the end of the week, they advanced up a level (bronze, silver, gold, and platinum). […] Fifth, families were informed that if they finished the intervention period at the gold or platinum level they each would receive a coffee mug with the study logo as a reward."
John, 2016	Points	App (AchieveMint)	"Every time an AchieveMint user takes 200 steps, he or she earns one point from the platform. Points are redeemable for cash rewards: after a user has taken 200,000 steps, he or she earns $1.00. Users receive a check for every $25 earned. AchieveMint sends all users a weekly update email that contains information on a user's current number of earned points"
King, 2016	Avatars	App	"Small avatars reflecting the current physical activity/sedentary behavior levels of the

Author, year	Gamification elements	Delivery platform	Quotes
			participant and other members of the "virtual team" to which he/she had been automatically assigned, as well as another "virtual team", were viewable on the phone's glance-able display throughout the day. Team members could also interact with one another through the app's online message board."
Melton, 2016	None	N/A	N/A
Patel, 2016 I	Lottery	SMS/email/automated call	"In the individual incentive arm, each participant on a winning team was eligible to collect $50, but only if he or she had at least 7000 steps on the prior day. In the team incentive arm, each participant on the winning team was eligible to collect $50 only if all four members of their team had each achieved at least 7000 steps on the prior day. In the combined incentive arm, each participant on the winning team was eligible to collect $20 if he or she had at least 7000 steps on the prior day and then an additional $10 for each team member who also had at least 7000 steps on the prior day."
Patel, 2016 II	None	N/A	N/A
Walsh, 2016	None	N/A	N/A
Cowdery, 2015*	Exergame	App (Zombies, Run! And The Walk)	"Zombies, Run! is an immersive running game and audio adventure that instructs players to collect supplies and avoid being attacked by Zombies as they exercise."; "The Walk is also an audio adventure game that presents episodes and challenges to the player, who is tasked with a package that must be delivered in order to save the world. In order to stay alive, the player must walk/run the length of the United Kingdom."
Wang, 2015	None	N/A	N/A
Glynn, 2014	None	N/A	N/A

*Exergame. Abbreviations: App: application; email: electronic mail; N/A: not applicable; SMS: Short Messaging Service (i.e. text-messaging).

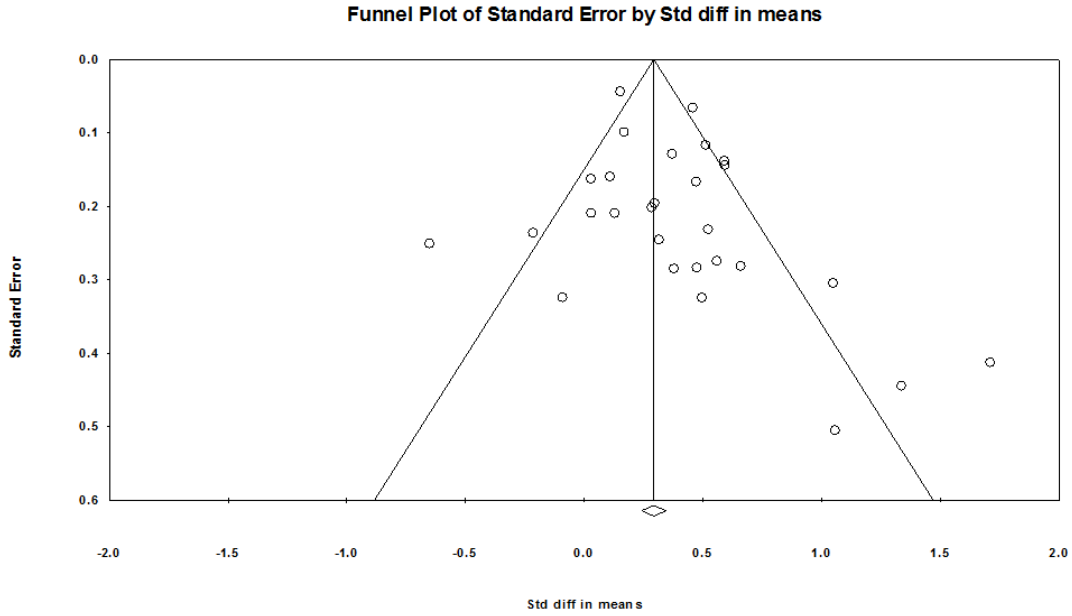
Supplement 20: eTable 13. Presence of personalization in included studies

