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The Impact of Wearable Motion Sensing Technology on Physical Activity in Older Adults.

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Abstract

Background and Purpose: Physical activity provides substantial health benefits. Older adults are less physically active than the rest of the population, and interventions that promote physical activity are needed. In this meta-analysis, we investigate how different wearable activity trackers (pedometers and accelerometers) may impact physical activity levels in older adults.

Methods: We searched MEDLINE, Embase and CINAHL for randomized controlled trials including participants that were ≥ 65 years, using wearable activity trackers with the intent of increasing physical activity. Studies whose comparator groups were engaged in active or inactive interventions, such as continued a physical therapy program or goal-setting counseling, were not excluded simply for implementing co-interventions. We used random-effects models to produce standardized mean differences (SMDs) for physical activity outcomes. Heterogeneity was measured using I^2 .

Results: Nine studies met the eligibility criteria: Four using accelerometers, four using pedometers, and one comparing accelerometers and pedometers, for a total number of 939 participants. Using pooled data, we found a statistically significant effect of using accelerometers (SMD=0.43 (95% CI 0.19 – 0.68), $I^2=1.6\%$, $p=0.298$), but not by using pedometers (SMD=0.17 (95% CI -0.08 – 0.43), $I^2=37.7\%$, $p=0.174$) for increasing physical activity levels.

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Conflicts of Interest: The authors declare no conflicts of interest.

Discussion and Conclusions: In this study, we found that accelerometers, alone or in combination with other co-interventions, increased physical activity in older adults however pedometers were not found to increase physical activity. The high risk of bias found in most studies limits these findings. High quality studies that isolate the effects of accelerometers on physical activity changes are needed.

Keywords

Pedometers; accelerometers; physical activity; older adults

1. Introduction

It has been demonstrated that regular physical activity in older adults plays an important role in maintaining mental and physical health (Centers for Disease Control and Prevention, 2015). For older adults, increasing daily physical activity may reduce the risk of certain conditions, help maintain weight, strengthen bones and muscles, improve mental health, decrease chance of falls, improve overall function, reduce healthcare expenditure and increase life expectancy (Centers for Disease Control and Prevention, 2015). Despite well-known evidence to support the benefits of physical activity, older adults are reported to be the most inactive population, with approximately 43.4% of adults aged 65–74 who report leisure-time activity meeting the federal physical activity guidelines for aerobic activity, 15.5% meeting the guidelines for aerobic and muscle strengthening, and approximately one in four adults aged 50 years reporting no physical activity outside of work (Centers for Disease Control and Prevention, 2013; Ward, 2016; Watson et al., 2016). Additionally, as of 2015, 21.7% of adults aged 65 rate their health as poor and the prevalence of obesity in adults aged 60 is 30.1% in the United States (National Center for Health Statistics, 2016; Ward, 2016). Walking, a preferred form of exercise for older adults (Centers for Disease Control and Prevention, 2013), may be a relatively safe and efficient way to achieve daily recommended amounts of physical activity. Self-monitored walking may be done easily with small, unobtrusive wearable activity trackers.

Implementing self-monitoring and feedback in order to positively effect physical activity behavior, goal attainment, and adherence has shown success in previous systematic reviews, yet these reviews also suggest the need for further investigation (Burke et al., 2011; Stephens & Allen, 2013). Pedometers and accelerometers have been found feasible for self-monitoring movement in older adult populations (de Bruin et al., 2008), despite suggestions that older adults face challenges using this technology (Wandke et al., 2012). Pedometers track steps in one plane of motion based on trunk swing during gait. Accelerometers combine tri-planar motions to better detect steps. Both devices are relatively simple, valid, and reliable tools designed to objectively detect physical activity. Furthermore, pedometers are considered more affordable and easy to use with little training (Tudor-Locke & Lutes, 2009). Some limitations noted with pedometers are the inability to capture intensity as well as underestimating step-count in certain populations with slower ambulation speeds (Le Masurier & Tudor-Locke, 2003; Tudor-Locke et al., 2002). In comparison, more expensive accelerometers may overcome the previously mentioned limitations with the potential to detect multi-planar movement and intensity levels (Aparicio-Ugarriza et al., 2015). While

both pedometers and accelerometers offer opportunities for objective self-monitoring, accelerometers provide data in real-time via computer programs that allows for in depth analysis and third party participation(Gonzalez et al., 2013; Lyons et al., 2014).

Current systematic reviews and meta-analyses that focus individually on accelerometers or pedometers have shown positive effects on increasing physical activity in the general adult population(Goode et al., 2016; Kang et al., 2009). To our knowledge, no previous systematic review has conducted a comparative analysis of the effects of wearable motion sensing technology (pedometers and accelerometers) in older adults, a population at high risk of adverse health sequelae as a result of sedentary behavior(Watson et al., 2016). Therefore, the purpose of this systematic review was to determine the effect of interventions that incorporate wearable motion sensing technology and compare efficacy of accelerometers and pedometers in increasing older adult physical activity levels. Information gained from this systematic review may help guide physical activity intervention plans for older adults or future research.

2. Methods

We followed a standard protocol for this review, conducting it in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement. Each step was pilot-tested to train and calibrate study investigators.

2.1 Data Sources and Search Strategy

We searched MEDLINE (via PubMed), Embase, and CINAHL from each respective database inception date to May 2017. We used Medical Subject Heading (MeSH) terms and selected free-text terms for wearable activity monitors and for outcomes of interest (e.g., movement, exercise therapy, physical fitness) along with validated search terms for study designs of interest. Each bibliography of included trials and systematic reviews was reviewed for missed publications. A complete listing of the search strategy can be found in the Appendix.

