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The effectiveness of a wearable activity tracker (WAT)-based intervention to improve physical activity levels in sedentary older adults: A systematic review and meta-analysis

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ABSTRACT: *Background:* The evidence shows that WAT-based interventions enhance the physical activity (PA) levels of young people by sustainably delivering behavior change techniques (BCTs). These results may not be replicable among older adults. This paper aims to evaluate the effectiveness of WAT-based interventions in improving PA levels in sedentary older adults. *Methods:* Eight electronic databases were searched for randomized controlled trials published January 2008 to December 2018. BCTs delivered by WAT aimed at increasing PA levels using step counts or time spent on moderate-to-vigorous (MVPA) exercise as an outcome were eligible for inclusion. *Results:* In nine out of the ten included studies, higher PA levels were seen in the intervention group than in the control group. One study where the participants' mean age was 80+ showed no significant increase in PA levels. Significant effects were also demonstrated from the meta-analysis, which included four studies using a passive control (i.e., the usual care or health information) on step counts ($n = 207$, Hedges $g = 1.27$, 95 % CI = 0.51–2.04, $p = 0.001$) and two studies on MVPA ($n = 83$, Hedge's $g = 1.23$, 95 % CI = 0.75–1.70, $p < 0.001$). A non-significant effect was found on step counts ($n = 201$, Hedge's $g = 0.22$, 95 % CI = −0.62 to 1.06, $p = 0.61$) in three studies that used an active control comparison group (i.e., traditional pedometer). *Conclusions:* A WAT-based intervention is effective at improving PA levels among older adults over the short term when compared with the usual care or health information. However, when compared with a traditional pedometer or when used among old-old adults, the results were inconclusive.

1. Introduction

Regular participation in physical activity (PA) confers a number of physical and psychological health benefits for older people. However, many older people are considered sedentary or physically inactive. Around 25%–60% of older adults failed to meet the recommended level of PA, which requires 150 min of moderate-intensity aerobic PA or 75 min of vigorous-intensity aerobic PA, or an equivalent combination of moderate to vigorous-intensity physical activity (MVPA) per week (Bauman, Merom, Bull, Buchner, & Fiatarone Singh, 2016). It was ob served that older people often have high dropout and non-adherence rates to different exercise programs due to lower self-efficacy in over coming barriers to maintaining a physically active lifestyle (Mullen et al., 2013). Adopting behavior change techniques (BCTs) including goal setting, feedback on performance, rewards contingent on successful behavior, and social support in the design of an exercise program is a common way to get old people to increase their self-efficacy to remain physically active (Olander et al., 2013). The traditional method of delivering BCTs by personal contact is costly, less flexible, and not sustainable due to limitations in time and venue (Lyons, Lewis, Mayrsohn, & Rowland, 2014). In addition, the effect is likely to stop once the program has been terminated and older people resume their sedentary lifestyle (Chase, 2015).

Nowadays, technology is becoming important in promoting a healthy lifestyle. A new trend in fitness technology, Wearable Activity Trackers (WATs) such as Apple Watch, FitBit, and UP® by JawBone are now easily available in the market (Mercer et al., 2016; Walker, Hickey, & Freedson, 2016). WAT is an electronic device that can be worn on the body as an accessory (Ruiz & Goransson, 2015), and integrated with a pedometer and accelerometer to measure physical movements such as step counts, energy expenditure, movements of different durations and intensities, and periods of inactivity (Mercer et al., 2016). WATs can record and provide users with feedback on their physical performance and activity levels.

When WATs collaborate with mobile devices to provide interactive BCTs, they allow users to do things such as self-monitor, set goals, and seek social support (Higgins, 2016; Shih, Han, Poole, Rosson, & Carroll, 2015), and also to record the data for regular reviews (Cadmus Bertram, Marcus, Patterson, Parker, & Morey, 2015; Lyons & Lewis, 2014; Ruiz & Goransson, 2015). Therefore, BCTs can be continuously delivered to users by WATs, to increase the self-efficacy of the users and encourage them to improve and sustainably maintain their PA levels with less professional support (Lyons & Lewis, 2014; Sullivan & Lachman, 2017; Taylor, 2014).

A systematic review of 11 studies was conducted with the aim of synthesizing information on the efficacy of using WAT versus WAT based interventions (Choi, Lee, Vittinghoff, & Fukuoka, 2016). Of the five studies in which a significant improvement was found in the par ticipants' physical activity levels, all went beyond simply giving WATs to the participants and involved interventions grounded in BCTs. The authors of that review argued that WATs might be more appropriately used as a medium for delivering BCTs (i.e., as a WAT-based intervention grounded in BCTs), rather than as an intervention in and of the device itself (Choi et al., 2016). Therefore, WAT-based interventions grounded in BCTs are the major focus in the current review.

A number of reviews have been conducted to examine the effec tiveness of WAT-based interventions grounded in BCTs in promoting PA levels. Several reviews concluded that interventions applying computer, mobile, and wearable technologies are effective at increasing PA levels among younger adults (Goode et al., 2017; Lewis, Lyons, Jarvis, & Baillargeon, 2015; Stephenson, McDonough, Murphy, Nugent, & Mair, 2017). A recent systematic review of 28 papers with 3646 participants' age ranged from 17.9 years to 79.5 years included 13 studies that tar geted young adults ($\leq$39.9 years), 14 studies that targeted middle aged adults (40–64.9 years), and only 1 study that target adults over the age of 65 (Brickwood, Watson, O'Brien, & Williams, 2019). This review included studies using WAT as either the basis of the intervention (11 studies) or as a component of a multifaceted intervention, such as one using established behavioral change techniques (17 studies). The result also showed that those interventions that adopted BCTs appeared to have a greater effect on PA levels when compared with control groups than those interventions that included just the use of WAT compared with control groups. However, no subgroup analysis has been con ducted to determine if the age of the participants influenced the ef fectiveness of the intervention. Of all of the studies that were included in this review, 18 specified that the participants must have regular access to the Internet, a computer, and/or a smartphone. It is believed that the findings of this review tended to represent people who were more ready to use technology or more accepting of the use of tech nology in their daily life.

Whether or not similar results can be replicated in older adults, particularly those who are sedentary or physically inactive, is unclear. This is because all of the abovementioned reviews focused on exploring the effects on adults in general instead of older people in particular. Studies have shown an increased trend among people aged 55 or above to adopt technology (Lyons, Swartz, Lewis, Martinez, & Jennings, 2017; Mini & Janetius, 2012), although many older adults are also fearful of technology and of the associated cost of using a new technology (Deng, Mo, & Liu, 2014), leading to low levels of adoption or to non-adoption. Thus, the acceptability of technology in daily life varies among people aged ≥ 55. It is interesting to explore the effects of using WAT, which is a kind of technology used in daily life by people aged 55 or above. Although some older adults were highly interested in using wearable technology (Kekade et al., 2018), the continual use of a WAT leading to an increase in PA levels depends on recognizing the long-term benefits of tracker use, social support, and internal motivation (Kononova et al., 2019). Thus, the objective of this review was to evaluate the effec tiveness of WAT-based interventions aimed at improving PA levels in sedentary older people with aged ≥ 55 and to describe the different BCTs that were adopted in different interventions.

2. Material and methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) (Moher, Liberati, Tetzlaff, & Altman, 2009). The BCTs adopted by the different WAT-based interventions were coded ac cording to BCT Taxonomy (v1) (Michie et al., 2013). The review pro tocol was registered in PROSPERO (CRD42018109609).

2.1. Search strategy

A combination of Medical Subject Headings (MeSH) and free text terms was used to search for eight databases, namely, the Cochrane Library, MEDLINE, EMBASE, CINAHL, PsycINFO, Science Direct, Web of Science, and PubMed, for potential relevant abstracts. Search stra tegies were developed according to the two primary concepts of this review: the use of a WAT-based intervention and its effectiveness in enhancing the PA levels of sedentary older adults. To identify studies using a WAT-based intervention, we used search terms such as *Wearable activity tracker*, *Wearable device*, and *Fitness tracker*, and the names of different commercial

WATs, such as *Pedometer* and *Accelerometer*. Search terms that were used to identify studies focusing on modifying the behavior of sedentary older adults to increase their PA levels in cluded *Behavio*r change*, *Physical activity*, *Physical fitness*, *Sedentary be havio*r*, *Step count*, and *older or elder* or Community dwelling or Independent living* (Appendix A: Supplementary online information). These terms were revised appropriately for different databases. Additional methods of searching included hand searches by reviewing the reference lists of all of the relevant articles that were identified from the electronic databases, Google Scholar, and hard copies in university libraries to identify any articles missed by the database search.

2.2. Eligibility criteria

This review included randomized controlled trials (RCTs) published in English between January 2008 and January 2018. The aim of the trials was to evaluate the effects of WAT-based interventions in im proving PA levels among community-dwelling sedentary older adults. WATs began to become popular in 2008. That was the year that new wearable technologies began to be put to healthcare uses; therefore, in reviewing the recent trend of using WAT-based interventions, the search was limited to articles published starting from the year 2008 (Arnault, 2015).

