TBM

SYSTEMATIC REVIEWS

Are physical activity interventions for healthy inactive adults effective in promoting behavior change and maintenance, and which behavior change techniques are effective? A systematic review and meta-analysis

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Abstract

Physical inactivity and sedentary behavior relate to poor health outcomes independently. Healthy inactive adults are a key target population for prevention. This systematic review and meta-analysis aimed to evaluate the effectiveness of physical activity and/or sedentary behavior interventions, measured postintervention (behavior change) and at follow-up (behavior change maintenance), to identify behavior change techniques (BCT) within, and report on fidelity. Included studies were randomized controlled trials, targeting healthy inactive adults, aiming to change physical activity and/or sedentary behavior, with a minimum postintervention follow-up of 6 months, using 16 databases from 1990. Two reviewers independently coded risk of bias, the "Template for Intervention Description and Replication" (TIDieR) checklist, and BCTs. Twenty-six studies were included; 16 pooled for meta-analysis. Physical activity interventions were effective at changing behavior (d = 0.32, 95% confidence intervals = 0.16–0.48, n = 2,346) and maintaining behavior change after 6 months or more (d = 0.21, 95% confidence intervals = 0.12–0.30, n = 2,190). Sedentary behavior interventions (n = 2) were not effective. At postintervention, physical activity intervention effectiveness was associated with the BCTs "Biofeedback," "Demonstration of the behavior," "Behavior practice/rehearsal," and "Graded tasks." At follow-up, effectiveness was associated with using "Action planning," "Instruction on how to perform the behavior," "Prompts/cues," "Behavior practice/rehearsal," "Graded tasks," and "Self-reward." Fidelity was only documented in one study. Good evidence was found for behavior change maintenance effects in healthy inactive adults, and underlying BCTs. This review provides translational evidence to improve research, intervention design, and service delivery in physical activity interventions, while highlighting the lack of fidelity measurement.

Keywords

Inactive lifestyle, Physical activity, Behavior change, Systematic review, Behavior change techniques, Behavior change maintenance

Implications

Practice: Physical activity practice, gradually increasing intensity, using heart rate monitors, creating detailed plans, receiving instructions, using prompts, and rewarding oneself for progress may promote a change in physical activity behavior.

Policy: Healthy but inactive adults represent a key population that may be on the cusp of ill health and interventions in this population can be effective in producing sustained changes in physical activity.

Research: Future research should address the lack of fidelity assessment in physical activity interventions and the dearth of randomized controlled trials aimed at reducing the sedentary behavior of inactive adults that assess maintenance of behavior change.

INTRODUCTION

Physical activity has a beneficial effect on the risk factors associated with cardiovascular disease, stroke, type 2 diabetes, and cancer [1]. When compared to individuals who participate in low levels of physical activity, highly active and moderately active people have a reduced risk of all-cause mortality [2]. However, only 60% of adults in England, 56% in Australia, and 50% in the USA report participating at the recommended levels of 150 min/week of moderate to vigorous physical activity [3–5]. Inactive adults (those not meeting the recommended levels), even if they are currently healthy, are therefore a key target for intervention as they may be at risk of developing ill health without long-term lifestyle change. This review also includes interventions aimed at reducing sedentary behavior as high levels are associated with a range of risk factors independently of physical activity levels [6].

Although previous reviews exist for physical activity interventions, they have combined inactive and active populations [7] or summarized highly heterogeneous samples (e.g., those suffering from diabetes and pregnant women [8]), or combined healthy and unhealthy adults [9]. The importance of physical activity as a primary preventative approach for healthy adults has long been acknowledged [10]. Individuals not currently engaging in physical activity, nor presenting with ill health may not have experienced a "teachable moment" or any cause for concern for their health that would act as a catalyst for change [11, 12]. Consequently, despite a proliferation of reviews of physical activity interventions, there has been no systematic review of interventions targeting *healthy* and *inactive* adults. The biggest reductions in future health problems are often seen when moving people from inactive to moderately active lifestyles [1]. Therefore, healthy adults, who may not yet be suffering the effects of inactivity, represent a key target population for public health prevention efforts.

Behavioral science highlights the need to draw an important distinction between initial behavior change and behavior change maintenance, which is reportedly harder to achieve [13]. A number of reviews that have attempted to analyze longer-term outcomes have not specified a minimum postintervention follow-up period [8, 14, 15]. Therefore, the majority of reviewed studies, despite being 12 or more months in duration only captured facilitated behavior change (i.e., directly after active components are completed). Maintenance is hypothesized to occur at a minimum of 6 months after initial behavior change [16]. Six-month postintervention outcomes, where no contact with participants is made, are therefore needed to capture behavior change maintenance. This is not always clear in the literature, with reviews including studies where active components such as motivational newsletters or phone calls are still occurring during the "follow-up" period [8, 17, 18]. This review provides a unique contribution in distinguishing clearly between behavior change and behavior change maintenance of physical activity/sedentary behavior interventions.