2.2 Eligibility Criteria

To be included, studies had to (1) include a sample of over 75% adults 65 years of age as determined by a mean age and standard deviation, (2) use wearable motion sensing technology (accelerometer or pedometer) within an intervention designed to increase physical activity or compare devices in increasing physical activity, (3) report changes in the outcomes of physical activity (ie. daily steps, minutes walking, etc.) (4) be a randomized controlled trial (RCT) with a total sample size of >20 participants and outcomes >6 weeks, and (5) be published in an English-language peer-reviewed journal. Studies were excluded if they did not include a population of interest, did not include an outcome of interest or were a pilot or feasibility study due to the potential for low quality or high risk of bias. Studies whose comparator groups were engaged in co-interventions, whether active or inactive interventions, such as continued a physical therapy program or goal-setting counseling, were not excluded simply for implementing co-interventions. A detailed list of eligibility criteria can be found in the Appendix.

2.3 Screening and Eligibility

Two trained investigators screened titles and abstracts (CC and ADG) against eligibility criteria. Full-text articles identified by either investigator as potentially relevant were retrieved for further review and examined by two investigators (CB and RP) against the eligibility criteria. Disagreements were resolved by discussion or by a third investigator (CC). In addition, trials with three or more arms were examined for appropriateness of all arms for inclusion.

2.4 Data Abstraction

Data from included trials were abstracted into a customized database by a trained investigator and confirmed by a second investigator. Disagreements were resolved by consensus or by obtaining a third investigator's opinion when consensus could not be reached. We grouped the devices into two categories as to whether the manufacturer classified the device as a pedometer or accelerometer. Each device may have a different accuracy (sensitivity or specificity) for measuring physical activity, and these differences may influence the overall summary estimate for each wearable device category. However, we anticipate these influences to be small since most accelerometers have high accuracy values (de Bruin et al., 2008). Data elements included date of publication, sample size, population characteristics (e.g., chronic medical illness status, sex, age), and descriptors to assess applicability, quality elements, and outcomes. Key intervention characteristics abstracted were the type of activity monitor (e.g., brand, location worn on body), type of adjunctive intervention (e.g., counseling and goal setting education), and duration as well as frequency of intervention.

2.5 Risk of Bias

We used key quality criteria described in the Cochrane Collaboration Risk of Bias Tool to assess risk of bias in each included study. The tool evaluates six different domains across seven questions: (1) selection bias (i.e., adequacy of random-sequence generation, allocation concealment), (2) performance bias for each outcome (i.e., knowledge of allocated intervention by participants and study personnel that could introduce bias), (3) detection bias for each outcome (i.e., knowledge of allocated intervention by outcome assessors), (4) attrition bias (i.e., amount, nature, or handling of incomplete outcome data), (5) reporting bias (i.e., selective outcome reporting), and (6) other bias (e.g., differences in relation to baseline measures, reliable primary outcomes, protection against contamination).

We evaluated each domain as low, unclear, or high risk of bias. An overall score of low risk of bias required selection bias related to random sequencing and allocation concealment, performance bias, and detection bias to be scored "low risk" with no other important concerns. For performance bias and detection bias, studies did not need to blind study personnel and participants to receive a low risk of bias if outcome measurement was not likely to be influenced by lack of blinding. A judgment of unclear risk of bias was assigned if 1 or 2 domains were scored "not clear" or "not reported." Studies judged to be high risk of bias had more than 2 domains scored "not clear" or "not reported."

2.6 Data Synthesis

When meta-analysis was feasible (≥ 3 studies within a category), we computed summary estimates of effect. We aggregated outcomes when at least three studies investigated the same outcome. Due to differences in the reporting of units of measurement, as some studies reported walking per day versus steps per day, outcomes were analyzed using standardized mean differences (SMDs) in a random-effects model. Standardization allows combining studies from different outcomes measuring a similar construct but removes the unit of measurement. Therefore, the method we used to interpret the SMD as an effect size is as follows: small effect size, SMD = 0.2; medium, SMD = 0.5; and large, SMD = 0.8. We evaluated for statistical heterogeneity using visual inspection of forest plots and the I^2 statistic with significant heterogeneity being an I^2 value >50%. Due to the low statistical power for detecting publication bias with a small number (<10) of included studies (Sterne JA, 2000) we assessed for potential publication bias by comparing registered clinical trials in [ClinicalTrials.gov](https://www.clinicaltrials.gov) with published literature. In addition, due to the small number of included studies in each wearable device category we did not attempt formal meta-regression or stratified analysis to examine potential moderators. All quantitative analyses were performed in Stata V.14 (College Station, TX). If a quantitative synthesis was not feasible (≥ 3 studies in a group), we analyzed the data qualitatively.

3. Results

Our search identified 1720 references; after the elimination of duplicates, 1353 remained. Following title and abstract screening, 34 articles were eligible for full text review. A total of nine articles met study eligibility criteria and were analyzed quantitatively (n=8) or qualitatively (n=1) (Butler et al., 2009b; Cadmus-Bertram et al., 2015; Croteau et al., 2007; Kawagoshi, Kiyokawa, Sugawara, et al., 2015; Koizumi et al., 2009; McMurdo et al., 2010; Nicklas et al., 2014; Thompson et al., 2014; Wijsman et al., 2013). Details about how studies were chosen for this systematic review can be seen in Figure 1. No studies were identified in [ClinicalTrials.gov](https://www.clinicaltrials.gov) that would indicate completed but unpublished work in this field suggesting no evidence of publication bias.

3.1 Study Characteristics

A total of four articles investigated the efficacy of accelerometers and four examined pedometers for increasing physical activity in older adults, seen in Table 1 below. One article compared the difference in physical activity of older adults when using an accelerometer or a pedometer. Six studies incorporated exercise counseling in their intervention with varying objectives such as goal setting, motivation, education, and identifying barriers to exercise in subjects. Among these six studies, however, in three of the studies the control group also received exercise counseling. All of the studies reviewed, except for one, instructed participants receiving the intervention to set physical activity goals for the study duration. In five studies (n=1 for accelerometers, n=3 for pedometers and n=1 accelerometer versus pedometer) the comparator in the control group utilized some form of active intervention (i.e., self-monitoring, self-pacing, coaching, counseling, etc.). Three studies structured their control groups to engage in physical activity without pedometers, relying on self-report measures to capture activity. The one study directly comparing

accelerometers to pedometers instructed their comparator subjects to self-monitor exercise with pedometers, but did not receive guided exercise counseling. All but two studies measured physical activity through minutes walking each day. The other studies used daily steps as a physical activity measure. Intervention duration for the reviewed studies varied from 6 weeks ($n=2$), 12 weeks ($n=4$), 16 weeks ($n=1$), 24 weeks ($n=2$), 40 weeks ($n=1$), to 52 weeks ($n=1$). A specific study characteristics summary of the nine included studies, stratified by pedometer or accelerometer use, can be seen in Table 1 below.