The abstracts of the identified articles, followed by the full text of the articles, were reviewed against the inclusion and exclusion criteria listed below:

2.2.1. Inclusion criteria

- All of the included trials were published in English.
- The participants were community-dwelling older adults with a mean age of > 55 years who were following a sedentary lifestyle, regardless of gender and race.

- WAT-based interventions were adopted as a major medium for delivering BCTs to increase and maintain the participants' PA levels.
- RCTs with any type of control condition, including passive and active controls. A previous systematic review of 32 studies demonstrated that the use of a pedometer had a moderate effect on increasing the PA levels of older people (Kang, Marshall, Barreira, & Lee, 2009). Thus, in the current review, we would like to determine whether the type of control (i.e., active versus passive) would influence the effect of the WAT-based intervention. A passive control is defined as a no-treatment control or a minimal-treatment control, such as a group that receives the usual care or a health talk. An active control is defined as a group that receives an alternative treatment, such as being given a traditional pedometer without an online interactive platform (Lindquist, Wyman, Talley, Findorff, & Gross, 2007).
- Time (minutes per day) spent on MVPA and daily step count were the two primary outcomes that reflected a person's PA levels; these needed to be measured objectively using an instrument such as an accelerometer.

2.2.2. Exclusion Criteria

Studies were excluded if they were aimed at

- validating the accuracy of WATs;
- examining the feasibility (e.g., acceptability and perception) of using WATs among other people;
- evaluating the effects of WAT-based interventions delivered in hospital or laboratory settings;

- investigating the effects of WAT-based interventions for managing chronic diseases

2.3. Study selection and data extraction

The search results were imported into EndNote X7 bibliographic software (Thompson Reuters, San Francisco, CA, USA) and duplicate studies were removed. The titles and abstracts of all identified studies were screened independently by two researchers (JL and PK) to identify potentially relevant papers. The preliminary results of the review were compared by both researchers (JL and PK) to reach an agreement. Once agreement had been reached, the full-text version of every potentially relevant study was obtained and reviewed by the same researchers (JL and PK) independently, based on the inclusion and exclusion criteria. The researchers came to a consensus on the eligibility of the articles by discussing the results of their assessment. Where uncertainties arose regarding the inclusion of a study, a consensus was achieved through a discussion among the members of the research team.

A specific data extraction matrix was created to collect information from each included study, including the author, year, country of origin, study design, characteristics of the participants, definition of inactive/ sedentary used for sample recruitment, intervention description, WAT used in the intervention, personal contact in the intervention, com parison group, PA outcome measures, follow-up time points, attrition rate, and major findings.

2.4. Coding of the behavior change techniques adopted in the WAT-based intervention

All of the interventions were coded independently by two trained BCT coders (JL and CC) using BCT Taxonomy (v1) (Michie et al., 2013). BCT Taxonomy is a hierarchically-clustered taxonomy of 93 distinct BCTs that permit and facilitate the precise reporting of complex beha vioral interventions (Michie et al., 2013). Each adopted BCT that was aimed at increasing and sustaining the PA level of the participants was coded based on the intervention described in the methodology sections of the identified papers and their published study protocols (when available). The BCTs delivered through the WATs or by human contact were coded separately. To minimize bias in the interpretation of dif ferent items in the BCT Taxonomy, two papers at a time were coded independently by the two trained BCT coders. Any inconsistencies in coding were reviewed and a consensus reached, prior to the analysis of the next two papers. If uncertainties persisted, the members of the re search team discussed the content to achieve a consensus. This procedure continued until the BCT coding was completed in all of the included studies.

2.5. Quality assessment

The quality appraisal for each study was assessed initially by the two researchers (JL and PK) using the Cochrane Collaborations' risk of bias assessment tool (Higgins et al., 2011). The assessment tool in cluded seven items related to "random sequence generation," "alloca tion concealment," "blinding of the participants and personnel," "blinding of the assessment of outcomes," "incomplete data on out comes," "selective reporting of outcomes," and others (e.g., baseline imbalance). Each item was rated as "high risk," "low risk," or "unclear risk." The final score was discussed by the two researchers (JL and PK), and any disagreements about the rating were solved by having the re search team come to a consensus.

Studies were judged to be at a low risk of selection biases if the procedures of randomization and allocation concealment were clearly described. The PA levels in all of the included trials were measured objectively by the WAT. Studies that used a type of accelerometer employed in research (such as the ActiGraph GTX3), with the partici pants blinded to the PA-related data, were judged to be at a low risk. Trials that used the WAT for delivering interventions at the same time as the participants' PA levels were measured for outcome analyses were judged to be at a high risk of detection bias because of the potential for the development of expectation bias in the participants. Where a dropout rate of more than 20 % in any group for outcomes of up to one year was reported, studies were judged to be at a high risk of bias for incomplete outcome data. Studies were judged to be at a low risk of bias for selective outcome reporting if the final publication of the study followed what had been planned in a published protocol paper. Where no protocol paper was publicly available, studies were deemed to be at a low risk of selective outcome reporting if all of the outcomes men tioned in the method section were reported.

The aim of this assessment of the risk of bias was to determine the quality of a study, but the risk of bias was not used as a criterion for the inclusion of a study in this review. A trial was judged to be at a low risk of bias overall when all of the items in the risk of bias assessment tool were rated as being at "a low risk of bias". Conversely, a study was judged to be at a high risk of bias when it reported a procedure that would be judged as being at "a high risk of bias" or "unclear" in any item. Due to the nature of the intervention, it was impossible to blind the participants; thus, we did not include the "blinding of participants or personnel" when determining a study's overall risk of bias (Shrestha et al., 2018).

2.6. Data analysis

For the narrative analysis, data on each included study were entered into the data extraction table, with each study treated as a separate case. Descriptive characteristics of the studies were categorized manually.

Statistical analyses were conducted using the computer software program Review Manager 5.1 (RevMan). We aimed to evaluate the effects of WAT-based interventions on daily step counts, as well as on time (minutes/day) spent in MVPA. Data were pooled to compare the intervention and comparison groups in terms of post-intervention standardized mean differences (SMD) and their 95 % confidence in tervals in step counts and time spent on MVPA (minutes/day). Both the passive control group (PCG) (such as those who received the usual care or health information) and the active control group (ACG) (such as those who were asked to use a simple pedometer) were compared with the experimental group using a WAT-based intervention. The results were calculated using a random effects model. The heterogeneity of the studies was assessed using an I2 value of ≤ 50 % as an indication of low heterogeneity (Higgins, Thompson, Deeks, & Altman, 2003). We calculated overall effect sizes and their 95 % confidence intervals to estimate their pooled treatment effects.