Another crucial need is to explore the fine-grain detail of intervention content in an attempt to uncover effective elements. Specifying the active components of an intervention is essential for implementing, replicating, and synthesizing successful approaches [19]. The Behavior Change Technique (BCT) taxonomy v1 [19] includes 93 items that allow the "active ingredients" of interventions to be systematically described, reviewed, and replicated. Previous reviews have either failed to identify behavior change techniques [20] or have analyzed BCTs using older less comprehensive taxonomies [18, 21]. In previous taxonomies such as the 40-item CALO-RE taxonomy [22] a number of BCTs were missing and many more were not irreducible (i.e., these BCTs were composites and needed to be further broken down into more basic elements) [23]; as such, using this taxonomy is less likely to provide interventionalists with sufficient information for clear replication. This review is the first in the area of physical activity and sedentary behavior interventions that aims to investigate behavior change and maintenance using the 93 item BCT taxonomy v1 [19] in healthy inactive adults.

Finally, to enable replication, intervention designers would benefit from the knowledge of factors such as mode of delivery, duration, frequency, and fidelity (an evaluation of the delivery of the intervention as planned). However, this detail is rarely reported. The "Template for Intervention Description and Replication" (TIDieR) [24] allows for a systematic description of interventions using a 12-item checklist detailing the why, what, who, where, and how of intervention delivery. The current review will provide this additional insight, essential for intervention replication. In summary, this review aimed to fill a number of important evidence gaps. This is the first review to synthesize randomized controlled trials (RCTs) of physical activity and sedentary behavior interventions for healthy inactive adults. It is also the first review to analyze outcomes in this population representing both behavior change (postintervention) and behavior change maintenance (follow-up). Finally, it is the first review to provide evidence from these interventions using the BCT taxonomy v1 and analyze the content from items on the TIDieR checklist. We aimed to answer three research questions:

- Are RCTs of interventions aimed at increasing physical activity or reducing sedentary behavior in healthy inactive adults effective immediately postintervention (behavior change) and at a minimum of 6-month postintervention follow-up (behavior change maintenance)?
- Which behavior change techniques, are associated with effectiveness at postintervention and follow-up?
- How often is the fidelity of such interventions checked?

METHODS

The protocol was registered with PROSPERO (registration number: CRD42014014321), and a detailed preregistered protocol was also published [25].

Eligibility criteria

Study characteristics

Participants

Healthy adults (aged 18 or older) who were inactive (defined as less than 150 min of moderate or 75 min of vigorous-intensity activity per week, or less than 10,000 steps/day). Included studies had a minimum of 70% of participants classified as inactive. Healthy was defined as those without serious injury, long-term physical incapacity, or suffering or rehabilitating from chronic conditions and risk factors that require medication.

Intervention

Any intervention evaluated in an RCT with a primary aim (as stated in the full paper and/or study protocol) to increase physical activity and/or reduce sedentary behavior. We included all settings (e.g., leisure centre, primary care) and delivery formats (e.g., group, individual).

Comparator or control

Any passive (e.g., usual care) or active (e.g., alternative behavioral approaches) control group.

Outcomes

Primary outcomes were self-reported or objectively measured physical activity and/or sedentary behavior assessed at baseline and/or postintervention (defined as directly after intervention completion), and a minimum of 6 months after intervention completion. Secondary outcomes, where available, were recorded.

Information sources

Searches were conducted on the following electronic databases from January 1, 1990 to August 2016: Applied Social Sciences Index (ASSIA); British Nursing Index (BNI); Cumulative Index to Nursing and Allied Health Literature (CINAHL); Cochrane Central Register of Controlled Trials (CENTRAL); Cochrane systematic review database; current controlled trials register; Database of Abstracts of Reviews of Effects (DARE); EMBASE; Health Technology Assessment (HTA) database; National Institute of Health Research (NIHR) portfolio; PsycINFO; PubMed; Scopus; SPORTDiscus; System for Information on Grey Literature (SIGLE); Web of Science. In addition, 18 published systematic reviews [8, 14, 15, 17, 20, 26–38] were screened to make sure relevant articles were not missed by the electronic searches. Furthermore, we screened the reference lists of all included studies and requested from experts (e.g., members of European Health Psychology Society) in the field any relevant information on published, unpublished, and ongoing research.