3.2 Participant Characteristics

This systematic review evaluated 975 participants through nine studies. Overall, five articles ($n=547$) simply recruited a sample over 75% of adults 65 years old. The other four studies chose to investigate specific subsets of the older adult populations. Two studies examined physical activity increase in older women ($n=255$) and two other studies focused on older patients with Chronic Obstructive Pulmonary Disease (COPD) ($n=27$) and older patients engaging in cardiac rehabilitation ($n=110$).

3.3 Device Characteristics

Table 2 describes the device characteristics and compliance within the nine included studies. Of the five studies that used accelerometers, only two studies used the same device, a Lifecorder. In the pedometer-based studies, researchers from three of six studies relied on Yamax Digiwalker pedometers. Seven of the nine studies in this review instructed subjects to wear the device at hip or waist level for the duration of the intervention. One study supplemented the waistline device with two accelerometer sensors on the thigh and chest. One study directed subjects to wear the device on the right wrist or right ankle. The other remaining study did not report where the subject wore the device. All but three studies encouraged subjects to self-monitor daily activity feedback through constant display and updates of real time minutes or steps per day. Subjects in two studies received physical activity feedback from investigators at specific points during the study, but could not view the pedometer feedback in between. One study chose not to give control subjects feedback at all throughout the study in order to have a more objective measure of physical activity level compared to self-report measures. Four of the nine studies did not report compliance with the entire intervention given (wearing motion-sensing technology, goal setting, counseling, etc.). Of the five studies that did disclose compliance, one study held subjects to a 100% compliance standard for inclusion, three studies had over 90% subject adherence, and one study reported over 80% compliance.

3.4 Meta-Analysis

Figure 2 illustrates those included accelerometer and pedometer studies and pooled effect for each device across the 4 trials. Four studies ($n=400$ subjects) measuring physical activity with accelerometers were pooled. The effects from included studies utilizing accelerometers varied with effects favoring the control group to strong effects favoring the intervention groups. A statistically significant small-to-medium effect was found ($SMD=0.43$ (95% 0.19, 0.68) for accelerometers and changes in physical activity, without significant heterogeneity present ($I^2=18.6\%$, $p<0.298$). Four studies were pooled ($n=488$ subjects) that utilized pedometers to measure physical activity. Consistent effects across studies were found with

effect estimates ranging from small (0.03) to large (0.84) effect. No statistically significant effect was found between pedometer use and increased physical activity (SMD=0.22 (95% CI -0.08, 0.51, $I^2=48.2\%$, $p=0.122$)).

3.5 Risk of Bias

Figure 3 provides the risk of bias with judgments for each individual domain, and Figure 4 provides the risk of bias with our judgments about each risk of bias item presented as total percentages across all included studies. The majority of studies (6 of 9 [66.67%]) were judged to be at high risk of bias, two studies were judged to be unclear (2 of 9 [22.2%]) and one study (1 of 9 [11.11%]) was judged to be at low risk of bias. For risk of selection bias, two of the nine trials (22.2%) did not give details about the method for generating the random sequence, resulting in an unclear risk of bias rating. For a large proportion of trials (5 of 9 [55.56%]), there was an unclear risk of bias due to inadequate detail about allocation concealment provided by authors. In 6 of 9 trials (66.7%) there is high risk of bias due to knowledge of the allocated intervention by study personnel (ie. performance bias). In 3 of 9 (33.3%) trials there is unclear risk of bias and 2 of 9 (22.2%) due to knowledge of the allocated intervention by the outcome assessor (ie. detection bias). The majority of studies (7 of 9 [77.8%]) were judged to be of high risk of bias due to other types of potential bias. All of the trials reported complete outcome data that included information on attrition and exclusions from analysis.

4. Discussion

We systemically reviewed the existing literature on the effectiveness of pedometers and accelerometers alone or in combination with other interventions for increasing physical activity levels in the older adult population. We analyzed nine studies that met the inclusion criteria. This review showed participant groups that used an accelerometer alone or as part of an intervention approach resulted in improvements of physical activity levels. The use of pedometers alone or as part of an intervention approach, however, did not demonstrate a statistically or clinically important increase in physical activity. Our accelerometer results are consistent with previous findings from other systematic reviews that have shown improvements in physical activity from interventions that incorporate accelerometer usage (Bravata et al., 2007; Goode et al., 2016). Our improvement effect size is higher than most studies, possibly due to higher precision of accelerometers for slower gait speeds. Five of nine studies reported high compliance of the devices used during the intervention.

Our results indicate a moderate to strong statistically significant effect supporting the use of accelerometers with no statistically significant effect found for pedometer use. Previous reviews have identified a similar result for accelerometers, small but statistically significant (Goode et al., 2016). However, those studies did not focus exclusively on older adults, a sub-group at high risk of functional decline as a result of sedentary behavior (Watson et al., 2016). The stronger effects for accelerometers compared to pedometers may be accounted by the accelerometers' multi-planar motion capture, or that pedometers have difficulty reporting step counts during slower ambulation, which is more typical in older adults (Gonzales et al., 2015; Le Masurier & Tudor-Locke, 2003). This is

also supported by the only study we found that compared the two types of devices against one another (Cadmus-Bertram et al., 2015). Two studies (Butler et al., 2009a; Kawagoshi, Kiyokawa, Iwakura, et al., 2015) both showed significant medium-to-strong associations between pedometers and increased physical activity. However, both of these studies included populations participating in a structured exercise program within a rehabilitation setting (cardiac and pulmonary). It may be the case that a structured and more aggressive rehabilitation program resulted in these significant improvements when compared to the two other pedometer studies. In addition, the other two pedometer studies (Butler et al., 2009a; McMurdo et al., 2010) included community dwelling women or older adults with a substantial portion having either long standing illness or chronic comorbidities (i.e., osteoarthritis or osteoporosis) that could potentially limit activity. The differences in the included populations may be the reason for the moderate heterogeneity we found in this summary estimate for pedometers.