3. Results

3.1. Literature search results

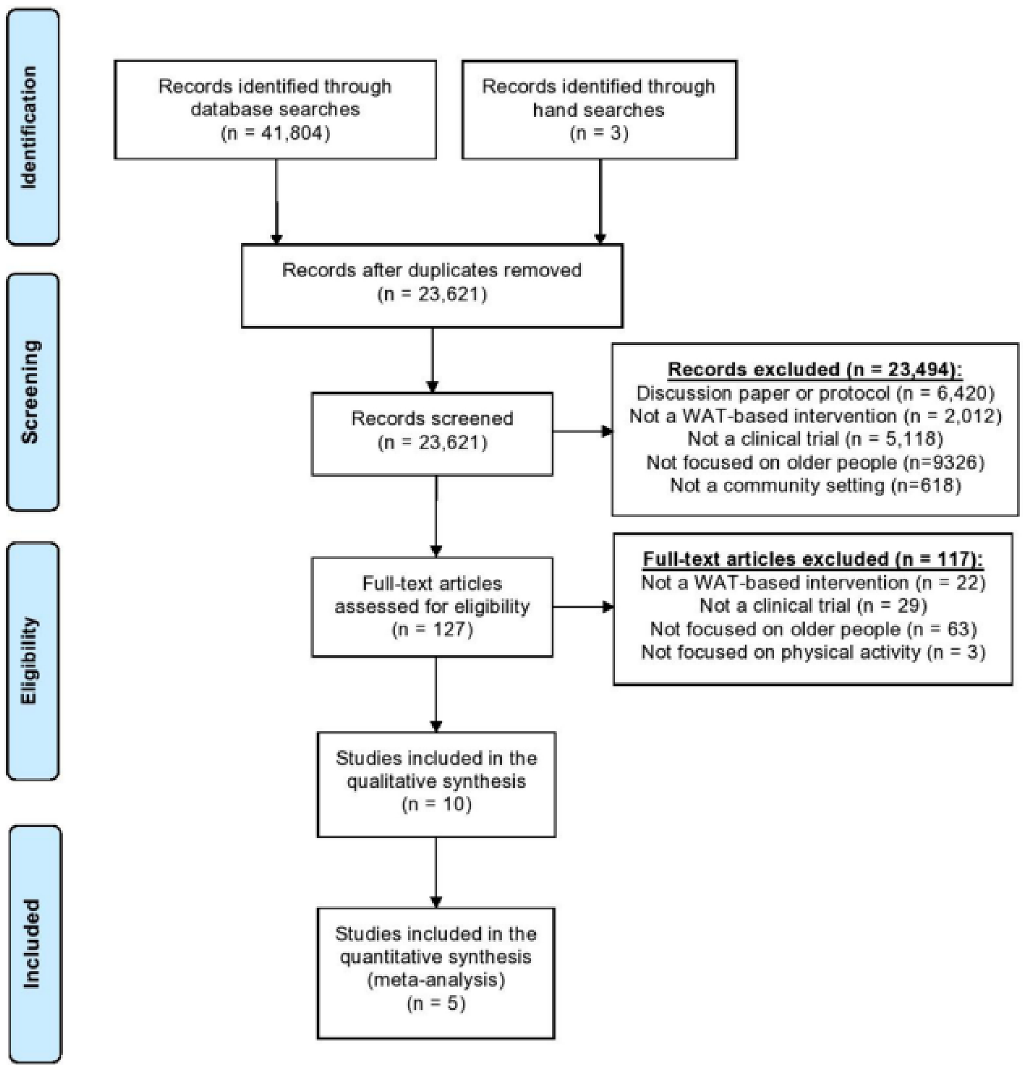

Fig. 1. Literature research.

Fig. 1 displays the PRISMA flow diagram of the literature search. Following our search strategy, we initially identified 41,807 publications. After the removal of duplicates, 23,621 abstracts were screened. Book chapters, study protocols of published studies, non-English-language papers, non-clinical trials, and studies that did not focus on older people were excluded (n = 23494). The remaining 127 articles were selected for further assessment. One hundred and seventeen articles were excluded for the following reasons: (a) the studies were not randomized controlled trials (n = 29); (b) the intervention did not involve the use of a wearable activity tracker (n = 22); (c) the study population was aged below 55 (n = 63); and (d) the outcome did not focus on a physical activity (n = 3). In the end, 10 studies that fulfilled the selection criteria were analyzed (Ashe et al., 2015; Bickmore et al., 2013; Cadmus-Bertram et al., 2015; Lewis et al., 2017; Lyons et al., 2017; Martin et al., 2015; Rowley et al., 2017; Suboc et al., 2014; Thompson, Kuhle, Koepp, McCrady-Spitzer, & Levine, 2014; Wijsman et al., 2013). A meta-analysis was conducted of the results of five stu dies that used step counts with no active treatment (i.e., PCG) or an alternative treatment (i.e., ACG), and time spent on PA with no active treatment (i.e., PCG) (Ashe et al., 2015; Lewis et al., 2017; Lyons et al., 2017; Rowley et al., 2017; Suboc et al., 2014). The outcome data in the remaining studies were insufficient to conduct a statistical analysis, even after we attempted to contact the authors of the studies to obtain more information.

3.2. Overview of the included studies

Table 1 offers an overview of all of the included studies and the extracted main data. The 10 studies, which included 1035 participants, were conducted in community settings in the United States, Canada, and the Netherlands between 2013 and 2017. All of the studies included sedentary/inactive community-dwelling participants aged $\geq$55 years. Of the participants, 64.4 % were female. Eight out of ten included studies used "inactive" to define their target participants, whereas "sedentary" was used in two studies (i.e., Suboc et al., 2014; Thompson et al., 2014). Although the criterion of inactive or sedentary used in the studies varied, the methods used to measure inactive or sedentary levels were similar. In their studies, Rowley et al. (2017) used daily step counts of < 7500 as measured by pedometer to identify in active participants, whereas Suboc et al. (2014) used ≤ 8000 steps/day to identify participants with a sedentary lifestyle. Cadmus-Bertram et al. (2015) defined as

Table 1
Summary Table of the included studies.

Author/ year/ country	Study design	Sample size	Age [Mean ± SD] / Gender	Definition of inactive / sedentary for sample recruitment	Aim	Intervention	WATs used in the intervention	Personal contact in the intervention	Comparison group	Outcome measure of PA	Follow-up time points	Attrition rate	Major findings
Ashe MC, 2015, Canada	2-arm pilot RCT	Total: 25 IG: 13 CG: 12	IG: 64.8 ± 4.6 CG: 63.1 ± 4.8 Female: 100 %	Inactive was defined as not engaged in strength training or > 30 min of brisk walking or moderate exercise / week; based on self-reporting	↓SB + ↑ PA	A 6-month group-based education and social support, involving individualized physical activity prescriptions (named Activity 4-1-1), where Fitbit was used as an activity monitor. There were 2 main phases: (1) a ramp-up phase (consisting of 4 weekly sessions) and (2) an activation phase (consisting of 5 monthly sessions).	Fitbit One provided immediate feedback on PA. An online tool monitored sleep quality and nutrition and facilitated social networking.	The study coordinator led the group sessions; Exercise professionals gave exercise prescriptions; A pedorthist advised on choosing appropriate footwear for the PA.	Health information	Average daily step count and MVPA (min/ day) by hip-worn ActiGraph GTX3+ (LLC, Fort Walton Beach, FL, USA)	3 months (midpoint) and 6 months (imme-diate intervention effect)	IG:0% at 3 months and 7.69 % at 6months [loss of 1 participant] CG: 0% at 3 months and 33.33 % at 6 months [loss of 4 participants] Overall: 20 % at 6 months	A statistically significant between-groups difference in step count (i.e., the IG had an average of 2,080 [95 % CIs 704, 4,918] more steps/day at 6 months compared with the CG. No statistically significant differences between groups in MVPA or sedentary time.
Bickmore TW, 2013, US	2-arm RCT	Total: 263 IG: 132 CG: 131	IG: 71.7 ± 5.6, Female: N = 89 (67.4 %) CG: 70.8 ± 5.2, Female: N = 72 (55 %)	Inactive was defined as not engaged in regular moderate-intensity or greater PA ≥ 3 days/week for at least 20 min/day over the previous 6 months; assessed by self-reporting	↑PA	A 12-month intervention involving portable tablet computers with touch screens for the IG to use for 2 months (phase 1). The IG were directed to connect their pedometers to the computers and interact with a computer-animated virtual exercise coach daily to discuss their progress and to set walking goals. After returning the computers after 2 months (phase 2), the participants were then instructed to interact with the virtual exercise coach in a clinic kiosk for the	A digital pedometer (HJ-720ITC, Omron Healthcare, Inc., Bannockburn, IL) provided immediate feedback on PA. An animated computer character simulated face-to-face conversations with individual participants using pre-set messages.	Nil.	Pedometer for tracking daily step counts	Average daily step count by digital pedometer (HJ-720ITC, Omron) worn on the waist or placed in a pants pocket	2 months (phase 1: imme-diate intervention effect) and 12 months phase II: (long-term effect)	IG: 4.5 % at 2 months and 15.2 % at 12 months [loss of 6 and 15 participants at 2 and 12 months, respectively] CG: 5.3 % at 2 months and 13 % at 12 months [loss of 7 and 13 participants at 2 and 12 months, respectively] Overall: 5% at 2 months and 14 % at 12 months	The IG walked significantly more steps than the CG at 2 months (adjusted mean 4,041 vs. 3,499 steps/day, P = .01), but this effect waned by 12 months (3,861 vs. 3,383, P = .09).

Table 1 (*continued*)