Author, year	Personalisation quotes from the article
Wyke, 2019	"track progress against individualized, incremental goals to increase both their daily step count and time spent upright"
Donoghue, 2018	NR
Pope, 2018	NR
Vandelanotte, 2018	"To generate the personalized module content in the non-Fitbit group, participants were asked questions about how active they have been the previous week in conjunction with questions relating to individual, social, environmental, and theory-based correlates of physical activity behaviour. On the basis of the answers of participants, and through applying IF-THEN algorithms, personally relevant physical activity content was automatically selected from a database."
Ashton, 2017	"The individual session took place in week three of the program and provided personalized feedback from the Jawbone physical activity data"; "personal tailored goals were set"
Brakenridge, 2016	NR
Finkelstein, 2016	"personalised feedback from Fitbit."; "tailored website with customized information for participants, employers, and/or charities"
Poirier, 2016	"Internet-based walking program that assigns daily step goals tailored to each participant"; "The system generates goals that are tailored to the participant based on their most recent activity level. The goal-setting algorithm is modelled on a rank-order percentile approach developed following principles of behavioural economics and operant shaping"
Ashe, 2015	"the exercise professionals (personal trainer or exercise physiologist) used recorded step counts (from the Fitbit) to calculate step increases at individualized sessions."
Cadmus, 2015	"Individualized goals were set for the first 4 weeks of the study (using data observed on the baseline ActiGraph) and the participant committed to a specific plan to achieve these."
Martin S, 2015	"On the day of enrolment, all participants completed an online questionnaire to provide information on 16 personal and clinical characteristics, which was later used for personalizing text messages within the texting arm."
Thorndike, 2014	"the subject will have access to a personalized Fitbit website to view his or her daily and weekly totals of all measurements"
Patel, 2019	NR
Ellingson, 2019	NR
Zhang, 2019	NR
Patel, 2018	NR
Robinson, 2018	"multi-component, personalised implementation intention intervention"; "intervention condition received instructions to plan how, where, and when they would add steps to their daily routine to meet their step goal, using personalised schedules and maps"
Fanning, 2017	"Feedback was highly individualized to encourage adherence while supporting self-efficacy"; "Emails contained an opening paragraph that was tailored by position within the program, weekly educational content, and progress toward the previous weekly goal"
Patel, 2017	NR
John, 2016	NR
King, 2016	"personalised and quantified goal-setting and behavioural feedback"
Melton, 2016	NR
Patel, 2016 I	NR
Patel, 2016 II	NR
Walsh, 2016	NR
Cowdery, 2015	NR

Wang, 2015	NR
Glynn, 2014	NR

Abbreviations: NR: not reported.

Supplement 21: eFigure 1. Funnel plot of standard error by standardised difference in means



The funnel plot indicates the presence of publication bias, with small studies showing inflated SDMs; Trimming 5 of those studies using Duval and Tweedie's trim and fill method adjusts the estimate, which remained significant (SDM 0.275; 95% CI 0.16 to 0.39).

Duval and Tweedie's trim and fill

		Fixed Effects			Random Effects			Q Value
	Studies Trimmed	Point Estimate	Lower Limit	Upper Limit	Point Estimate	Lower Limit	Upper Limit	
Observed values		0.29218	0.24062	0.34374	0.35037	0.23591	0.46483	88.09486
Adjusted values	5	0.27182	0.22092	0.32271	0.27524	0.15567	0.39481	116.26799

Look for missing studies where?

- ○ Not specified
- ◉ To left of mean
- ○ To right of mean

Look for missing studies using which model?

- ○ Not specified
- ○ Fixed effect model
- ◉ Random effects model

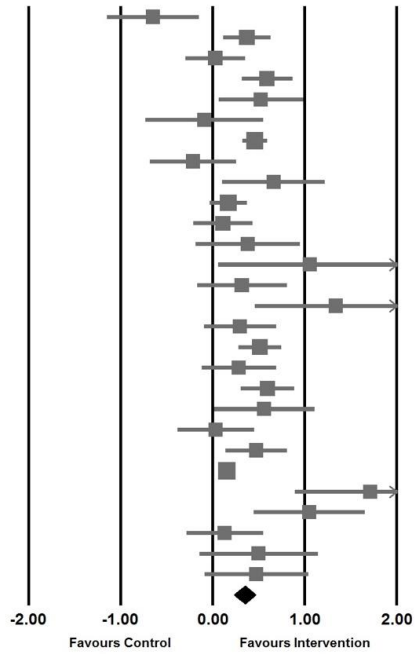
Supplement 22: eTable 14. Sensitivity analyses

