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The Impact of Wearable Motion Sensing Technologies on Physical Activity: A Systematic Review

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PREFACE

The VA Evidence-based Synthesis Program (ESP) was established in 2007 to provide timely and accurate syntheses of targeted healthcare topics of particular importance to clinicians, managers, and policymakers as they work to improve the health and healthcare of Veterans. QUERI provides funding for four ESP Centers, and each Center has an active University affiliation. Center Directors are recognized leaders in the field of evidence synthesis with close ties to the AHRQ Evidence-based Practice Centers. The ESP is governed by a Steering Committee comprised of participants from VHA Policy, Program, and Operations Offices, VISN leadership, field-based investigators, and others as designated appropriate by QUERI/HSR&D.

The ESP Centers generate evidence syntheses on important clinical practice topics. These reports help:

- Develop clinical policies informed by evidence;
- Implement effective services to improve patient outcomes and to support VA clinical practice guidelines and performance measures; and
- Set the direction for future research to address gaps in clinical knowledge.

The ESP disseminates these reports throughout VA and in the published literature; some evidence syntheses have informed the clinical guidelines of large professional organizations.

The ESP Coordinating Center (ESP CC), located in Portland, Oregon, was created in 2009 to expand the capacity of QUERI/HSR&D and is charged with oversight of national ESP program operations, program development and evaluation, and dissemination efforts. The ESP CC establishes standard operating procedures for the production of evidence synthesis reports; facilitates a national topic nomination, prioritization, and selection process; manages the research portfolio of each Center; facilitates editorial review processes; ensures methodological consistency and quality of products; produces “rapid response evidence briefs” at the request of VHA senior leadership; collaborates with HSR&D Center for Information Dissemination and Education Resources (CIDER) to develop a national dissemination strategy for all ESP products; and interfaces with stakeholders to effectively engage the program.

Comments on this evidence report are welcome and can be sent to Nicole Floyd, ESP CC Program Manager, at Nicole.Floyd@va.gov.

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INTRODUCTION

Participation in regular physical activity is associated with a wide range of mental and physical health benefits. Patients with diabetes, obesity, and musculoskeletal disease, in particular, derive significant benefits from regular physical activity including favorable effects on blood pressure, lipid profiles, joint swelling and pain, weight control and body fat distribution, and psychological well-being.[1] Despite these known benefits, a large proportion of adults, including military Veterans, are insufficiently active. Less than 50% of Veterans report engaging in physical activity at the level to promote health.[2] Comparisons also show disparities among VA users and non-users, with higher rates of physical inactivity (20%) observed among Veterans using VA services.[2] This is a significant concern for VHA clinicians, managers, and policymakers given published reports showing that low aerobic fitness, stemming from inactivity, is associated with increased healthcare costs.[3,4]

Physical activity has previously been measured using self-reported measures (*eg,* questionnaires, interviews); however there are problems with self-report measures, as these measures do little to motivate or change physical activity behavior and can be subject to reporting bias.[5-7] Wearable motion sensing technologies (activity monitors), such as pedometers and accelerometers, have become popular tools to overcome some of these barriers. Epidemiologic and observational studies have used activity monitors to characterize activity intensity and daily activity patterns across diverse samples.[8-12] Pedometers were the first generation of activity monitors and continue to be widely used to monitor daily ambulation activity, as a tool for prescribing increased mobility (*eg,* daily step targets) and motivating individuals to increase their activity level.[13,14] However, the reduced measurement properties of pedometers in overweight/obese populations and among individuals with slower ambulation speeds continues to be a limitation.[15,16]