Author/ year/ country	Study design	Sample size	Age [Mean ± SD] / Gender	Definition of inactive / sedentary for sample recruitment	Aim	Intervention	WATs used in the intervention	Personal contact in the intervention	Comparison group	Outcome measure of PA	Follow-up time points	Attrition rate	Major findings
						following 10 months.							
Cadmus-Bertram LA, 2015, US	2-arm pilot RCT	Total: 51 IG: 25 CG: 26	IG: 58.6 ± 6.5 CG: 61.3 ± 7.5 Female: 100 %	Inactive was defined as performing < 60 minutes/ week of MVPA measured by ActiGraph GT3X+	↑PA	A 16-week intervention in which the IG received Fitbit One, an instructional session aimed at training the participants in self-monitoring skills combined with other self-regulatory skills (e.g., goal setting, frequent behavioral feedback). Individualized goals were set for the first 4 weeks of the study (using data observed on the baseline ActiGraph), and the participants committed to a specific plan to achieve these goals. A follow-up call at week 4 was used to evaluate progress and refine goals.	Fitbit One displayed PA-related data; information on PA intensities and temporal patterns were also available on the website.	The study coordinator demonstrated how to download and use the software / website; provided training to the participants on self-monitoring and self-regulatory skills.	Pedometer and printed tips for increasing step counts and completing a brief goal-setting process based on steps observed on the ActiGraph at baseline	MVPA (min/ day) and step count by hip-worn ActiGraph GT3Xþ	16 weeks (immediate intervention effect)	IG: 0% CG: 7.7 % [loss of 2 participants] Overall: 3.9 %	In a within-group comparison, the IC showed a significant increase in time spent on MVPA and step count, compared to non-significant increases for the CG. However, the between-group tests did not show a significant difference.
Lewis ZH, 2017, US	2-arm pilot RCT	Total: 40 IG: 20 CG: 20	IG: 64 ± 5.1 Female: N = 17 (85 %) CG: 63.2 ± 5.7 Female: N = 13 (65 %)	Inactive was defined as < 60 min/week of PA by self-reporting	↑PA	A 12-week intervention in which the IG received a Jawbone UP24 wearable device after receiving 5A's counseling from a counselor during the first assessment prior to randomization. Participants were instructed to wear the device daily and sync the data	A UP24 wearable device manufactured by Jawbone and a UP application (mobile app) provided feedback on PA. A UP app recorded and analyzed the participants' PA progress and interactions with other participants.	A counselor provided counseling lasting approx. 5 – 10 min on the contents of the 5A's exercise prescription (goals and action plans).	Digital pedometer and activity log to record the CG participants' daily steps, activity time, and distance walked as measured by the pedometer	Steps per day and MVPA (min/day) by a Sense Wear Armband	12 weeks (immediate intervention effect)	IG: 5% [loss of 1 participant] CG: 35 % [loss of 7 participants] Overall: 40 %	The IG increased their PA by 11.1 min/day, while the CG maintained their level of activity (0.2 min/day), with no significant group difference.

Table 1 (*continued*)

Author/ year/ country	Study design	Sample size	Age [Mean ± SD] / Gender	Definition of inactive / sedentary for sample recruitment	Aim	Intervention	WATs used in the intervention	Personal contact in the intervention	Comparison group	Outcome measure of PA	Follow-up time points	Attrition rate	Major findings
						to the Jawbone UP app installed in their smart phone. The IG were encouraged to socialize with other participants in the group via the app.							
Lyons EJ, 2017, US	2-arm pilot RCT	Total: 40 IG: 20 CG: 20	IG: 61.25 ± 5.00, Female: N = 17 (85 %) CG: 61.70 ± 6.26, Female: 17 (85 %)	Inactive was defined as excluding self-reported habitual physical activity of more than 60 min per week	↓SB + ↑ PA	A 12-week program with the IG receiving a Jawbone UP24 monitor, a tablet with the Jawbone Up app installed, and brief weekly telephone counseling. Participants set daily and weekly step goals and used the monitor's idle alert to notify them of when they were sedentary for more than 1 h. Interventionists provided brief counseling once per week by telephone.	A wearable electronic activity monitor (Up24, Jawbone) provided feedback on PA. A mini tablet mobile device with a pre-loaded UP app recorded and analyzed the participants' PA progress.	A face-to-face orientation was held to guide the participants on the use of devices and deliver the BCT. Weekly telephone counseling was given to monitor progress.	Wait list control, received no intervention	Time spent (min/day) on PA, step count, mean steps per day were measured by a thigh-worn ActivPAL device (PAL Technologies Ltd, Glasgow, Scotland)	6 weeks (mid-point) and 12 weeks (imme-diate intervention effect)	IG: 5% [loss of 1 participant] at 12 weeks CG: 5% [Loss of 1 participant] at 12 weeks Overall 5% at 12 weeks	A statistically significant difference between groups was identified in stepping time per day with an effect size of d = 0.35, but not in step count per day with an effect size of d = 0.26, or sedentary time per day with an effect size of d = 0.21.
Martin SS, 2015 US	3-arm RCT with sequential randomization	Total: 48: IG 1: 16 ACG: 16 PCG: 16	IG 1: 55 ± 8 Female: N = 8 (50 %) ACG: 58 ± 8 Female: N = 7 (44 %) PCG: 60 ± 7 Female: N = 7 (44 %)	Inactive was defined as < 3days/week of MVPA lasting ≥ 30 min/day based on IPAQ by self-reporting	↑PA	A 5-week program in which the IG received both an activity tracker to monitor their step count and an app to monitor their PA level. Smart texts provided by smartphone delivered coaching 3 times/day aimed at individual encouragement and fostering feedback loops by a fully automated, physician-written, theory-based	Digital physical activity tracking (Fitbug Orb, Chicago, IL) provided immediate feedback on PA; A Fitbug app provided a history tab allowing PA-related data from previous days and smart text to be reviewed.	Nil.	ACG: Were provided with a digital physical activity tracker similar to that provided to the IG PCG: No intervention besides giving a blinded WAT	Step count and time spent on PA and aerobic exercise (min/day) measured by a wrist-worn Fitbug Orb Aerobic time was defined as the time spent walking continuously for > 10 min without breaking for > 1 min	3 weeks (midpoint) and 5 weeks (immediate intervention effect)	IG: 0% ACG: 0% PCG: 0% at 3 weeks; 6.25 % [Loss of 1 participant] at 5 weeks Overall 2.08 % at 5 weeks	The IG (n = 16) significantly increased their daily steps over the ACG (n = 16) by 2,534 ($P < 0.001$) and over the PCG (n = 16) by 3,376 ($P < 0.001$). The IG increased their total activity time by 21 min/day (a 23 % increase) and aerobic time by 13 min/day (a 160 %

Table 1 (*continued*)

Author/ year/ country	Study design	Sample size	Age [Mean ± SD] / Gender	Definition of inactive / sedentary for sample recruitment	Aim	Intervention	WATs used in the intervention	Personal contact in the intervention	Comparison group	Outcome measure of PA	Follow-up time points	Attrition rate	Major findings
						algorithm using real- time activity data and 16 personal factors with a goal of 10,000 steps/day.							increase), which was highly statistically significant compared to the ACG and PCG.
Rowley TW, 2017, US	3-arm RCT	Total: 170 IG: 57 ACG: 62 PCG: 51	IG: 67.4 ± 6.4, Female: N = 46 (81.3%) ACG: 68.3 ± 7.1, Female: N = 48 (78.5 %) PCG: 66.1 ± 4.9, Female: N = 40 (78.6 %)	Inactive was defined as < 7,500 steps per day (measured by a digital pedometer)	↑PA	A 12-week intervention in which the IG received a pedometer and an interactive website for education, goal setting, rewarding, and feedback. Participants were instructed to log on to the website once a week to receive information, which included: - Phase 1 (wks. 1-3): PA awareness boosting. - Phase 2 (wks. 4-12): continued PA information plus goal setting, barrier identification, and professional support.	Digital pedometer (Omron HJ-7201TC) provided feedback on PA; an interactive website provided BCTs and education.	A trained behaviorist and member of the research team hosted the online forum and Q and A sessions.	ACG: provided with a digital pedometer same as that given to the IG PCG: website intervention on the benefits of joining this study	Step count by Omron HJ-720ITC pedometer (no mention of where the participants wore the device)	12 weeks (imme-diate intervention effect)	IG: 19 %; [loss of 11 participants] ACG: 18 %; [loss of 11 participants] PCG: 37 % [loss of 19 participants] Overall: 24 %	The ACG ($p < .001$) and IG ($p < .001$) increased their step count pre-to-post test, at levels higher than that of the PCG group at 12 weeks (ACT, $p < .001$; PCG, $p < .001$). There was a significant group, time, and Group X Time interaction ($p < .001$) in step count among the three groups. The IG group had a higher step count at 12 weeks than the ACG group ($p < .001$).
Suboc TB, 2014, US	3-arm RCT	Total: 114 IG: 34 ACG: 38 PCG: 42	IG: 63 ± 8, Female: N = 12 (40 %) ACG: 64 ± 7, Female: N = 14 (8.9%) PCG: 62 ± 7, Female: N = 10 (24.4 %)	Sedentary was defined as participants who averaged ≤ 8,000 steps /day in the past week measured by a pedometer (Omron Hj-720ITC) and an accelerometer (GTX3; ActiGraph); participants were blinded to the step count during the recruitment stage	↑PA	A 12-week intervention in which the IG were given a pedometer combined with an automatic interactive website to receive frequent feedback, self-regulation, education, practice in realistic BCTs and goal setting, and rewards.	A digital pedometer worn on a belt provided the step count; A secure website through the University of Wisconsin-Milwaukee provided BCTs	An "ask the expert" session was delivered by an inter-ventionist through an online interactive program to asnwer the participants' questions.	ACG received a pedometer and completed a brief goal-setting process PCG received no intervention	MVPA (min/ day) and step count by an ActiGraph GT3X worn on the belt	12 weeks (imme-diate intervention effect)	IG: 11.76 % [loss of 4 participants] ACG: 5.26 % [loss of 2 participants] PCG: 2.38 % [loss of 1participant] Overall: 6.14 %	The average step count increased significantly among the IG, ACG, and PCG for time X group interaction ($P < 0.001$). There was no significant difference between the IG and ACG in their12-week step counts ($P = 0.16$). The time spent on MPA