Moderator	Description	Number of studies	SDM (95% confidence interval)	I^2 (%)	*P*
1.Sample size above the median	Studies with a sample size above the median (99 participants)	16	0.303 (0.192 to 0.413)	65.7	0.19
	Remaining studies	12	0.539 (0.203 to 0.876)	73.3	
2.Low risk of bias	Studies with 4 or more categories assessed as low risk of bias, from a total of 6 possible[a]	17	0.387 (0.259 to 0.515)	60.2	0.455
	Remaining studies	11	0.289 (0.066 to 0.512)	69.6	
3.Primary outcome	Studies where the outcome included in the analysis was the primary outcome	20	0.397 (0.257 to 0.537)	72.9	0.239
	Remaining studies	8	0.244 (0.03 to 0.458)	60.1	
4a.Outcome type (as per main analysis)	Daily step count	21	0.346 (0.211 to 0.481) Difference in means: 753.2 (460.1 to 1046.2)	72.6	0.555
	MVPA	4	0.53 (0.122 to 0.938)	69.3	
	Other	3	0.214 (-0.193 to 0.621)	62.1	
4b.Outcome type (all studies reporting a given outcome)[b]	Daily step count	23	0.331 (0.208 to 0.454 Difference in means: 705.531 (440.4 to 970.7)	70.6	N/A
	MVPA	8	0.396 (0.165 to 0.626)	57.7	
5.Outcome measurement*	Accelerometer	11	0.225 (0.025 to 0.426)	67.6	0.14
	Self-reported	3	0.214 (-0.193 to 0.621)	62.1	
	Tracker or mobile app	14	0.476 (0.303 to 0.65)	74.9	
6.Longest follow-up available	Mean duration: 18 weeks (8 studies contributing new data for longest follow-up)	28	0.322 (0.218 to 0.426)	N/A	N/A
7.Control group	True control	12	0.345 (0.170 to 0.52)	67.1	0.92
	Active control	16	0.358 (0.196 to 0.520)	70.3	

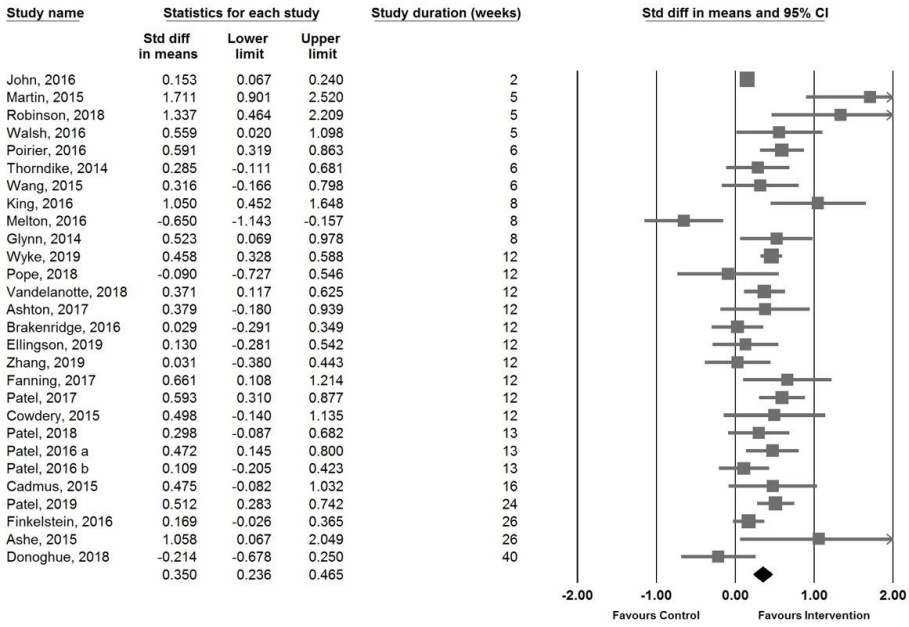
[a]Assessed based on the Cochrane risk of bias tool; [b]Outcome assessed in at least 5 studies
Abbreviations: MVPA, moderate-to-vigorous physical activity (min/week); NA, not applicable; SDM, standardised difference in means