Search strategy

Searches included a combination of terms from medical subject headings (MeSH) and keywords in the title, abstract, and text (Supplementary Table 1). The search included multiple terms for population (e.g., adult, inactive), intervention (e.g., health promotion, physical activity), comparator (e.g., clinical trial), and outcome themes (e.g., exercise, sedentary behavior). All terms within each theme were combined with "OR" and then the four themes were combined with "AND."

Study selection

Search results were imported into Endnote X7 reference management software and duplicates were removed. Titles and abstracts were screened by N.H. with a random 10% done independently (N.T.). Full texts of potentially relevant studies were assessed independently by two reviewers (N.H., N.T.). Where information was missing or only protocols were available, study authors were contacted for relevant information regarding eligibility criteria. Any disagreements were resolved through discussions with the other reviewers (A.C., D.T.).

Data extraction

All data from included studies were extracted into Excel using a prepiloted data extraction form. Data from each included paper were extracted independently by two reviewers (N.H., N.T.) and included the variables listed in Table 1. We contacted 10 authors requesting additional outcome data for the meta-analysis and obtained further information from two.

Classification of intervention and control condition content

Behavior change techniques were coded as present or absent using the BCT taxonomy v1 for all intervention and active control conditions. Two experienced reviewers (A.C., N.H.) coded all available primary papers, related papers, and protocols for each study independently (as per [23]). The TIDieR checklist

Table 1 | Data extraction table

Extraction categories	Extraction items
General	Author(s); article title; type of publication (e.g., published article); related papers; country of origin; source of funding.
Method	Design: aims/objectives of the study; target behavior/s; study design (including control groups); inclusion and exclusion criteria; recruitment and sampling methods (including unit of randomization and blinding); unit of allocation; power calculations.
	Participants: population type; inclusion and exclusion criteria; number of participants; age; gender; weight status; ethnicity.
Intervention features	Frequency and length of sessions; intervention duration; intervention setting; intervention provider; delivery format; behavior change techniques; TIDieR guidelines: theoretical basis.
Outcomes	Primary outcomes: unit of measurement; type of measurement (e.g., subjective); follow-up duration and frequency; mean and standard deviation at baseline, postintervention, and follow-up; effectiveness at postintervention and follow-up; effect size; attrition rate.
	Secondary outcomes: adverse effects; effectiveness at postintervention and follow-up for any of the following (if available): objectively measured health indicators (e.g., BMI), subjective well-being (e.g., QOL), self-efficacy and metabolic health (e.g., blood pressure).

BMI body mass index.

describes reporting items that are essential for accurate intervention description and replication. The 12 items on the checklist were coded independently by two reviewers (N.H., N.T.) as either present, absent, unclear, or not applicable. Items 11 and 12 were of particular interest as they cover planned and actual adherence/fidelity assessment respectively. Interrater reliability throughout this review was assessed using Krippendorf's α, a reliability coefficient that compares favorably to alternatives [39].

Risk of bias

Two reviewers (N.H., D.T.) independently assessed risk of bias using the Cochrane tool for assessing risk of bias [40] in RevMan software. Assessment was performed for the domains of allocation sequence generation and concealment, blinding of participants, personnel and outcome assessors, completeness of outcome data (postintervention and follow-up), selective reporting of outcomes (if protocol available), and any other potential sources of bias. We assessed risk of bias as either low, unclear, or high risk.

Quality of the evidence

The quality of evidence for primary outcomes was assessed using the Grading of Recommendations Assessment, Development and Evaluation guidelines (GRADE) [41]. Assessment was performed in the areas of design, study limitations, consistency, directness, precision, and publication bias. Risk of publication bias was assessed with funnel plots using Stata 14. Grading was assessed for continuous physical activity and sedentary behavior outcomes at postintervention and follow-up. Quality of the included studies was judged as high, moderate, low, or very low depending on our confidence that the estimates of the effect were accurate based on the GRADE guidelines [41, 42]. RCTs start as high quality but can be downgraded for serious problems on any of the five domains.

Statistical analysis

Effect sizes

As per Cochrane guidelines for the meta-analysis, it was assumed that baseline figures were equal between groups based on the RCT design [43]. Postintervention and follow-up means, standard deviations, and sample sizes for each condition were analyzed to produce standardized mean differences (Cohen's d), with 95% confidence intervals (CIs). This analysis was performed for the studies reporting continuous outcomes (16 out of 26) [44–59].