We identified one article that met our inclusion criteria directly comparing accelerometers to pedometers to increase PA in older adults (Cadmus-Bertram et al., 2015). Because this study was heterogeneous with the other studies in our meta-analysis described above, we did not include it. However, it did directly compare accelerometers and pedometers and deserved a discussion within this review, despite exclusion from statistical analysis. This study asked participants to perform 150 minutes/week of moderate to vigorous physical activity (MVPA) and walk 10,000 steps/day for 16 weeks. The participants were fifty-one inactive, postmenopausal women who were overweight with a BMI ≥ 25.0 . The accelerometer group received a Fitbit One, a 3-axis accelerometer that clips onto clothing, set individualized goals for the first 4 weeks and received a follow-up call at 4 weeks to evaluate progress and refine goals. The pedometer group received a basic pedometer and printed materials with tips for increasing steps and received a brief goal-setting process. Ninety-six percent of participants reported wearing their device ≥ 4 days/week. The accelerometer group increased MVPA in bouts by 38 (83) minutes/week ($p=0.01$); increased total MVPA by 62 (108) minutes/week ($p=0.008$); and increased steps/day by 789 (1,979) ($p=0.01$), while the pedometer group experienced non-significant increases in physical activity.

We also found the studies that allowed the subjects to receive continuous feedback from their device had an associated higher compliance level. Although, similar to a previous systematic review, neither higher compliance nor continuous feedback correlated with increased physical activity levels (French et al., 2014). We did not find that counseling had an effect on physical activity; in fact, we found that the studies that did not counsel their subjects had generally higher physical activity levels. This is inconsistent with current literature that recommends counseling and behavior programs as part of best practices in increasing physical activity in older adults (Cress et al., 2004). However, Sawchuk et al. (Sawchuk et al., 2011) found that goal setting when used in conjunction with pedometer use had no statistical impact on physical activity over pedometer use alone.

Technology adoption among older adults has often been reported to present challenges. Just over half of this review's included studies reported on the compliance of older adults using wearable technology. However, of those studies reporting on device compliance, the majority report a high compliance rate with over 80% of older adults adhering to the study

requirements. There are various theories about technology being too difficult for older adults due to decreased processing speed, decreased fine manipulation, and high learning curve(Wandke et al., 2012). However, evidence shows that with well-designed interfaces, proper training or guidance, and possible adaptations, older adults can successfully use newer technology(Pew Research Center, 2017; Wandke et al., 2012).

Our review has several strengths including a rigorous search and duplicate inclusion process; however, our review is not without limitations. In comparing accelerometers and pedometers efficacy of increasing physical activity, preferably our systematic review would have more than one study directly comparing the two. In the absence of more direct comparison studies, we were left to compare isolated studies of pedometers or accelerometers to non-device interventions. Additionally, the heterogeneity of physical activity outcome measurements (e.g., steps per day or minutes per day) across studies required us to standardize summary estimates, which can lead to challenges in interpretation. This is because standardization removes the original units of measurement and summary estimates are interpreted as a correlation. A standard guideline for measuring and reporting physical activity by accelerometers or pedometers in future studies would improve future meta-analyses and interpretation of estimates. The included studies varied in duration of intervention length, which may influence our overall pooled estimates. Due to the small number of studies included within each device category we did not attempt meta-regression or stratified analysis to determine if there was a moderation effect from intervention duration. In our previous work (Goode et al., 2016) we have identified a small moderator effect from intervention duration, where shorter duration studies have larger effects on physical activity. For this study on older adults, however, no consistent relationship appears to exist, shorter duration studies seem to have a larger effect among the accelerometers. However, the intervention duration and individual study estimates vary widely among the pedometers. Lastly, several studies included a co-intervention, both active and inactive, therefore we are unable to isolate the direct effect of the wearable device on physical activity changes.

5. Conclusion

Accelerometers, alone or in conjunction with other co-interventions, increased physical activity in older adults however, with pedometers alone or in conjunction with other co-interventions no increase in physical activity was identified. Higher step detection accuracy in accelerometers may explain the difference. The high risk of bias found in most studies limits these findings. Since only one study directly compared the two devices, our recommendations are based on current research comparing individual devices against or in combination with other interventions. As previous systematic reviews have also recommended(Allet et al., 2010; Bravata et al., 2007; de Bruin et al., 2008), our review supports the need for additional well-designed controlled studies that investigate the benefit of wearable motion-sensing technology in older adults. Further research should examine pedometer use compared to accelerometer use. Specifically these studies should investigate: 1) tracking activity intensity level using heart rate monitors; (2) include an inactive control group that does not rely on self-report; (3) split interventions to have different cohorts that would include counseling compared to goal setting compared with sole accelerometer/

pedometer use to determine the isolated effect of a wearable device without co-interventions; and (4) intervention groups with and without continuous feedback from the accelerometer. Information gained from this systematic review may help guide physical activity intervention plans for older adults.