Supplement 23: eFigure 2. Forest plot of effect sizes and 95% confidence intervals by ascending order of retention rate representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)

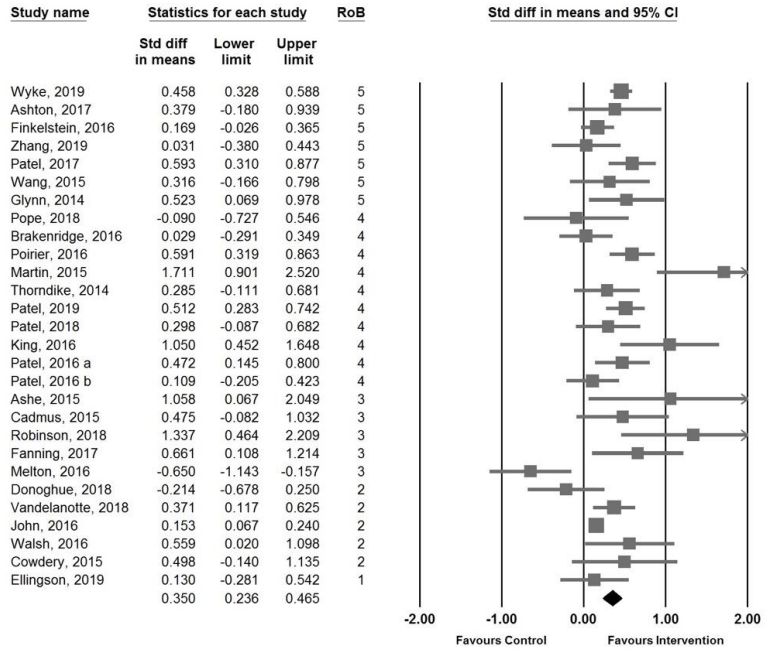
Study name	Std diff in means	Lower limit	Upper limit	Retention (intervention)
Melton, 2016	-0.650	-1.143	-0.157	61
Vandelanotte, 2018	0.371	0.117	0.625	64
Brakenridge, 2016	0.029	-0.291	0.349	78
Poirier, 2016	0.591	0.319	0.863	80
Glynn, 2014	0.523	0.069	0.978	82
Pope, 2018	-0.090	-0.727	0.546	84
Wyke, 2019	0.458	0.328	0.588	88
Donoghue, 2018	-0.214	-0.678	0.250	88
Fanning, 2017	0.661	0.108	1.214	90
Finkelstein, 2016	0.169	-0.026	0.365	92
Patel, 2016 b	0.109	-0.205	0.423	92
Ashton, 2017	0.379	-0.180	0.939	92
Ashe, 2015	1.058	0.067	2.049	92
Wang, 2015	0.316	-0.166	0.798	94
Robinson, 2018	1.337	0.464	2.209	94
Patel, 2018	0.298	-0.087	0.682	94
Patel, 2019	0.512	0.283	0.742	95
Thorndike, 2014	0.285	-0.111	0.681	96
Patel, 2017	0.593	0.310	0.877	96
Walsh, 2016	0.559	0.020	1.098	97
Zhang, 2019	0.031	-0.380	0.443	98
Patel, 2016 a	0.472	0.145	0.800	98
John, 2016	0.153	0.067	0.240	100
Martin, 2015	1.711	0.901	2.520	100
King, 2016	1.050	0.452	1.648	100
Ellingson, 2019	0.130	-0.281	0.542	100
Cowdery, 2015	0.498	-0.140	1.135	100
Cadmus, 2015	0.475	-0.082	1.032	100
	0.350	0.236	0.465	