Table 1 (*continued*)

Author/ year/ country	Study design	Sample size	Age [Mean ± SD] / Gender	Definition of inactive / sedentary for sample recruitment	Aim	Intervention	WATs used in the intervention	Personal contact in the intervention	Comparison group	Outcome measure of PA	Follow-up time points	Attrition rate	Major findings
													increased significantly among the IG, ACG, and PCG for the time X group interaction (P < 0.001). There were no significant differences in the amount of MPA between the IG and ACG at the conclusion of the intervention period (p = 0.08).
Thompson WG, 2014, US	2-arm RCT	Total: 49 IG: 25 CG: 24	79.5 ± 7.0, Female: N = 39 (79.6 %) IG 79.1 ± 8.0, Female: N = 19 (76 %); CG: 79.8 ± 6.0, Female: N = 20 (83.3 %)	Sedentary lifestyle was defined as preforming ≤ 30 min of vigorous activity or ≤ 90 min of moderate activity per week by self-reporting	↑PA	A 48-week intervention, which was divided into two phases: The IG received a Fitbit accelerometer for the first 24 weeks (Phase I) with feedback from the device, and weekly exercise counseling based on the teaching and BCT materials from the Go4life website, by telephone and through face-to-face consultations every two months to refine their goals. The IG group continued to use a Fitbit accelerometer and to receive feedback with no counseling in the 2nd 24 weeks (phase II).	FitBit (San Francisco, CA), provided feedback on PA.	A counselor worked with each individual subject to increase their physical activity levels using Go4Life materials developed by the National Institute on Aging at NIH (www.Go4Life.nia.nih.gov), with the contents of the counseling mainly guided by BCT concepts.	Fitbit without receiving any feedback from the device for the first 24 weeks Fitbit with feedback from the device and received exercise counseling in the 2nd 24 weeks	Time spent on PA measured by a waist-worn Tr—axial accelerometer (MSR Electronics GmBH, Seuzach, Switzerland)	6 months (phase 1; immediate intervention effect) and 12 months (phaseII: long-term effect)	IG: 4% [loss of 1 participant] at 6 months IG: 0% at 12 months CG: 0% at both 6 and 12 months. Overall: 2.04 %	There were no differences within either group or between groups from 6 to 12 months on any of the variables.
Wijsman CA 2013, Netherlands	2-arm RCT	Total: 235 IG: 119 CG: 116	IG: 64.7 ± 3.0	Inactive was defined as having < 3 h of	↑PA	A 12-week intervention in which the IG	An activity monitor from DirectLife	Coaching included general recommen-	Wait list control,	MVPA (min/ day) measured by	13 weeks (imme-diate	IG: 4.2 % [loss of 5 participants]	Daily physical activity measured by the

Table 1 (*continued*)

Author/ year/ country	Study design	Sample size	Age [Mean ± SD] / Gender	Definition of inactive / sedentary for sample recruitment	Aim	Intervention	WATs used in the intervention	Personal contact in the intervention	Comparison group	Outcome measure of PA	Follow-up time points	Attrition rate	Major findings
			Female: N = 47 (39.5 %) CG: 64.9 ± 2.8 Female: N = 49 (42.2 %)	exercise weekly; assessed by GPPAQ, a self-reported general practice physical activity questionnaire		received an Internet program called Philips DirectLife, which consisted of an accelerometer-based activity monitor, a personal website, and a personal e-coach, who provided regular by email updates of the PA status of individuals and gave advice to increase their PA.	(Philips), which was a tri-axial Accelerometer, measured daily PA. A commercially available Web-based physical activity program (DirectLife, Philips, Consumer Lifestyle, Amsterdam) was used to upload PA-related data.	dations on physical activities, and coaches were available to answer further questions and give advice by email.	received no intervention	tri-axial accelero-meter (GENEActiv, Kimbolton, Cambs, United Kingdom) worn on the ankle and wrist	intervention effect)	CG:3.45 % [loss of 4 participants] Overall: 3.83 %	wrist-worn accelerometer increased by 11% in the IG, and by 5% in the CG but there was no significant between-group difference (P = 0.11). Daily physical activity measured by an ankle-worn accelerometer increased by 46 % in the IG and 12 % in the CG with a significant difference ($P < 0.001$) in the between-groups comparison. After processing of the data, this corresponded to a daily increase of 11 min in MVPA in the IG versus 0 minutes in the CG with a significant difference ($P < 0.001$) in the between-groups comparison.

BCT: Behavioral change techniques; CI: Confidence intervals; (A/P)CG: (Active/Passive)Control group; IG: Intervention group; MVPA: Moderate-to-vigorous intensity physical activity; IPAQ: International Physical Activity Questionnaire ; PA: Physical activity; RCT: Randomized controlled trial; SB: sedentary behavior; US: United States.

inactive those who performed < 60 min/week of MVPA as measured objectively using an ActiGraph GT3X (Cadmus Bertram et al., 2015). The remaining six studies used self-reported data on time spent on PA to define an inactive lifestyle (Ashe et al., 2015; Bickmore et al., 2013; Lewis et al., 2017; Lyons et al., 2017; Martin et al., 2015; Wijsman et al., 2013). Similarly, drawing on self-reported data, Thompson et al. (2014) defined as sedentary those who spent ≤ 30 min/week on vigorous PA or < 90 min/week on moderate PA. The standard varied from < 30 min/week of moderate PA (Ashe et al., 2015) to < 3 days/week of MVPA lasting ≥ 30 min/day (Martin et al., 2015).

3.2.1. Design of the randomized controlled trials

Seven studies were two-armed (Ashe et al., 2015; Bickmore et al., 2013; Cadmus-Bertram et al., 2015; Lewis et al., 2017; Lyons et al., 2017; Thompson et al., 2014; Wijsman et al., 2013), of which four were pilot studies (Ashe et al., 2015; Cadmus-Bertram et al., 2015; Lewis et al., 2017; Lyons et al., 2017). Three studies were three-armed (Martin et al., 2015; Rowley et al., 2017; Suboc et al., 2014) with both active and passive comparison groups. The types of comparison groups varied between studies. Six studies provided health information or no treatment to the (passive) comparison group (Ashe et al., 2015; Lyons et al., 2017; Martin et al., 2015; Rowley et al., 2017; Suboc et al., 2014; Wijsman et al., 2013). Seven studies provided the (active) comparison group with a simple pedometer or accelerometer with no connection to an interactive online or mobile platform (Bickmore et al., 2013; Cadmus-Bertram et al., 2015; Lewis et al., 2017; Martin et al., 2015; Rowley et al., 2017; Suboc et al., 2014; Thompson et al., 2014).

3.2.2. Intervention components

All of the interventions were designed to increase daily PA levels, and two also aimed to reduce sedentary behavior (Ashe et al., 2015; Lyons et al., 2017). Increased PA levels were defined in six studies as an increase in daily step counts and in time spent on MVPA (Ashe et al., 2015; Cadmus-Bertram et al., 2015; Lewis et al., 2017; Lyons et al., 2017; Martin et al., 2015; Suboc et al., 2014). Two studies defined PA levels as only an increase in step counts (Bickmore et al., 2013; Rowley et al., 2017), whereas two studies aimed to only increase the amount of time that the participants spent on MVPA (Thompson et al., 2014; Wijsman et al., 2013). The commercial WATs, which included Fitbit 1, Fitbug Orb, Omron HJ, UP24 Jawbone, and Philips DirectLife, were used in the majority of the interventions for self-monitoring daily PA levels. In seven studies, the WATs were connected to an interactive website (Ashe et al., 2015; Bickmore et al., 2013; Cadmus-Bertram et al., 2015; Rowley et al., 2017; Suboc et al., 2014; Thompson et al., 2014; Wijsman et al., 2013) or to a mobile app in two studies (Lewis et al., 2017; Lyons et al., 2017) or to both a website and a mobile app in one study (Martin et al., 2015) to continually deliver BCTs such as goal setting, planning, coaching, and providing feedback to the participants. Either an accelerometer or a digital pedometer was used to objectively measure the participants' step counts and time spent on MVPA. Hip/waist-worn devices were used in six studies (Ashe et al., 2015; Bickmore et al., 2013; Cadmus-Bertram et al., 2015; Martin et al., 2015; Suboc et al., 2014; Thompson et al., 2014), arm/wrist-worn accelerometers in two studies (Lewis et al., 2017; Wijsman et al., 2013), an ankle-worn accelerometer in one study (Wijsman et al., 2013), and a tights-worn accelerometer in one study (Lyons et al., 2017) to investigate the effects of the WATs. One study did not mention where the participants wore the device (Rowley et al., 2017).