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Appendix: Search Strategy Report

Database: PubMed		
Set #		Results
1	Aged[mesh] OR elderly[tiab] OR "older adult"[tiab] OR "older adults"[tiab]	2615477
2	Movement[mesh] OR "exercise therapy"[mesh] OR "Physical fitness"[mesh] OR "Physical Endurance"[mesh] OR "physical exertion"[mesh] OR running[tiab] OR swimming[tiab] OR walking[tiab] OR exercising[tiab] OR exercise[tiab] OR "physical activity"[tiab] OR "fitness"[tiab] OR "physical endurance"[tiab] OR "physical exertion"[tiab]	728343
3	Accelerometry[mesh] OR Magnetometry[mesh] OR "Motor Activity/instrumentation"[Mesh] OR Accelerometry[tiab] OR Accelerometer[tiab] OR Accelerometers[tiab] OR Magnetometry[tiab] OR actigraphy[tiab] OR actigraph[tiab] OR actigraphs[tiab] OR actigraphic[tiab] OR Gyroscope[tiab] OR gyroscopic[tiab] OR wearable[tiab] OR wearables[tiab] OR "motion sensor"[tiab] OR "motion sensors"[tiab] OR "motion sensing"[tiab] OR "fitness monitor"[tiab] OR "fitness monitors"[tiab] OR "activity monitor"[tiab] OR "activity monitors"[tiab] OR tracker[tiab] OR trackers[tiab] OR GPS[tiab] OR "global positioning"[tiab] OR ((step[tiab] OR steps[tiab]) AND (count[tiab] OR counter[tiab] OR counters[tiab] OR counts[tiab] OR counted[tiab] OR counting[tiab])) OR Pedometer[tiab] OR Pedometers[tiab]	54355
4	#1 AND #2 AND #3	3215
5	(randomized controlled trial[pt] OR controlled clinical trial[pt] OR randomized[tiab] OR randomised[tiab] OR randomization[tiab] OR randomisation[tiab] OR placebo[tiab] OR randomly[tiab] OR trial[tiab] OR groups[tiab]) NOT (animals[mh] NOT humans[mh]) NOT (Editorial[ptyp] OR Letter[ptyp] OR Case Reports[ptyp] OR Comment[ptyp])	1969517
6	#4 AND #5	1120
7	#6 Limit to English	1107
Database: Embase		
Set #		Results
1	'aged'/exp OR 'elderly':ab,ti OR 'older adult':ab,ti OR 'older adults':ab,ti	2490704
2	'movement (physiology)'/exp OR 'physical activity, capacity and performance'/exp OR 'kinesiotherapy'/exp OR 'fitness'/exp OR 'running':ab,ti OR 'swimming':ab,ti OR 'walking':ab,ti OR 'exercising':ab,ti OR 'exercise':ab,ti OR 'physical activity':ab,ti OR 'fitness':ab,ti OR 'physical endurance':ab,ti OR 'physical exertion':ab,ti	1105152
3	'accelerometry'/exp OR 'magnetometry'/exp OR 'Accelerometry':ab,ti OR 'Accelerometer':ab,ti OR 'Accelerometers':ab,ti OR 'Magnetometry':ab,ti OR 'actigraphy':ab,ti OR 'actigraph':ab,ti OR 'actigraphs':ab,ti OR 'actigraphic':ab,ti OR 'Gyroscope':ab,ti OR 'gyroscopic':ab,ti OR 'wearable':ab,ti OR 'wearables':ab,ti OR 'motion sensor':ab,ti OR 'motion sensors':ab,ti OR 'motion sensing':ab,ti OR 'fitness monitor':ab,ti OR 'fitness monitors':ab,ti OR 'activity monitor':ab,ti OR 'activity monitors':ab,ti OR 'tracker':ab,ti OR 'trackers':ab,ti OR 'GPS':ab,ti OR 'global positioning':ab,ti OR (('step':ab,ti OR 'steps':ab,ti) AND ('count':ab,ti OR 'counter':ab,ti OR 'counters':ab,ti OR 'counts':ab,ti OR 'counted':ab,ti OR 'counting':ab,ti)) OR 'Pedometer':ab,ti OR 'Pedometers':ab,ti	560678
4	#1 AND #2 AND #3	3515

Database: PubMed		
Set #		Results
5	'randomized controlled trial'/exp OR 'crossover procedure'/exp OR 'double blind procedure'/exp OR 'single blind procedure'/exp OR random* OR factorial* OR crossover* OR cross NEAR/1 over* OR placebo* OR doubl* NEAR/1 blind* OR singl* NEAR/1 blind* OR assign* OR allocat* OR volunteer*	1955197
6	#5 NOT ('case report'/exp OR 'case study'/exp OR 'editorial'/exp OR 'letter'/exp OR 'note'/exp)	809
7	#6 AND [embase]/lim NOT [medline]/lim	214
8	#7 AND [english]/lim	212
Database: CINAHL		
Set #		Results
1	MH "Aged+" OR TI (elderly OR "older adult" OR "older adults") OR AB (elderly OR "older adult" OR "older adults")	590560
2	MH "Movement+" OR MH "Therapeutic Exercise+" OR MH "Physical Fitness+" OR MH "Physical Endurance+" OR MH "Exercise+" OR MH "Exertion+" OR TI (running OR swimming OR walking OR exercising OR exercise OR "physical activity" OR "fitness" OR "physical endurance" OR "physical exertion") OR AB (running OR swimming OR walking OR exercising OR exercise OR "physical activity" OR "fitness" OR "physical endurance" OR "physical exertion")	216183
3	MH "Accelerometry+" OR TI (Accelerometry OR Accelerometer OR Accelerometers OR Magnetometry OR actigraphy OR actigraph OR actigraphs OR actigraphic OR Gyroscope OR gyroscopic OR wearable OR wearables OR "motion sensor" OR "motion sensors" OR "motion sensing" OR "fitness monitor" OR "fitness monitors" OR "activity monitor" OR "activity monitors" OR tracker OR trackers OR GPS OR "global positioning" OR ((step OR steps) AND (count OR counter OR counters OR counts OR counted OR counting)) OR Pedometer OR Pedometers) OR AB (Accelerometry OR Accelerometer OR Accelerometers OR Magnetometry OR actigraphy OR actigraph OR actigraphs OR actigraphic OR Gyroscope OR gyroscopic OR wearable OR wearables OR "motion sensor" OR "motion sensors" OR "motion sensing" OR "fitness monitor" OR "fitness monitors" OR "activity monitor" OR "activity monitors" OR tracker OR trackers OR GPS OR "global positioning" OR ((step OR steps) AND (count OR counter OR counters OR counts OR counted OR counting)) OR Pedometer OR Pedometers)	15263
4	#1 AND #2 AND #3	1329
5	(ZT "randomized controlled trial") OR MH "Randomized Controlled Trials" OR TI ("randomized controlled trial" OR "controlled clinical trial" OR "randomized" OR "randomized" OR "randomization" OR "randomization" OR "placebo" OR "randomly" OR "trial" OR "groups") OR AB ("randomized controlled trial" OR "controlled clinical trial" OR "randomized" OR "randomized" OR "randomization" OR "randomization" OR "placebo" OR "randomly" OR "trial" OR "groups") AND (ZT "journal article")	360895
6	#4 AND #5	402
7	#6 Limit to English	401