Synthesis of results

We conducted two meta-analyses using a random effects model in Stata 14 to calculate pooled effect sizes for postintervention and follow-up physical activity outcomes. Heterogeneity was investigated using Higgins I^2, with heightened levels (over 50%—moderate; over 75%—high) being explored further in subgroup or sensitivity analysis.

Subgroup, sensitivity, and additional analysis

Preplanned analysis by subgroups was conducted by type of physical activity measure (self-report vs. objective) and targeting single versus multiple behaviors. Sensitivity analysis was completed on the follow-up meta-analysis with and without a study, which produced an effect size different in magnitude from the others. Prespecified additional analysis was conducted using a set of univariate meta-regression models to examine the association between 20 individual behavior change techniques (behavior change techniques had to be present in at least two studies for inclusion), total number of behavior change techniques, intervention duration, follow-up duration, age, and intervention effectiveness. Prespecified additional analyses of sedentary behavior outcomes, mode of delivery, and theoretical basis were not possible due to the small number of studies (sedentary behavior: n = 2) and wide range of approaches across studies respectively. The association between behavior change techniques and effect size was investigated using regression coefficients (β), with values > .10 in conjunction with an adjusted R^2 of >10%, indicating an important association [26]. Due to the large number of univariate meta-regressions, there was a risk of false-positive findings. Therefore, we used the Monte Carlo permutation test (10,000 permutations) to calculate adjusted p values [60].

RESULTS

Study selection

The final review included 26 studies [44–59, 61–70] published across 47 papers (Fig. 1).

Study and participant characteristics

The country in which the 26 studies were conducted was diverse with the largest number from America (11 studies [46–50, 53–55, 58, 61, 62]; Supplementary Table 2). The behavior targeted was physical activity in 20 studies [45–55, 57–59, 64–69], physical activity and sedentary behavior in two studies [44, 56], physical activity and diet in three studies [61–63], and physical activity, diet, and smoking in one study [70]. Intervention provider was mixed with the most common involving an instructor [50, 51, 56, 57] or student counselor [45, 49, 52, 67]. Intervention setting was most frequently primary care [64–67, 70], an exercise facility/leisure center [18, 50, 51, 56, 57], or delivered by post [47, 53, 54, 68, 69]. Duration and frequency ranged from receiving a single information pack [69] to 33 individual and group sessions over 14 months [60]. Theoretical basis was highly variable with the transtheoretical model utilized most often [50, 52, 64–66, 68–70].