No human contact was involved in delivering any component of the intervention in two studies (Bickmore et al., 2013; Martin et al., 2015). Three studies involved very little human contact with the participants; in these the interventionists acted as a credible source in favor of in creased PA levels by clarifying misunderstandings among the participants (Rowley et al., 2017; Suboc et al., 2014; Wijsman et al., 2013). The involvement of interventionists in the other five studies varied greatly, and included leading group discussions, overseeing a prescription and planning exercise regime, providing face-to-face or telephone consultations, and running an online forum with the participants. The duration of the interventions varied from 5 weeks (Martin et al., 2015) to 12 months (Bickmore et al., 2013), with the majority (5 studies) lasting for 12 weeks (Lewis et al., 2017; Lyons et al., 2017; Rowley et al., 2017; Suboc et al., 2014; Wijsman et al., 2013). Only two studies had a follow up after the completion of the study, at 6 months (Thompson et al., 2014) and 10 months (Bickmore et al., 2013), respectively.

3.2.3. Use of behavior change techniques

A total of 205 BCTs were coded in the 10 studies, of which 138 were delivered via the WAT or its associated online/mobile platform and 67 were delivered by interventionists (Table 2). In these 10 studies, 46/93 (49.5 %) unique BCTs were used to enhance the participants' self-efficacy so as to increase their PA levels. The number of BCT items delivered by WATs or by human contact in each study varied from 15 (Wijsman et al., 2013) to 29 (Lyons et al., 2017). The four most frequently used BCTs delivered by WATs were "Goal setting (behavior & outcome)" (10 times), "Feedback on behavior & outcome(s) of behavior" (10 times), "Self-monitoring of behavior & outcome(s) of behavior" (10 times), and "Adding objects to the environment" (10 times); whereas the three most frequently used BCTs delivered by interventionists

Table 2
BCT coding and frequency.

BCT Label	1 Ashe 2015	2 Bickmore 2013	3 Cadmus 2015	4 Lewis 2017	5 Lyons 2017	6 Martin 2015	7 Rowley 2017	8 Suboc 2014	9 Thompson 2014	10 Wijsman 2013	Total coded (technology approach)	Total coded (human approach)
1. Goals and planning											**35**	**18**
& 1.3. Goal setting (behavior & outcome) [a]	x o	x	x o	x o	x o	x	x	x	x	x	10	4
1.2. Problem solving	o	x		o	o	x	x	x	x		5	3
1.4. Action planning	x o		x o	x o	x o				x		5	4
1.5 & 1.7. Review behavior & outcome goal(s) [a]	x o	x	x o	x o	x o		x	x	x o	x	9	5
1.6. Discrepancy between current behavior and goal		x			x o	x	x	x			5	1
1.9. Commitment			o		x						1	1
2. Feedback and monitoring											**20**	**6**
2.2 & 2.7. Feedback on behavior & outcome(s) of behavior[a]	x o	x	x o	x o	x o	x	x	x	x o	x	10	5
2.3 & 2.4.Self-monitoring of behavior & outcome(s) of behavior[a]	x	x	x	x	x o	x	x	x	x	x	10	1
3. Social support											**5**	**7**
3.1. Social support (unspecified)	o	x	o		x o						2	3
3.2. Social support (practical)				o			x	x	o		2	2
3.3. Social support (emotional)				o	x o						1	2
4. Shaping knowledge (4.1 Instruction on how to perform the behavior)	o	x	o	o	x o	x	x	x	x o	x	**7**	**5**
5. Natural consequences											**9**	**2**
5.1. Information about health consequences	o			o	x	x	x	x	x		5	2
5.3. Information about social & environmental consequences					x				x		2	0
5.4 & 5.6. Information about & Monitoring of emotional[a] consequences					x						2	0
6. Comparison of behavior											**3**	**1**
6.1. Demonstration of the behavior	o								x		1	1
6.2. Social comparison				x	x						2	0
7. Associations											**9**	**6**
7.1. Prompts/cues	o		x o	x	x o	x	x	x	x o	x	8	4
7.3. Reduce prompts/cues	o	x							o		1	2
8. Repetition and substitution											**17**	**11**
8.1. Behavioral practice/rehearsal	o		x o	x		x			x o	x	5	3
8.2 & 8.4. Behavior substitution & Habit reversal[a]	o				o						0	2
8.3. Habit formation	o	x	x o	x	x o	x				x	6	3
8.7. Graded tasks	o	x			x o		x	x	x o	x	6	3
9. Comparison of outcomes											**6**	**8**
9.1. Credible source	o	x		o	x o		x o	x o	x o	x o	6	6
9.2. Pros and cons				o							0	1
9.3. Comparative imagining of future outcomes				o							0	1
10. Reward and threat											**13**	**0**
10.3 & 10.10 Non-specific reward on behavior & outcome	x		x			x	x	x			5	0
10.4. Social reward				x	x						2	0
10.5. Social incentive				x							1	0
10.6 & 10.8 Non-specific incentive on behavior & outcome[a]	x		x			x	x	x			5	0

Table 2 (*continued*)

BCT Label	1 Ashe 2015	2 Bickmore 2013	3 Cadmus 2015	4 Lewis 2017	5 Lyons 2017	6 Martin 2015	7 Rowley 2017	8 Suboc 2014	9 Thompson 2014	10 Wijsman 2013	Total coded (technology approach)	Total coded (human approach)
11. Regulation (11.3 Conserving mental resources)				o							**0**	**1**
12. Antecedents											**11**	**1**
12.1. Restructuring the physical environment		x									1	0
12.2. Restructuring the social environment				o							0	1
12.5. Adding objects to the environment	x	x	x	x	x	x	x	x	x	x	10	0
13. Identity (13.2. Framing/Reframing)						x					**1**	**0**
14. Scheduled consequences (14.4. Reward approximation)						x					**1**	**0**
15. Self-belief (15.3. Focus on past success)					o	x					**1**	**1**
16. Covert learning											**0**	**0**
Total no. of BCTs used in each study	**27**	**18**	**20**	**26**	**29**	**21**	**21**	**21**	**21**	**15**		
									Sum of BCTs coded:		**138** **Total: 205**	**67**

x denotes that the BCTs were delivered using a technology approach.
o denotes that the BCTs were delivered in a human approach.
[a] Two BCT items were involved.

"Feedback on behavior & outcome(s) of behavior" (5 times).

3.2.4. Risk of bias in the included studies

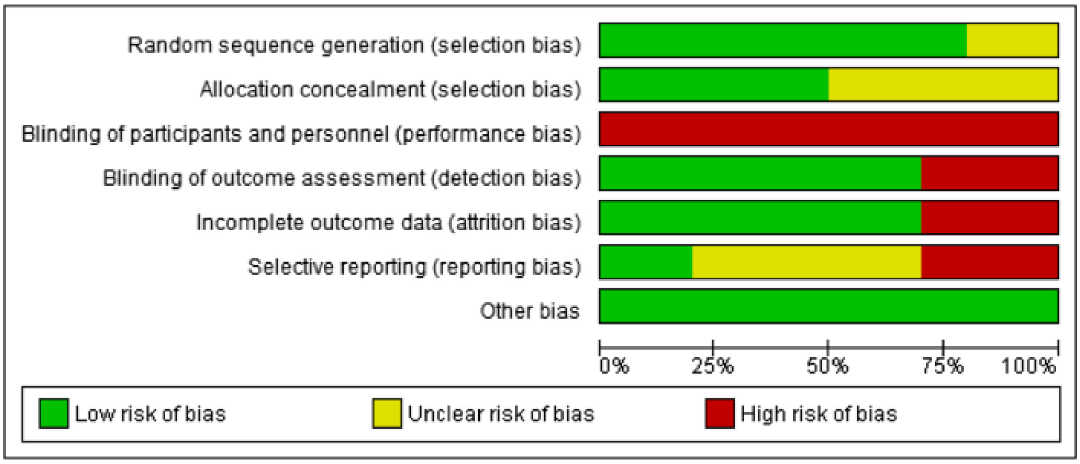

Fig. 2. Risk of bias graph (all studies)

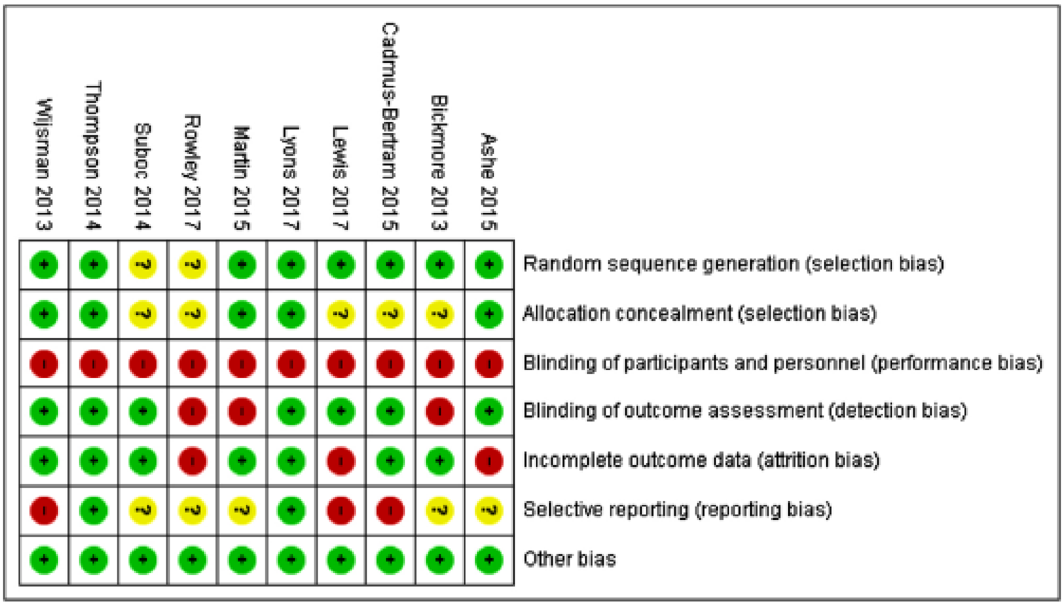

Fig. 3. Risk of Bias summary.