Eligibility criteria

Study Characteristic	Inclusion Criteria	Exclusion Criteria
Population	<ul style="list-style-type: none"> Majority of participants aged 65 years and over as determined by the mean age and standard deviation. 	<ul style="list-style-type: none"> Elite athletes Children Inpatient populations Pregnant women
Interventions	<ul style="list-style-type: none"> Studies will be included if at least one of the groups used wearable activity devices for physical activity that provide objective feedback to the wearer (eg, non-pedometer-based & pedometer-based trackers such as accelerometer-based fitness trackers, smartphone applications, GPS-based trackers), alone or in combination with other interventions to enhance physical activity. 	<ul style="list-style-type: none"> Non-wearable systems (including manual entry on the computer or online) Systems that do not objectively monitor activity Systems that do not provide feedback to the wearer Interventions that use wearable devices to measure the effects of another intervention

Study Characteristic	Inclusion Criteria	Exclusion Criteria
		(eg, drugs) on ability to perform physical activity
Comparators	<ul style="list-style-type: none"> Usual care/standard of care, waitlist control Other active comparator focused on enhancing physical activity (eg, educational or behavioral interventions to enhance physical activity) 	<ul style="list-style-type: none"> Validation studies of head-to-head comparisons of different wearable physical activity devices used to assess validity of devices
Outcomes	<ul style="list-style-type: none"> Change in physical activity behavior (eg, total steps, total activity, proportion of participants at activity goal) 	<ul style="list-style-type: none"> Any outcomes not listed
Timing	<ul style="list-style-type: none"> 3 months post-randomization 	<ul style="list-style-type: none"> <3 months post-randomization
Setting	<ul style="list-style-type: none"> Outpatient general medical settings (geriatrics, family medicine, general internal medicine, integrative medicine) Specialty medical care clinics (eg, orthopedic, rheumatology, endocrine, cardiology) Community settings 	<ul style="list-style-type: none"> Intervention delivered primarily in hospital inpatient setting Studies where monitoring of physical activity is confined to a supervised setting
Study design	<ul style="list-style-type: none"> RCTs 	<ul style="list-style-type: none"> Not a clinical study (eg, editorial, nonsystematic review, letter to the editor, case series) Prospective and retrospective observational studies Pilot studies or samples sizes n < 20 Measurement or validation studies
Publication type	<ul style="list-style-type: none"> English-language only Peer-reviewed articles 	<ul style="list-style-type: none"> Non-English articles Abstracts only

References:

- Allet L, et al. (2010). Wearable systems for monitoring mobility-related activities in chronic disease: a systematic review. *Sensors (Basel)*, 10(10), 9026–9052. 10.3390/s101009026 [PubMed: 22163393]
- Aparicio-Ugarriza R, et al. (2015). Physical activity assessment in the general population; instrumental methods and new technologies. *Nutricion Hospitalaria*, 31 Suppl 3, 219–226. 10.3305/nh.2015.31.sup3.8769 [PubMed: 25719789]
- Bravata DM, et al. (2007). Using pedometers to increase physical activity and improve health: a systematic review. *JAMA*, 298(19), 2296–2304. 10.1001/jama.298.19.2296 [PubMed: 18029834]
- Burke LE, et al. (2011). Self-monitoring in weight loss: a systematic review of the literature. *Journal of the American Dietetic Association*, 111(1), 92–102. 10.1016/j.jada.2010.10.008 [PubMed: 21185970]
- Butler L, et al. (2009a). Effects of a pedometer-based intervention on physical activity levels after cardiac rehabilitation: a randomized controlled trial. *Journal of Cardiopulmonary Rehabilitation and Prevention*, 29(2), 105–114. 10.1097/HCR.0b013e31819a01ff [PubMed: 19305235]
- Butler L, et al. (2009b). Effects of a pedometer-based intervention on physical activity levels after cardiac rehabilitation: a randomized controlled trial. *Journal of Cardiopulmonary Rehabilitation and Prevention*, 29(2), 105–114. 10.1097/HCR.0b013e31819a01ff [PubMed: 19305235]
- Cadmus-Bertram LA, et al. (2015). Randomized Trial of a Fitbit-Based Physical Activity Intervention for Women. *American Journal of Preventive Medicine*, 49(3), 414–418. 10.1016/j.amepre.2015.01.020 [PubMed: 26071863]
- Centers for Disease Control and Prevention. (2013). The State of Aging and Health in America Retrieved from Atlanta, GA: <https://www.cdc.gov/aging/pdf/state-aging-health-in-america-2013.pdf>
- Centers for Disease Control and Prevention. (2015). The Benefits of Physical Activity Retrieved from <http://www.cdc.gov/physicalactivity/basics/pa-health/index.htm>
- Cress ME, et al. (2004). Physical activity programs and behavior counseling in older adult populations. *Medicine and Science in Sports and Exercise*, 36(11), 1997–2003. [PubMed: 15514518]