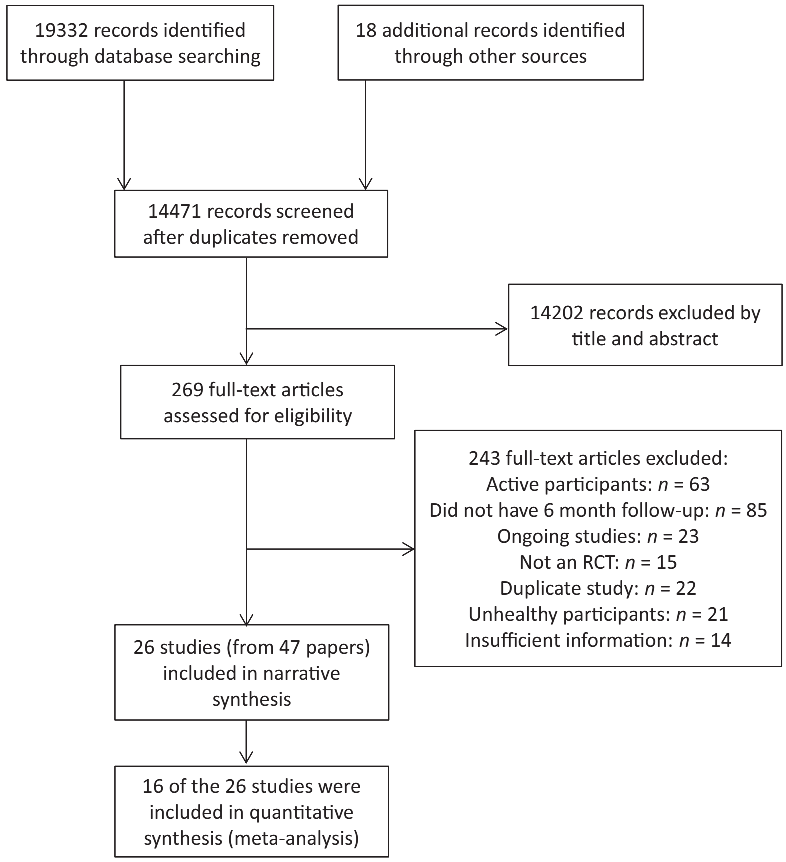

Fig 1 | PRISMA flowchart of literature search results

Participants were on average 51.4 years old and mostly female (77%) with an average body mass index of 29.2 and 28.9 kg/m^2 in intervention and control conditions, respectively. Participants in 16/19 studies reporting body mass index were overweight. Average sample size was 129 participants for the intervention conditions (3,350 total) and 143 for the control conditions (3,713 total) at baseline. Only 12 studies reported ethnicity, with nine having a majority of white/Caucasian participants [47, 48, 50, 52–54, 61, 65, 67]. Average intervention length was 21 weeks (range 0–61) and the average length between the intervention finishing and the last follow-up measurement was 41 weeks (range 24–121). The attrition rate from baseline to follow-up was 28% in the intervention and 26% in the control conditions. For primary outcomes, 21 studies used a subjective measure [44, 47–49, 51–55, 58, 61–70], three used a mixture of subjective and objective measures [50, 57, 59], and two an objective measure only [45, 46]. Both sedentary behavior measures were self-report [44, 56].

For secondary outcomes, one study found improvements in physical fitness (postintervention and follow-up [63]), one found postintervention increases in self-efficacy [53], one found an intervention effect at follow-up for physical functioning and mental health [66], and one found an improvement for women only on three subscales of quality of Life (QOL), but a decrease on four other subscales, all at follow-up [64]. Only seven studies reported adverse effects, with three showing some imbalance between groups (two showed increased risk of injury/falls in the intervention condition [53, 67] and one showed more adverse events for controls) [46].

Behavior change techniques

The 26 interventions contained an average of 8.4 behavior change techniques, with a range between 0 and 17 and a total of 37 different behavior change techniques implemented across the interventions (Supplementary Table 3). The most frequently used behavior change techniques were “Goal setting (behavior)” (22 studies) and “Social support (unspecified)” (20 studies). The 19 active control conditions contained an average of 5.1 behavior change techniques, with a range between 0 and 15 and a total of 24 behavior change techniques implemented across the control conditions. The most frequent behavior change techniques in the active control conditions were “Goal setting (behavior)” and “Information about health consequences” (both 10 studies). Average inter-rater reliability for the 24 behavior change techniques coded in more than one study was good (Krippendorf's α = 0.91, range = 0.58–1.00).

TIDieR checklist

Reporting in the 26 intervention conditions was adequate for 69% of items (Supplementary Table 4). For the 19 active control conditions, reporting was adequate for 54% of items. For intervention and control conditions, a brief description (item 1%–92% for intervention; 89% for control), mode of delivery (item 6%–100% for intervention; 79% for control), and procedure (item 4%–88% for intervention; 84% for control) were the most well reported. Where the intervention was delivered (item 7%–47% for intervention; 50% for control) and how and by whom fidelity or adherence was assessed (item 11%–36% for intervention; 19% for control) were the items with the most inadequate reporting in both conditions. Average inter-rater reliability for the TIDieR items was good (Krippendorf's α = 0.75).

Risk of bias within studies

Nineteen studies were judged to be at high risk of bias on at least one domain (Supplementary Figure 1). The domain judged as having the lowest risk of bias was completeness of outcome reporting (low risk in 15/26 studies for follow-up outcomes and 12/21 studies for postintervention outcomes). Random sequence allocation was reported adequately in 12 studies. For the remaining indicators, the number of studies assessed as low risk was poor. The risk of bias domains that were judged to have a large number of high-risk studies were selective reporting (11 studies) and "other" (10 studies). The majority of the judgments in the "other" domain were caused by low sample sizes and/or high attrition rates at follow-up. Overall, the risk of bias rating across all domains was mostly unclear (60%). Good inter-rater agreement was achieved across the eight main domains (Krippendorf's α = 0.81).

Intervention effects on main outcomes

Physical activity

Five studies had more than one intervention group. In each instance, the most intensive intervention group was compared with controls. Five studies reported baseline and follow-up outcomes only. Of the 21 studies that reported physical activity outcomes postintervention, 13 studies showed a significant effect in favor of the intervention, 2 studies showed a significant effect in favor of the intervention on a subscale of the main outcome, and the remaining 6 studies showed no effect. At follow-up, 11 studies showed a significant effect in favor of the intervention, 2 studies showing a significant effect in favor of the intervention on subscales of the main outcome, and 13 studies showed no effect.