Refer to Figs. 2 and 3 for a graph and summary of judgments about each risk of bias item for each study. Due to reports of unclear procedures of randomization and /or allocation concealment, five studies were judged as being at an unclear risk of selection bias (Bickmore et al., 2013; Cadmus-Bertram et al., 2015; Lewis et al., 2017; Rowley et al., 2017; Suboc et al., 2014). Three studies were judged as being at a high risk of detection bias, as the measured PA outcome data were open to participants through the WAT (Bickmore et al., 2013; Martin et al., 2015; Rowley et al., 2017). This had the potential to induce expectation bias. Three studies were adjusted as being at a high risk of attrition bias, with either their intervention or comparison groups having an attrition rate of higher than 20 % (Ashe et al., 2015; Lewis et al., 2017; Rowley et al., 2017). Four studies were judged as being at a high risk of bias in selective reporting, due to differences in the outcomes of the protocols and published studies (Cadmus-Bertram et al., 2015; Lewis et al., 2015; Wijsman et al., 2013). In the end, only two studies were judged to be at a low risk of bias (Lyons et al., 2017; Thompson et al., 2014).

3.3. Effects of the interventions

3.3.1. Results of the individual studies

Compared with the passive control groups (i.e., no treatment or giving general health information), statistically significant between group differences were identified in the daily step count in four studies (Ashe et al., 2015; Martin et al., 2015; Rowley et al., 2017; Suboc et al., 2014). One study showed a statistically significant difference between the groups in daily stepping time, but not in step count (Lyons et al., 2017). Statistically significant between-group differences were identi fied when daily physical activity levels were measured by an ankle worn but not wrist-worn accelerometer in one study (Wijsman et al., 2013). One study identified no statistically significant difference be tween the groups in the time spent on MVPA (Ashe et al., 2015), al though a significant difference was identified in daily step count in the same study. One study reported no significant within-group or between group differences in any of the PA-related variables (Thompson et al., 2014).

When compared with an active control group (i.e., giving the par ticipants a simple pedometer with no connection to online interactive platforms), statistically significant between-group differences were identified in daily step count in three studies (Bickmore et al., 2013; Martin et al., 2015; Rowley et al., 2017) and in the time spent on MVPA in one study (Martin et al., 2015). However, three studies showed no significant differences in time spent on MVPA (Cadmus-Bertram et al., 2015; Lewis et al., 2017; Suboc et al., 2014) and two studies in time spent on step counts (Cadmus-Bertram et al., 2015; Suboc et al., 2014).

Three studies included both passive and active control groups, and two studies showed a significant time X group interaction in step count among the intervention group, the ACG, and the PCG. A further analysis showed that the intervention group had a higher step count than the ACG and PCG groups (Martin et al., 2015; Rowley et al., 2017). Another study also showed a significant time X group interaction in step count as well as in time spent on MVPA among the three groups; but no sig nificant difference was identified between the WAT-based intervention and the active control groups in step count or in the amount of time spent on MVPA (Suboc et al., 2014).

Two studies had attempted to identify the long-term effects of the WAT-based intervention when the devices were left for the participants to use on their own for 6 months (Thompson et al., 2014) and 10 months (Bickmore et al., 2013); however, no long-term effects could be identified in both studies.

3.3.2. Results of the pooled studies

Among the 10 studies, five were selected for a meta-analysis be cause their outcomes were comparable and similar (Ashe et al., 2015; Lewis et al., 2017; Lyons et al., 2017; Rowley et al., 2017; Suboc et al., 2014). The common components of these five studies were intervention periods of from 12 weeks to 6 months and a comparison group com prised of a passive or active (i.e., using a simple pedometer) control group. Although the duration of the intervention in one study was 6 months, we used the 12-week time point to conduct the meta-analysis (Ashe et al., 2015). The remaining five studies were excluded due to the absence of mean values or standard deviations in the post-intervention data, different outcome measurements, or the absence of data from a comparison group.

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Ashe 2015	34.31	24.32	12	12.22	9.5	7	22.7%	1.04 [0.03, 2.04]
Suboc 2014	35	11.04	29	18	14.56	35	77.3%	1.28 [0.74, 1.83]
Total (95% CI)			**41**			**42**	**100.0%**	**1.23 [0.75, 1.70]**

Heterogeneity: Tau² = 0.00; Chi² = 0.18, df = 1 (P = 0.67); I² = 0%
Test for overall effect: Z = 5.04 (P < 0.00001)

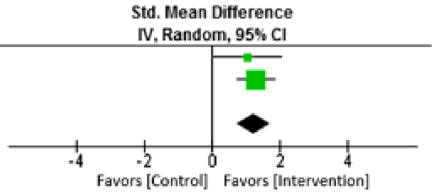

Fig. 4. Comparison of the effect of the WAT-based interventions and the passive control group on step count.

3.3.2.1. Effect of the WAT-based interventions on step counts (comparison with a passive control). Details of the pooled effect of WAT-based interventions on step counts (steps/day) are summarized in Fig. 4. In comparison with the control groups (n = 207), there was a significant positive effect on step count, and the standard mean difference was 1.27 (95 % CI [0.51, 2.04], overall effect Z = 3.26 at p = 0.001). Significant heterogeneity was found (I2 = 82 %, p = 0.0008), and the overall result indicated a significant favorable effect on increasing step count.

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Lewis 2017	73.1	21.5	19	71.4	11.5	20	31.5%	0.10 [-0.53, 0.73]
Rowley 2017	10,286	3,022	46	7,869	2,118	51	34.8%	0.93 [0.51, 1.35]
Suboc 2014	8,167	3,111	29	9,596	3,907	36	33.7%	-0.39 [-0.89, 0.10]
Total (95% CI)			**94**			**107**	**100.0%**	**0.22 [-0.62, 1.06]**

Heterogeneity: Tau² = 0.49; Chi² = 16.55, df = 2 (P = 0.0003); I² = 88%
Test for overall effect: Z = 0.51 (P = 0.61)

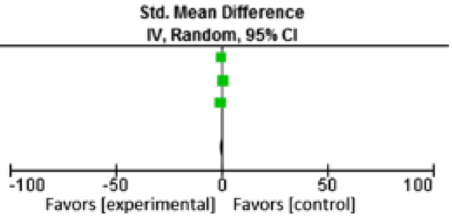

Fig. 5. Comparison of the effect of the WAT-based interventions and the passive control on MVPA.

3.3.2.2. Effect of the WAT-based interventions on MVPA (comparison with a passive control). Details of the pooled effect of WAT-based interventions on MVPA (minutes/day) are summarized in Fig. 5. In comparison with the control groups (n = 83), there was a significant positive effect on MVPA, the standard mean difference was 1.23 (95 % CI [0.75, 1.70], and the overall effect Z = 5.04 at p < 0.00001). A non-significant heterogeneity was found (I2 = 0%, p = 0.67), and the overall result indicated a significant favorable effect on increasing MVPA.

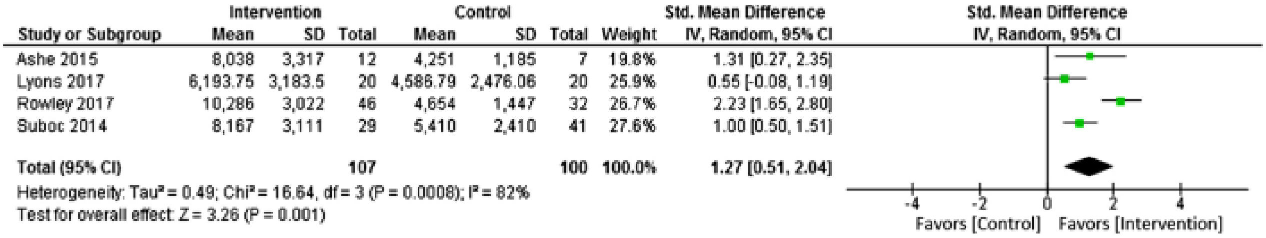

Fig. 6. Comparison of the effect of the WAT-based interventions and the active control group (a pedometer) on step count.