- Croteau KA, et al. (2007). Effect of a pedometer-based intervention on daily step counts of community-dwelling older adults. *Research Quarterly for Exercise and Sport*, 78(5), 401–406. 10.1080/02701367.2007.10599439 [PubMed: 18274211]
- de Bruin ED, et al. (2008). Wearable systems for monitoring mobility-related activities in older people: a systematic review. *Clinical Rehabilitation*, 22(10–11), 878–895. 10.1177/0269215508090675 [PubMed: 18955420]
- French DP, et al. (2014). Which behaviour change techniques are most effective at increasing older adults' self-efficacy and physical activity behaviour? A systematic review. *Annals of Behavioral Medicine*, 48(2), 225–234. 10.1007/s12160-014-9593-z [PubMed: 24648017]
- Gonzales JU, et al. (2015). Steps per Day, Daily Peak Stepping Cadence, and Walking Performance in Older Adults. *J Aging Phys Act*, 23(3), 395–400. 10.1123/japa.2014-0049 [PubMed: 25134524]
- Gonzalez C, et al. (2013). PREDIRCAM eHealth platform for individualized telemedical assistance for lifestyle modification in the treatment of obesity, diabetes, and cardiometabolic risk prevention: a pilot study (PREDIRCAM 1). *Journal of Diabetes Science and Technology*, 7(4), 888–897. [PubMed: 23911170]
- Goode AP, et al. (2016). The Impact of Interventions that Integrate Accelerometers on Physical Activity and Weight Loss: A Systematic Review. *Annals of Behavioral Medicine* 10.1007/s12160-016-9829-1
- Kang M, et al. (2009). Effect of pedometer-based physical activity interventions: a meta-analysis. *Research Quarterly for Exercise and Sport*, 80(3), 648–655. 10.1080/02701367.2009.10599604 [PubMed: 19791652]
- Kawagoshi A, et al. (2015). Effects of low-intensity exercise and home-based pulmonary rehabilitation with pedometer feedback on physical activity in elderly patients with COPD. *European Respiratory Journal*, 46.
- Kawagoshi A, et al. (2015). Effects of low-intensity exercise and home-based pulmonary rehabilitation with pedometer feedback on physical activity in elderly patients with chronic obstructive pulmonary disease. *Respiratory Medicine*, 109(3), 364–371. [PubMed: 25682543]
- Koizumi D, et al. (2009). Efficacy of an accelerometer-guided physical activity intervention in community-dwelling older women. *J Phys Act Health*, 6(4), 467–474. [PubMed: 19842461]
- Le Masurier GC, & Tudor-Locke C (2003). Comparison of pedometer and accelerometer accuracy under controlled conditions. *Medicine and Science in Sports and Exercise*, 35(5), 867–871. 10.1249/01.mss.0000064996.63632.10 [PubMed: 12750599]
- Lyons EJ, et al. (2014). Behavior change techniques implemented in electronic lifestyle activity monitors: a systematic content analysis. *Journal of Medical Internet Research*, 16(8), e192 10.2196/jmir.3469 [PubMed: 25131661]
- McMurdo MET, et al. (2010). Do pedometers increase physical activity in sedentary older women? A randomized controlled trial. *Journal of the American Geriatrics Society*, 58(11), 2099–2106 10.1111/j.1532-5415.2010.03127.x [PubMed: 21054290]
- National Center for Health Statistics. (2016). Health, United States, 2015: With Special Feature on Racial and Ethnic Health Disparities Retrieved from Hyattsville, MD:
- Nicklas BJ, et al. (2014). Obesity (Silver Spring), 22(6), 1406–1412. 10.1002/oby.20732 [PubMed: 24585701]
- Pew Research Center. (2017). Retrieved from <http://www.pewinternet.org/2017/05/17/tech-adoption-climbs-among-older-adults/>
- Sawchuk CN, et al. (2011). Does pedometer goal setting improve physical activity among Native elders? Results from a randomized pilot study. *American Indian and Alaska Native Mental Health Research*, 18(1), 23–41. [PubMed: 21866498]
- Stephens J, & Allen J (2013). Mobile phone interventions to increase physical activity and reduce weight: a systematic review. *Journal of Cardiovascular Nursing*, 28(4), 320–329. 10.1097/JCN.0b013e318250a3e7 [PubMed: 22635061]
- Sterne JA,GD, Egger M (2000). Publication and related bias in meta-analysis: power of statistical tests and prevalence in the literature. *Journal of Clinical Epidemiology*, 53(11), 1119–1129. [PubMed: 11106885]

- Thompson WG, et al. (2014). "Go4Life" exercise counseling, accelerometer feedback, and activity levels in older people. *Archives of Gerontology and Geriatrics*, 58(3), 314–319 10.1016/j.archger.2014.01.004 [PubMed: 24485546]
- Tudor-Locke C, & Lutes L (2009). Why do pedometers work?: a reflection upon the factors related to successfully increasing physical activity. *Sports Medicine*, 39(12), 981–993. 10.2165/11319600-000000000-00000 [PubMed: 19902981]
- Tudor-Locke C, et al. (2002). Utility of pedometers for assessing physical activity: convergent validity. *Sports Medicine*, 32(12), 795–808. [PubMed: 12238942]
- Wandke H, et al. (2012). Myths about older people's use of information and communication technology. *Gerontology*, 58(6), 564–570. 10.1159/000339104 [PubMed: 22739502]
- Ward BW, et al. (2016). National Health Interview Survey Early Release Program Retrieved from
- Watson KB, et al. (2016). Physical Inactivity Among Adults Aged 50 Years and Older - United States, 2014. *MMWR: Morbidity and Mortality Weekly Report*, 65(36), 954–958. 10.15585/mmwr.mm6536a3 [PubMed: 27632143]
- Wijsman CA, et al. (2013). Effects of a web-based intervention on physical activity and metabolism in older adults: randomized controlled trial. *Journal of Medical Internet Research*, 15(11), e233 10.2196/jmir.2843 [PubMed: 24195965]

PRISMA 2009 Flow Diagram

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit www.prisma-statement.org.

Figure 1:
PRISMA Flow Diagram

Figure 2:
Pooled summary estimates by accelerometers and pedometers for increasing physical activity in older adults.

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias	Overall
Butler, 2009	+	?	-	?	+	+	-	-
Cadmus-Betram, 2015	+	+	-	?	+	+	-	?
Croteau, 2007	+	?	-	-	+	+	-	-
Kawagoshi, 2015	+	?	-	-	+	+	-	-
Koizumi, 2009	?	?	?	?	+	+	+	-
McMurdo, 2010	+	+	-	+	+	+	-	?
Nicklas, 2014	?	?	?	+	+	+	+	-
Thompson, 2014	+	+	+	+	+	+	-	?
Wijsman, 2013	+	+	+	+	+	+	+	+

Green=low risk of bias; Yellow=unclear risk of bias; Red=high risk of bias

Figure 3:

Risk of bias across domains of the Cochrane risk of bias tool for individual studies.