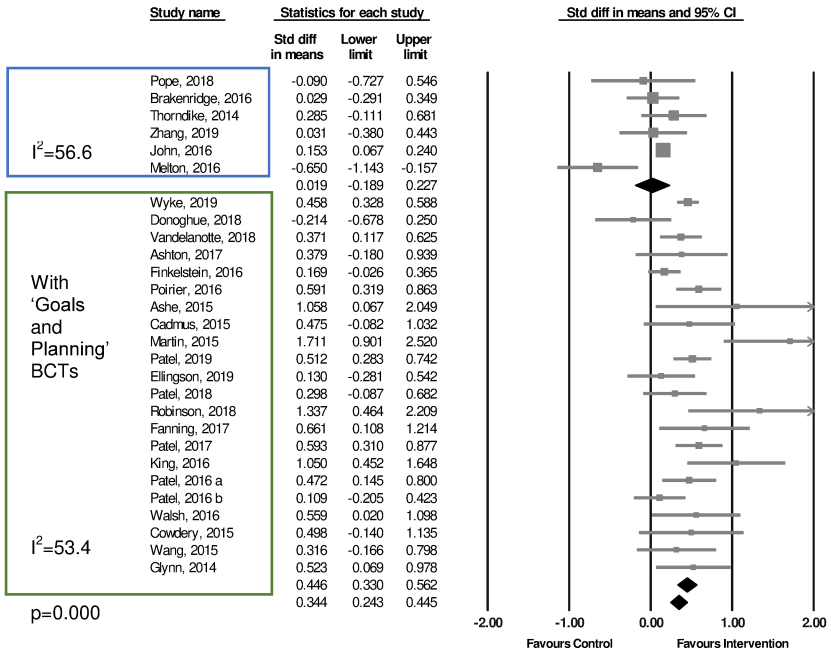
Supplement 24: eFigure 3: Forest plot of effect sizes and 95% confidence intervals by ascending order of study duration representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)



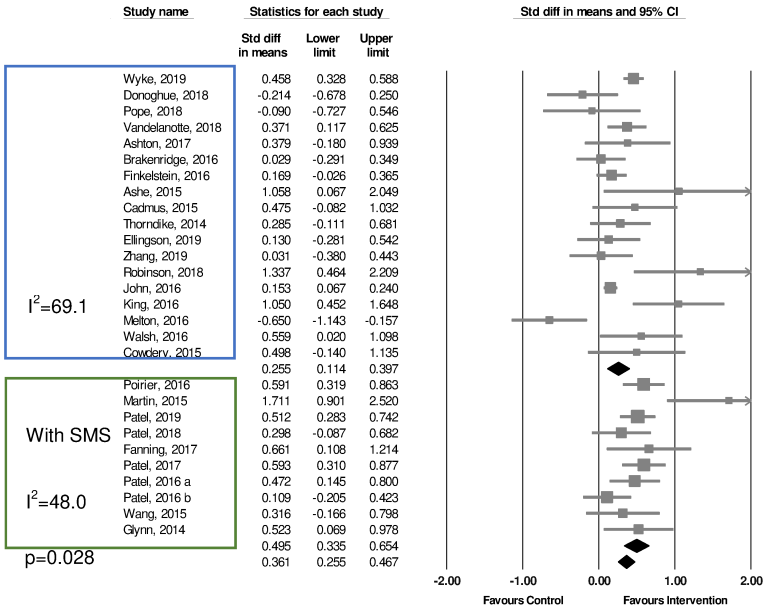
Supplement 25: eFigure 4: Forest plot of effect sizes and 95% confidence intervals by decreasing order of number of low risk of bias categories (out of 6 categories in the Cochrane risk of bias tool) representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)



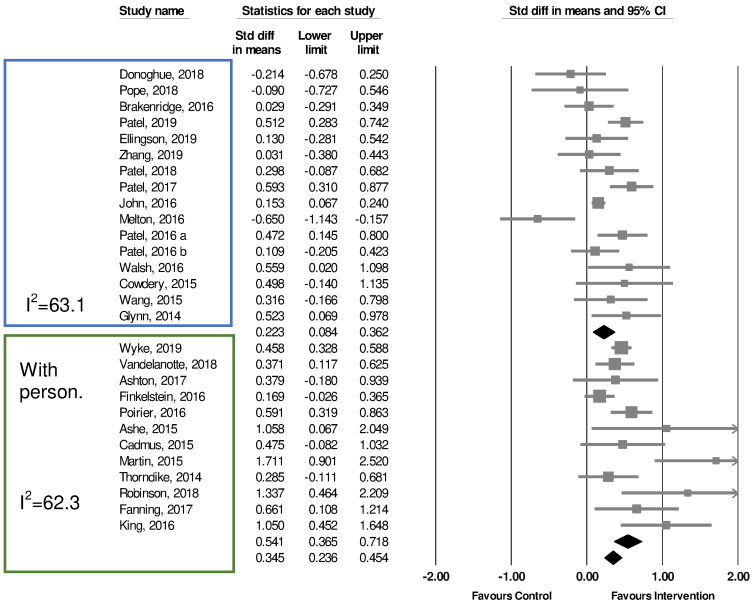
Supplement 26: eFigure 5. Forest plot of effect sizes and 95% confidence intervals by subgroup of studies where the intervention included behaviour change techniques in the 'goals and planning' category, representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)