3.3.2.3. Effect of the WAT-based intervention on step counts (comparison with an active control). Details of the pooled effect of the WAT-based interventions on step count (steps/day) are summarized in Fig. 6. In comparison with the active control groups (n = 201), there was a non-significant effect on step count and the standard mean difference was 0.22 (95 % CI [-0.62, 1.06], overall effect Z = 0.51 at p = 0.61). Significant heterogeneity was found (I2 = 88 %, p < 0.001), and the overall result indicated a non-significant favorable effect on increasing step count.

4. Discussion

The results of this systematic review and meta-analysis indicate that the combination of a WAT-based intervention grounded in BCTs produces significant effects on improving PA levels among sedentary older adults when compared with passive control groups. The findings in our meta-analysis showed that the WAT-based intervention grounded in BCTs produced a significant improvement in daily step count and time spent on MVPA. However, when compared with participants of active control groups, who were provided with a simple pedometer, no significant increase in step count was identified in the meta-analysis.

Generally, the findings, which are based on a narrative synthesis, suggest that WAT-based interventions grounded in BCTs had an effect immediately after the completion of the intervention on improving PA levels (i.e., either in terms of increased daily step count or time spent on MVPA, or both parameters) among older adults. These findings were in line with those of similar reviews, which reported that intervention groups comprised of general adults using a WAT (implying the employment of BCTs) experienced a significant increase in PA levels (Brickwood et al., 2019; Goode et al., 2017; Lewis et al., 2015; Stephenson et al., 2017).

Among all the included studies, only Thompson et al.'s study identified no significant differences either within groups or between groups from 6 to 12 months in any PA-related variables (Thompson et al., 2014). The mean age of the participants in Thompson et al. (2014)'s study was nearly 80 years compared with the overall mean age of approximately 60 years in the other nine studies. Age-related changes in the musculoskeletal system refer to the muscle and skeletal degeneration that hinders physical functioning and results in a decline in physical activity among old-old adults (Manini & Pahor, 2009; Touhy & Jett, 2013). In addition, the empirical evidence shows that older people tend to feel less comfortable with technology, and have lower efficacy and less control over technologies, which would affect their acceptance of any kind of technology-based intervention, leading to poor effects (Czaja et al., 2006; Morris & Venkatesh, 2000; Selwyn, Gorard, & Furlong, 2005). Consequently, in spite of engaging in a WAT based intervention, all of these factors may have hindered the attempts of the participants in Thompson et al.'s study to increase their PA levels (Thompson et al., 2014) through the WAT-based intervention. This may suggest that people of advanced age may require more intensive sup port to make daily use of WATs (Kononova et al., 2019). Such supports may include extending more human or personal contact to deliver BCTs, in order to enhance the self-efficacy and physical activity levels of this population.

When compared with a simple pedometer (active control) used in seven studies (Bickmore et al., 2013; Cadmus-Bertram et al., 2015; Lewis et al., 2017; Martin et al., 2015; Rowley et al., 2017; Suboc et al., 2014; Thompson et al., 2014), a significant improvement in the participants' AP levels was observed in four of those studies. When this result is compared with the result of the meta-analysis, no significant change in step count was identified. However, this analysis was based on only three studies with significant heterogeneity. The results should be interpreted with caution. In fact, a simple pedometer already provides the function of "self-monitoring" accompanied by "goal setting." These BCTs were already effective at improving PA levels in older people. Any extra BCTs provided in a WAT-based intervention group may not have an additional effect on improving PA levels in older adults (French, Olander, Chisholm, & Mc Sharry, 2014). This may lead to similar results in PA levels in both the active control group and the WAT-based intervention group. Our result is similar to the findings of another previous study, which identified "self-monitoring" as the major BCT for enhancing healthy eating and engagement in physical activity (Michie, Abraham, Whittington, McAteer, & Gupta, 2009).

The results of the meta-analysis indicate significant favorable effects on increased daily step count and time spent on MVPA when compared with the passive control group. However, significant heterogeneity among the four studies in the meta-analysis for the step count was identified, but no conclusion can be drawn regarding the components of the intervention that led to increased PA. For example, in the selection of the WAT, the number of BCTs adopted by these four students varied from 21 (Rowley et al., 2017; Suboc et al., 2014) to 29 (Lyons et al., 2017). In addition, the involvement in human contact with the participants varied in these four studies, from limited contact in delivering BCTs in the studies of Suboc and Rowley to the frequent involvement of interventionists in delivering BCTs in the studies of Ashe and Lyon.

Although the findings of Brickwood et al. (2019) tend to represent the situation of general adults, whereas the findings from the current review represent the situation of older adults aged 55 or above, in their meta-analysis Brickwood et al. identified a significant increase in different PA levels when compared with all types of a control comparator across all of the studies. However, significant effects were only identified when comparing WAT-based intervention groups with passive groups (i.e., where no-treatment or minimal treatment was given to the participants), but not with active control groups (i.e., those that were given a traditional pedometer to encourage an increase in PA). It seems that no additional benefit was observed when using a WAT-based intervention for older people, as a traditional pedometer was already shown to have led to similar improvements in the PA levels of older people. Therefore, more evidence is still required to determine whether more additional benefits can be identified when using a WAT-based intervention when compared with traditional pedometers in older people.

In this review, the BCTs used to enhance the physical activity levels of older people were collated by a WAT-based intervention. However, our aim was not to come to definitive conclusions on the most effective BCTs, but to identify which BCTs had been used to enhance PA in older people. Many of the interventions in this review adopted multiple BCTs and had different outcomes. We were unable to run an analysis to confirm which BCTs or other features in the interventions were better at enhancing PA levels in older people. Moreover, there was a lack of clear and consistent reporting on which BCTs were undertaken within each intervention, making the classification of

BCTs difficult (Stephenson et al., 2017). Research is warranted to identify which BCTs are effective at enhancing the self-efficacy of older people, so that they will adopt a physically active lifestyle. In order to assess the effectiveness of different BCTs, the reporting of the contents of interventions must be improved and be conducted in accordance with the well-established BCT Taxonomy (NICE, 2014). A clear definition as well as a rationale for all of the adopted BCTS should be provided in the intervention manuals.

Continuous delivery of BCTs by the WAT to produce possible long-term effects in enhancing PA levels is a potential advantage. However, only two studies had long-term follow-ups, at 6 months and 10 months after the completion of the intervention (Bickmore et al., 2013; Thompson et al., 2014). No significant long-term effects could be identified in both studies, which is similar to the finding of another review exploring the effects of behavior change using wearable technology. This review likewise identified no long-term effects. These results suggest that maintaining a change in behavior over the long term is challenging, possibly due to the wearing off of the initial "novelty" of the technology-mediated behavior change intervention (Stephenson et al., 2017).

4.1. Limitations

Our study has several limitations. One of the concerns about con ducting a meta-analysis with a small number of RCTs is the risk of se lection bias. Also, there was considerable heterogeneity in the included studies, such as in the type of WAT that was used, the overall mean age of the participants, the size of the samples, and the duration of the interventions, which may have led to variable effects from the interventions. Moreover, the long-term effect of WAT-based interventions on improving PA levels among older adults was not conclusive as a result of insufficient follow-up data. The involvement of a facilitator and the application of BCTs varied in the studies; therefore, the effectiveness of the application was not conclusive. It was also not possible to statistically analyze the effectiveness of individual BCTs or to assess the effectiveness of different combinations of BCTs due to the inclusion of a variety of BCTs in the studies. It is not common to define older people as those aged 55 or above. In addition, the imbalance in the gender and age of the participants, particularly in the diverse age range of from 55 to 80, and the mean age of 60 s in most of the included studies, may mean that the findings are not representative of the situation among the older population as a whole. The oldest-old group, in particular, may be under-represented. The daily WAT adherence data of the participants (such as the time of the wearing of the WATs during the intervention period, and the frequency of logins using different media to receive BCTs) may have affected the effectiveness of the WAT-based intervention. Unfortunately, no study in this review reported this information. In future studies, attempts should be made to collect data to reflect the participants' adherence to the regimen of using WATs, and to explore how participants' adherence affect the effects of WAT-based interventions. Publications not published in English were excluded from the review and the search was limited to peer-reviewed publications.

5. Conclusion

The findings of this review suggest that a WAT-based intervention can produce a statistically significant improvement in the PA levels of sedentary older adults over the period of a short-term follow-up, especially immediately after the intervention. Compared with the usual care, step counts and the time spent on MVPA increased significantly in the intervention group. However, both the WAT-based intervention and the traditional pedometer had similar effects on step count. It is re commended that multi-center RCTs of the effects of WAT-based interventions, involving larger and more diverse samples of older adults, be conducted to investigate their long-term effects and superiority over the traditional pedometer.

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