Figure 4:
Summary of risk of bias across included studies.

Table 1.

Description of included study populations, interventions, comparators and outcomes.

Article	Population	Intervention	Comparator	Outcome
ACCELEROMETERS				
Koizumi, 2009(Koizumi et al., 2009)	Older Adults (68)	12 weeks accelerometer with feedback + goal setting	Inactive: 12 weeks of blinded accelerometer use	Steps/Day
Nicklas, 2014(Nicklas et al., 2014)	Older Adults (48)	40 weeks accelerometer + 20 wks 4 day/wk supervised exercise + 20 wks self monitoring + 20 wks hypocaloric diet (2 prepared meals/day) + counseling 1x/wk for 6wks, 2x/mo for 4 mo, 1x/mo for 5mo	Active: 20 weeks weight loss intervention consisting of diet education and physical activity education, structured exercise and in-person counseling	Minutes Walking/Day
Thompson, 2014(Thompson et al., 2014)	Older Adults (49)	24 weeks accelerometer use and feedback + weekly telephone counseling sessions focused on accelerometer feedback + in-person counseling	Inactive: 24 weeks of blinded accelerometer use	Activity Units (undefined)
Wijsman, 2013(Wijsman et al., 2013)	Older Adults (235)	12 weeks of continuous accelerometer use and feedback + personal website + personal e-coach who gives updates on activity status and advice online	Inactive: 3-month waitlist control	Minutes Walking/Day
PEDOMETERS				
Butler, 2009(Butler et al., 2009b)	Cardiac Rehab Patients (110)	6 weeks pedometer + exercise counseling + goal setting + 24 week check up	Active: 6 weeks self monitoring + self reporting physical activity	Minutes Walking/Day
Croteau, 2007(Croteau et al., 2007)	Older Adults (147)	12 weeks pedometer + self monitoring + goal setting + counseling at baseline & end of each month + 12 weeks no counseling + pedometer self monitoring	Inactive: 12 weeks waitlist control + 12 weeks with pedometer + self monitoring + goal setting + counseling at baseline & end of each month	Steps/Day
Kawagoshi, 2015(Kawagoshi, Kiyokawa, Sugawara, et al., 2015)	Older COPD patients (27)	52 weeks pedometer use + pulmonary rehabilitation	Active: 52 weeks pulmonary rehab (breathing retraining, exercise training, & education)	Minutes Walking/Day
McMurdo, 2010(McMurdo et al., 2010)	Older Women (204)	24 weeks continuous pedometer use + counseling 1/wk for 1mo, 2/mo for 1mo, 1/mo for 3mo	Active: self report of minutes walking + counseling 1/wk for 1mo, 2/mo for 1mo, 1/mo for 3mo	Minutes Walking/Day
			Inactive: control group with no intervention for 6 months	
ACCELEROMETERS vs. PEDOMETERS				
Cadmus-Bertram, 2015(Cadmus-Bertram et al., 2015)	Overweight, Postmenopausal Women (51)	16 weeks accelerometer + self monitoring + goal setting + counseling phone call after 4 weeks	Active: 16 weeks pedometer + self monitoring + goal setting + printed brochure to increase steps	Steps/Day

Table 2.

Device Information Stratified by Study Device

Author	Device Type	Device Name	Location Worn	Feedback Given	Compliance
ACCELEROMETERS					
Koizumi, 2009(Koizumi et al., 2009)	uniaxial accelerometer	Kenz Lifecorder	waist level	intervention group was given their total step counts and minutes walking every 2 weeks	Not Reported
Nicklas, 2014(Nicklas et al., 2014)	tri-axial accelerometer	Lifecorder Plus	hip	Minutes per day feedback was constantly updated and displayed in real time	Intervention: Average 90% $\pm$ 16.0 Comparator: Average 91% $\pm$ 8.0
Thompson, 2014(Thompson et al., 2014)	tri-axial accelerometer	Control: MSR Electronics GmbH; Intervention: Fitbit	center of the back, directly above the iliac crest	Control: no feedback to the subject was provided; Intervention: constant feedback	Not Reported
Wijsman, 2013(Wijsman et al., 2013)	tri-axial accelerometer	GENEActive	right side, wrist and ankle	Minutes per day feedback was constantly updated and displayed in real time	Intervention: 91.2% completed Comparator: Not Reported
PEDOMETERS					
Butler, 2009(Butler et al., 2009b)	pedometer	Yamax Digiwalker 700B	Not Reported	Minutes per day feedback was constantly updated and displayed in real time	Not Reported
Croteau, 2007(Croteau et al., 2007)	pedometer	Yamax Digi-Walker SW-200	Worn at waist, clipped to a belt or clothing, and centered over the dominant foot	Steps per day feedback was constantly updated and displayed in real time	Not Reported
Kawagoshi, 2015(Kawagoshi, Kiyokawa, Sugawara, et al., 2015)	pedometer	Kens Lifecorder EX	Pedometer attached to belt at waist, then two sensors attached on the thigh and the chest	average daily PA feedback monthly from PR staff, 11 times during intervention year	Intervention & Comparator: Percentage of days per year of intervention: 80.4% $\pm$ 13.3
McMurdo, 2010(McMurdo et al., 2010)	pedometer	Omcron HJ-113	2 pedometers worn, one at neck, other at waistband	Minutes per day feedback was constantly updated and displayed in real time	Intervention & Comparators: 100% adherence for activity participation
ACCELEROMETERS vs. PEDOMETERS					
Cadmus-Bertram, 2015(Cadmus-Bertram et al., 2015)	accelerometer & pedometer	Fitbit™ & ActiGraph GT3X+	Fitbit™: waistband, bra, or pocket. ActiGraph GT3X+: waist level	Minutes per day feedback was constantly updated and displayed in real time	Intervention & Comparator: Percentage of participants who wore a pedometer 4days/week 96%