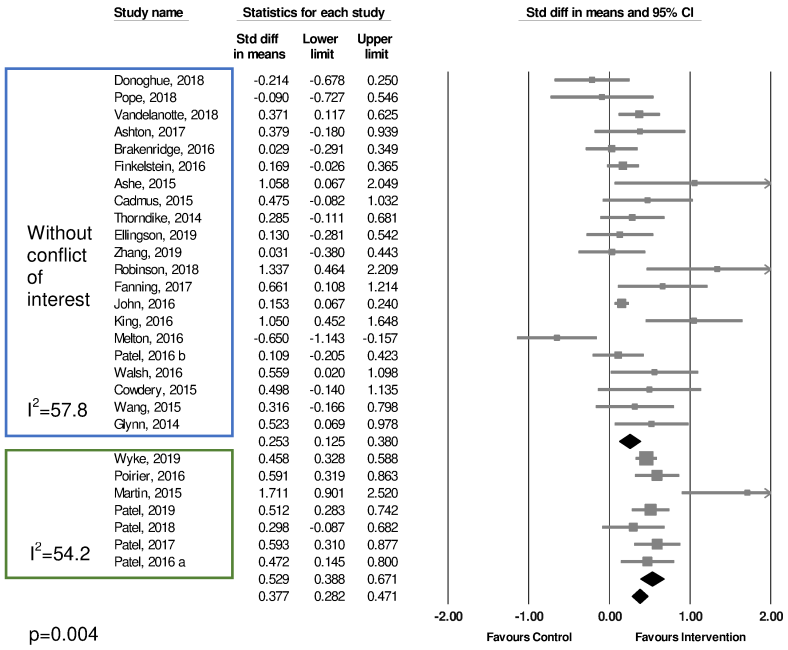
Supplement 27: eFigure 6. Forest plot of effect sizes and 95% confidence intervals by subgroup of studies where the intervention included text-messaging, representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)



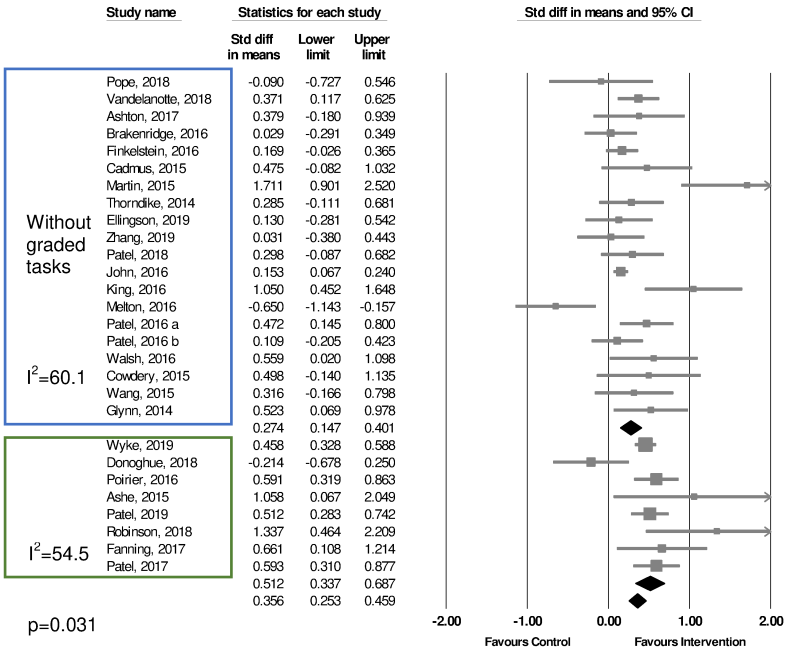
Supplement 28: eFigure 7. Forest plot of effect sizes and 95% confidence intervals by subgroup of studies mentioning personalisation features, representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)