Three studies provided sufficient noncontinuous data (percentage of participants classified as active). Only one of these studies showed a difference in favor of the intervention at follow-up. Fourteen studies provided sufficient continuous data (e.g., minutes per week/day of walking or moderate/vigorous activity) to pool for the postintervention meta-analysis and 16 for the follow-up meta-analysis. Postintervention, intervention participants engaged in significantly more physical activity than control participants (d = 0.32 [95% CI = 0.16–0.48]; Supplementary Figure 2), representing a relatively small effect, with a moderate to high level of heterogeneity (I^2 = 69%). The effective interventions showed postintervention improvements ranging from 31 to 247 min/week of physical activity and 606–1,849 steps/day.

At follow-up, intervention participants still engaged in significantly more physical activity but the effect was smaller (d = 0.21 [0.12–0.30]; Supplementary Figure 3), with very low heterogeneity (I^2 = 3%). The effective interventions showed improvements at follow-up ranging from 5 to 95 min/week of physical activity and 421–1,370 steps/day.

Sedentary behavior

Of the two studies that reported sedentary behavior outcomes (both sitting time), only one reported group differences, showing no intervention effect at postintervention or follow-up.

Quality of evidence across studies

Using the GRADE criteria [41, 42], the postintervention physical activity outcome was downgraded two levels to low quality because there was a high level of heterogeneity (serious inconsistency) and suspicion of publication bias based on the funnel plot (Table 2).

The follow-up physical activity outcome was judged to be high-quality evidence, with no obvious problems across the five domains. The postintervention and follow-up sedentary behavior outcomes were both downgraded one level to moderate quality based on the fact that one of the two studies showed high risk of bias (serious inconsistency).

Subgroup and sensitivity analysis

One study showed an effect size that was markedly different from the other studies at follow-up. Removing this study did not have any impact on the pooled effect or heterogeneity levels.

Studies using self-report measures had a significant, small-to-medium effect size postintervention (d = 0.39 [95% CI = 0.19–0.59]; I^2 = 72%), whereas studies using objective measures showed a small, nonsignificant effect size (d = 0.14 [−0.01 to 0.30]; I^2 = 0%). Studies using self-report measures also had a small but significant effect size at follow-up (d = 0.23 [0.12–0.35]; I^2 = 24%), whereas studies using objective measures had a small nonsignificant effect size (d = 0.16 [−0.02 to 0.33]; I^2 = 0%).

Table 2 | GRADE summary of quality of evidence for the four main outcomes

Quality assessment							Number of patients		Effect	Quality	Importance
Number of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	Physical activity/ sedentary behavior interventions	Controls	Absolute (95% CI)		
Physical activity postintervention (assessed with: minutes of walking, moderate, or vigorous activity per week; steps per day)											
14	Randomized trials	Not serious	Serious[a]	Not serious	Not serious	Publication bias strongly suspected[b]	1,127	1,219	SMD 0.32 higher (0.16 higher to 0.48 higher)	⊗⊗○○ Low[a,b]	Important
Sedentary behavior postintervention (assessed with: minutes per day or week of sitting)											
2	Randomized trials	Serious[c]	Not serious	Not serious	Not serious[d]	None	211	303	SMD 0.05 fewer (0.23 fewer to 0.13 more)	⊗⊗⊗○ Moderate[c,d]	Important
Physical activity at follow-up (follow-up: range 24–124 weeks; assessed with: minutes of walking, moderate, or vigorous activity per week; steps per day)											
16	Randomized trials	Not serious	Not serious	Not serious	Not serious	None	1,069	1,121	SMD 0.21 higher (0.12 higher to 0.3 higher)	⊗⊗⊗⊗ High	Critical
Sedentary behavior at follow-up (follow-up: range 24–46 weeks; assessed with: minutes per day or week of sitting)											
2	Randomized trials	Serious[c]	Not serious	Not serious	Not serious[d]	None	184	227	SMD 0.11 fewer (0.3 fewer to 0.09 more)	⊗⊗⊗○ Moderate[c,d]	Important

CI confidence interval; *SMD Standardized Mean Difference*.

[a]Moderate to high level of heterogeneity, $z = 4.03$, $p < .001$. $I^2 = 69\%$.

[b]Uneven funnel plot suggesting that the overall effect is heavily influenced by two high powered, highly significant studies.

[c]Inconsistent risk of bias between the two studies. One study showed high risk of bias for blinding participants and reporting bias (inconsistent reporting of outcomes).

[d]Relatively small sample size based on only two studies. Although rated as moderate quality overall this outcome needs to be interpreted cautiously.