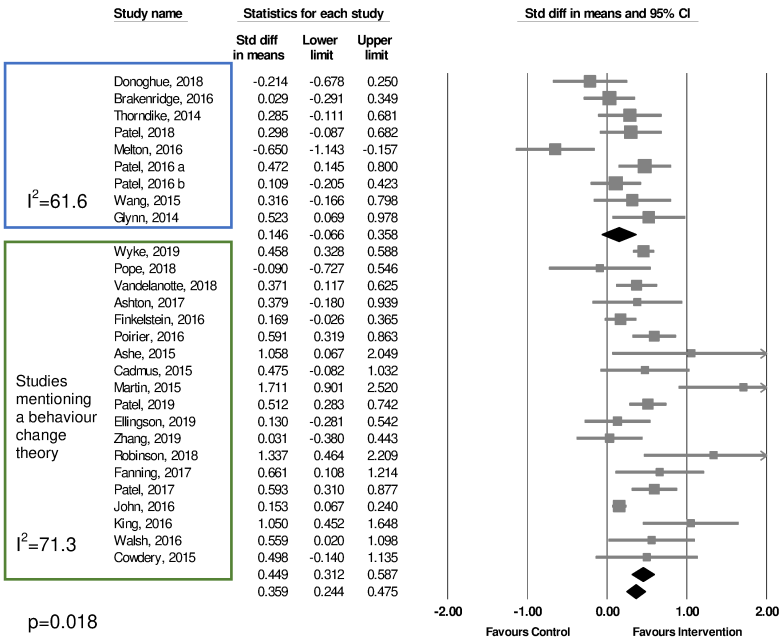
Supplement 29: eFigure 8. Forest plot of effect sizes and 95% confidence intervals by subgroup of studies where authors mentioned conflicts of interest, representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)



Supplement 30: eFigure 9. Forest plot of effect sizes and 95% confidence intervals by subgroup of studies where the intervention included the behaviour change technique 'graded tasks', representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)



Supplement 31: eFigure 10. Forest plot of effect sizes and 95% confidence intervals by subgroup of studies mentioning a behaviour change theory, representing the effect of interventions involving mobile applications or activity trackers in increasing physical activity (random effects model)



Supplement 32: eTable 15. Subgroup analyses

Moderator	Description	Number of studies	SDM (95% confidence interval)	I^2 (%)	*P*
Goals and planning*	Studies where the intervention includes BCTs in this category	22	0.446 (0.33 to 0.562)	53.4	***0.000***
	Remaining studies	6	0.019 (-0.189 to 0.227)	56.6	
Text-messaging*	Studies where the intervention includes text-messaging	10	0.495 (0.335 to 0.654)	48	***0.028***[a]
	Remaining studies	18	0.255 (0.114 to 0.397)	69.1	
Personalisation	Studies mentioning personalisation in the intervention	12	0.541 (0.365 to 0.718)	62.3	***0.006***
	Remaining studies	16	0.223 (0.084 to 0.362)	63.1	
Conflicts of interest	Studies where the authors mention conflicts of interest	7	0.529 (0.388 to 0.671)	45.1	***0.004***
	Remaining studies	21	0.253 (0.125 to 0.380)	56.9	
Graded tasks*	Studies where the intervention includes this BCT	8	0.512 (0.337 to 0.687)	54.5	***0.031***
	Remaining studies	20	0.274 (0.147 to 0.401)	60.1	
Studies mentioning behaviour change theories	Studies mentioning behaviour change theories, models, frameworks or constructs	19	0.449 (0.312 to 0.587)	71.3	***0.018***
	Remaining studies	9	0.146 (-0.066 to 0.358)	61.6	
Tracker or app are the only difference between I and C*	Studies where the tracker or app are the only difference between I and C	5	0.136 (-0.31 to 0.582)	82.4	0.284
	Remaining studies	23	0.388 (0.272 to 0.504)	65.3	
Tracker*	Studies where the intervention includes an activity tracker	20	0.308 (0.172 to 0.445)	74.7	0.22
	Remaining studies	8	0.453 (0.267 to 0.639)	28.1	
App*	Studies where the intervention includes a mobile application	21	0.354 (0.215 to 0.492)	71.9	0.957
	Remaining studies	7	0.347 (0.122 to 0.572)	64.5	
Social BCTs*	Studies where the intervention includes social BCTs[b]	16	0.351 (0.226 to 0.476)	59	0.846
	Remaining studies	12	0.379 (0.141 to 0.616)	73.3	
Shaping knowledge*	Studies where the intervention includes BCTs from this category	14	0.478 (0.285 to 0.672)	65.3	0.093
	Remaining studies	14	0.271 (0.126 to 0.416)	70	
Prompts/ cues*	Studies where the intervention includes this BCT	16	0.396 (0.21 to 0.583)	76.1	0.541
	Remaining studies	12	0.325 (0.193 to 0.457)	48.4	

Moderator	Description	Number of studies	SDM (95% confidence interval)	I^2 (%)	*P*
Reward and threat*	Studies where the intervention includes BCTs in this category	11	0.442 (0.274 to 0.611)	74.2	0.187
	Remaining studies	17	0.279 (0.105 to 0.453)	67.1	
Problem solving*	Studies where the intervention includes this BCT	8	0.509 (0.262 to 0.756)	43.4	0.155
	Remaining studies	20	0.307 (0.178 to 0.437)	73.7	
Action planning*	Studies where the intervention includes this BCT	5	0.492 (0.303 to 0.681)	30.4	0.123
	Remaining studies	23	0.313 (0.184 to 0.441)	68.9	
Information about health consequences*	Studies where the intervention includes this BCT	7	0.345 (0.182 to 0.509)	53.5	0.947
	Remaining studies	21	0.353 (0.201 to 0.505)	72.3	
Credible source*	Studies where the intervention includes this BCT	6	0.505 (0.248 to 0.761)	71.1	0.186
	Remaining studies	22	0.31 (0.178 to 0.442)	67.2	
Review behaviour goals*	Studies where the intervention includes this BCT	5	0.473 (0.354 to 0.593)	0	0.089
	Remaining studies	23	0.321 (0.192 to 0.45)	70.8	
Study duration ≥12 weeks*	Studies with duration equal or above 12 weeks	18	0.314 (0.203 to 0.424)	46.8	0.253
	Remaining studies	10	0.494 (0.205 to 0.783)	82.5	
Physically inactive/ sedentary	Studies recruiting only physically inactive or sedentary people	12	0.505 (0.274 to 0.736)	70.9	0.116
	Remaining studies	16	0.289 (0.152 to 0.427)	67.2	
Overweight/ obese	Studies recruiting only overweight/ obese individuals	6	0.368 (0.252 to 0.484)	11.5	0.802
	Remaining studies	24	0.345 (0.201 to 0.488)	71.7	
Face-to-face or telephone	Studies where the intervention includes human contact for face-to-face and/or phone call components[c]	11	0.383 (0.263 to 0.50)	11.1	0.65
	Remaining studies	17	0.337 (0.177 to 0.497)	76.3	
Gamification	Studies where the intervention includes gamification features	14	0.405 (0.267 to 0.544)	71.9	0.396
	Remaining studies	14	0.294 (0.078 to 0.51)	68.1	
Website	Studies where the intervention includes website	9	0.456 (0.248 to 0.663)	58.6	0.24
	Remaining studies	19	0.305 (0.164 to 0.446)	73	
Email	Studies where the intervention includes email	15	0.347 (0.168 to 0.527)	78	0.936
	Remaining studies	13	0.357 (0.223 to 0.49)	38.9	
Online Social Network	Studies where the intervention includes Online Social Network	5	0.397 (0.04 to 0.754)	65.8	0.768
	Remaining studies	23	0.34 (0.217 to 0.463)	70.3	
Study	Studies where there were	15	0.378 (0.229 to	67.5	0.561

Moderator	Description	Number of studies	SDM (95% confidence interval)	I^2 (%)	*P*
incentives	incentives for study compliance or completion		0.526)		
	Remaining studies	13	0.31 (0.138 to 0.483)	59.2	

* Pre-specified in the protocol; [a]In 5 studies out of the 10 where SMS is included, participants could should to received SMS, email, or both—a sensitivity analysis considering these 5 studies as not including SMS was still statistically significant (p=0.035); [b]Social BCTs are: social support, social comparison, social reward, social incentive; [c]Automated phone calls excluded. Abbreviations: BCT: Behaviour Change Technique; C: Control group; I: Intervention group; MVPA: Moderate-to-vigorous physical activity; SDM: Standardized difference in means.