Studies targeting only physical activity had a small significant effect size postintervention (d = 0.29 [0.15–0.43]; I^2 = 52%), whereas studies targeting multiple behaviors had a small-to-medium, but nonsignificant effect size (d = 0.43 [−0.26 to 1.12]; I^2 = 93%). Studies targeting only physical activity showed a small significant effect size at follow-up (d = 0.22 [0.11–0.32]; I^2 = 10%), whereas studies targeting multiple behaviors showed a small nonsignificant effect size (d = 0.19 [−0.00 to 0.39]; I^2 = 0%).

Meta-regression

All covariates (intervention duration, follow-up duration, number of behavior change techniques, age of participants, 20 individual behavior change techniques) were entered into univariate models to calculate the percentage of among-study heterogeneity (adjusted R^2) explained by the covariate and the strength of the association between the covariate and effectiveness (β; Supplementary Table 5). Studies that included the behavior change techniques "Biofeedback," "Demonstration of the behavior," "Behavior practice/rehearsal," and "Graded tasks" showed larger effect sizes at postintervention than studies that did not. The large R^2 for the BCT "Biofeedback" was due to the 95% CIs from each subgroup (present vs. absent) not overlapping. Studies that included the behavior change techniques "Problem solving," "Review behavior goal," and "Feedback on behavior" showed a smaller effect size at postintervention than studies that did not.

At follow-up, there was minimal heterogeneity (3%). Therefore, subgroup analyses were utilized with a criterion of a difference in Cohen's d of >0.10 defined as meaningful, consistent with the meta-regression (Supplementary Table 6). Studies that included "Action planning," "Instruction on how to perform the behavior," "Prompts/cues," "Behavior practice/rehearsal," "Graded tasks," and "Self-reward" showed larger effect sizes at follow-up than studies that did not. Studies that included "Information about antecedents" had a smaller effect size at follow-up than studies that did not.

DISCUSSION

This review showed that interventions aiming to increase physical activity in healthy inactive adults are effective in promoting behavior change and behavior change maintenance. The two eligible interventions measuring sedentary behavior were not effective at either. The quality of the evidence was high for follow-up physical activity outcomes, moderate for both sedentary behavior outcomes, and low for postintervention physical activity outcomes. The majority of risk of bias ratings was judged as unclear, reflecting a problem with poor reporting of details essential for judgments of study quality. Problems with inadequate reporting extended to the TIDieR coding, with reporting of active control conditions a serious problem for replication. Items 11 and 12 of the TIDieR guidelines combine adherence and fidelity, and therefore even for studies that did contain this information, it was focused on attendance and engagement, and not on the delivery of content as planned. In fact, only one study assessed the fidelity of intervention content. This is of real concern for future research, as without the knowledge or measurement of fidelity, details of the effectiveness of interventions must be taken with caution, as it could be the case that the intervention was not delivered as planned. The behavior change technique coding provided a detailed summary of intervention components and showed the potential for a number of techniques to be associated with intervention effectiveness.

Using subgroup analysis, the studies classified as using objective measurements all utilized pedometers and overall were found to be ineffective. This may be due to overestimation in self-report measures [71], pedometers not accurately distinguishing between intensities of activity or capturing activities such as cycling [72], or reliability issues when compared with accelerometers [73]. Lastly, only one of the four studies stated that pedometers were sealed. Pedometers could therefore have been used for the unintended purpose of self-monitoring behavior, particularly in one study where self-monitoring was not a stated part of the intervention or control group. It is unfortunately beyond the scope of this review to analyze why this difference has occurred.

Comparison with other studies

This is the first review to analyze only studies with a minimum of 6-month postintervention follow-up. Exploring maintenance of behavior change after a significant period of time in which no intervention contact has been made with participants is essential to investigate whether positive behavioral changes can be sustained [74]. Previous reviews of physical activity interventions have found similar effect sizes for postintervention physical activity outcomes [1, 15, 26]. Two previous reviews of long-term effectiveness in physical activity outcomes have not truly captured follow-up outcomes because the majority of the studies only measured outcomes until the end of an active intervention period [14, 15]. The same issue was found in one previous review, which highlighted long-term outcomes for sedentary behavior in 16 studies [8].

This review was also consistent with previous ones in finding that combined physical activity and sedentary behavior interventions are ineffective in changing sitting time [8, 27]. Both previous reviews found only four very small RCTs of sedentary behavior interventions, none of which collected any follow-up outcomes [8, 27]. Unsurprisingly, the present review found no interventions targeting only sedentary behavior from 26 years of literature that fit our criteria. This highlights a need for more interventions to assess the maintenance of changes in sedentary behavior and to include measures other than sitting time. The BCT analysis was consistent with a previous review of interventions targeting obese adults (using an older taxonomy), which showed that demonstrating the behavior, using prompts and cues, prompting behavioral practice, setting graded tasks, and rewarding progress were associated with effectiveness [28]. This review did not however find that interventions containing self-monitoring were more effective, contrasting it with previous reviews using much more heterogeneous samples [8, 26].

Implications for research and practice

Despite physical activity interventions, showing statistically significant effectiveness at both time points, the effect sizes could not be translated into meaningful units to judge potential clinical significance. This reflects a common pattern from other reviews of physical activity interventions (e.g., [26, 34]) that cannot quantify overall improvements for practitioners and policy makers in a more useable manner (e.g., minutes per day of moderate physical activity) because physical activity is measured in such diverse ways. This problem has led to a recent call for the measurement of physical activity to be more standardized so that data can be pooled more meaningfully to further knowledge [75]. However, two previous reviews showed that effect sizes of $d = 0.19$ and $d = 0.18$ equated to increases of 15 and 73 min of physical activity per week and 496 and 620 steps/day, respectively, dependent on baseline activity levels [7, 76]. Given that the interventions in this review were in people with low levels of baseline activity and effect sizes were somewhat larger, the increases may have been greater, particularly at postintervention.

Previous research has shown that for overweight adults, experiencing health events or "teachable moments," such as a doctor recommendation about health can be the catalyst for long-term changes in diet and physical activity [11]. The interventions highlighted in this review were for healthy inactive adults, who were overall in the overweight category across the included studies. This represents an ideal population to intervene with, by for instance, an intervention delivered through primary care, to lessen the risk of developing serious health conditions. This review aids commissioners, practitioners, officers, and policy makers in the design of future physical activity interventions for this population by showing that the inclusion of heart rate monitors to track exertion during exercise, providing a demonstration of the behavior, prompting practice of the behavior (often in supervised exercise classes), and increasing the intensity and duration of exercise in progressive stages, may be effective in producing changes in physical activity—the last two may also produce changes that can be maintained over longer periods. In addition, including detailed plans to perform the behavior, providing instruction on how to perform the behavior, encouraging the use of prompts/cues as a reminder to exercise, and rewarding oneself for making efforts to increase physical activity may lead to sustained improvements in physical activity.

Strengths and limitations

This review is the first to investigate physical activity interventions specifically with healthy inactive adults, to draw a distinction between outcomes of behavior change and behavior change maintenance, and to use the latest taxonomy to analyze BCTs in relation to these two outcomes. The strengths of this review include the comprehensive terms and databases searched, the RCT design of the studies included, the quality assessment using GRADE, and the preregistration and published protocol. In addition, this is the first review to incorporate coding of TIDieR guidelines against published physical activity intervention descriptions, which highlighted key characteristics such as dose and frequency of intervention contacts. This fine-grained detail is important in contributing to ongoing efforts such as the Human Behavior Change Project that aim to build an ontology of behavior change which will allow intervention designers to answer what works, with what behaviors, for who, and why [77].

Due to the limitations of reviewing BCTs prechosen by other researchers, or perhaps not reported within manuscripts, this review could not comment on the remaining items from the BCT taxonomy v1. Also, given the small number of studies included in the meta-regression, this analysis had limited power and more studies would be needed to provide stronger evidence for the true effects of individual BCTs, particularly the large postintervention effect found for "Biofeedback." Also, although every effort was made to include only healthy inactive adults, some of the studies only provided basic baseline data on which to make this decision. Furthermore, only English language studies were included and, for resource reasons only 10% of the initial titles and abstracts were double screened.

CONCLUSIONS

The population highlighted in this review overall were inactive, overweight, and not reported to have any serious health conditions. This population is key in targeting individuals that may be at the tipping point of developing chronic health problems without sustained behavior change. Physical activity interventions are effective in changing physical activity and maintaining these changes, with the evidence for maintenance effects being of greater quality. There is no evidence to date that longer-term changes in sedentary behavior can be achieved by intervening with this population.

Overall reporting of behavioral interventions is in need of improvement. Adoption of the TIDieR guidelines, particularly details of fidelity assessment, and structuring the description of content using the BCT taxonomy v1 would vastly improve the ability of researchers, practitioners, and policy makers to interpret and replicate effective interventions. Standardization of physical activity measurement would also be hugely beneficial for the translation of evidence synthesis into practical recommendations for practitioners and policy makers. This review provides those working across the spectrum of physical activity promotion with key information on how to commission, design, and implement physical activity interventions for adults who are at heightened risk of ill health due to inactivity.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *Translational Behavioral Medicine* online.

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Compliance with Ethical Standards

Conflict of Interest: None to report.

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