Although pedometers are a cost-effective tool, they are increasingly being replaced by accelerometers. Accelerometers offer the advantage of assessing all accelerative movements, in all directions, in addition to the ambulation data collected by a pedometer, and can be calibrated to detect differences in intensity.[13] Data from accelerometers also allow for intervention content to be tailored.[8] Until recently, research-grade activity monitors have not provided real-time feedback to patients due to a lack of a digital display, or required downloading and interpreting of data using specialized, costly analytic software. However, as the *consumer* market for wearable activity monitors has steadily grown, parallel shifts in the *research* market have also occurred, providing more options for personalized, real-time feedback. Activity monitors used by consumers and researchers now have extensive feedback programs that provide real-time data to the wearer via computer programs and mobile applications.[17,18] Some of these devices even provide an option to relay this information to a third party such as family, friends, or clinicians. This ability to transmit data to patients' physicians and care teams makes these devices attractive

for clinical applications, although this capability is in the early stages of implementation and evaluation.[18]

The Veterans Health Administration (VHA), the largest integrated healthcare system in the United States, recognizes the potential benefit of promoting the use of wearable activity monitors to increase physical activity among Veterans. Before care managers in the VHA embrace this technology and implement these tools in clinical care and wellness programs, the disease states affected, the types of devices studied, and the strategies most likely to affect physical activity outcomes need to be identified. The objective of this review is to synthesize the literature on newer wearable activity devices to determine effectiveness for physical activity outcomes and to describe factors that impact the effectiveness of wearable activity devices.

METHODS

TOPIC DEVELOPMENT

The topic was nominated after a process that included a preliminary review of published peer-reviewed literature and consultation with investigators, Veterans Affairs (VA) and non-VA experts, and key stakeholders. The VA National Center for Health Promotion and Disease Prevention (NCP) nominated this project. The goal of this report, as defined by NCP, is to assess whether the VA should invest in accelerometers and other wearable activity devices as a tool to motivate Veterans to be more physically active.

The final key questions (KQs), developed in consultation with stakeholders, were:

- KQ 1: Among adults, what is the effectiveness of wearable motion sensing technologies (*eg*, activity devices such as accelerometer-based fitness trackers, global positioning systems [GPS]) on:
    a. Physical activity levels?
    b. Weight loss or maintenance?
    c. Patient satisfaction with healthcare?

- KQ 2: Among adults, does the impact of wearable motion sensing technologies (*eg*, activity devices such as accelerometer-based fitness trackers, GPS) vary by:
    a. Characteristics of the population (overweight/obese/sedentary adults, older adults, healthy volunteers, and individuals with chronic medical illnesses)?
    b. Type of adjunctive interventions (does the activity device play a major or minor role)?
    c. Adherence to use of the device?
    d. Characteristics of the device (body location—waist, arm, wrist, or multisite)

We followed a standard protocol for this review, and each step was pilot tested to train and calibrate study investigators. The PROSPERO registration number is CRD42015017343.

SEARCH STRATEGY

In consultation with an expert librarian, we searched MEDLINE (via PubMed), Embase, CINAHL, SPORTDiscus, and Cochrane CENTRAL from January 1, 2000, to January 6, 2015, for peer-reviewed, English-language randomized controlled trials (RCTs). We used Medical Subject Heading (MeSH) terms and selected free-text terms for wearable motion sensing technologies and for activities/outcomes of interest (*eg*, movement, exercise therapy, physical fitness), along with validated search terms for RCTs.[19] The exact search strategies used are provided in Appendix A. We further reviewed the bibliographies of included trials and systematic reviews[20-26] for missed publications. To assess for possible publication bias, we searched ClinicalTrials.gov (www.clinicaltrials.gov) to identify completed but unpublished studies meeting our eligibility criteria. All citations were imported into 2 electronic databases (for referencing, EndNote® Version X5, Thomson Reuters, Philadelphia, PA; for data abstraction, DistillerSR; Evidence Partners Inc., Manotick, ON, Canada).

STUDY SELECTION

Using prespecified inclusion and exclusion criteria (Table 1), 2 trained investigators assessed titles and abstracts for relevance to the KQs. Full-text articles identified by either investigator as potentially relevant were retrieved for further review and examined by 2 investigators against the eligibility criteria. Disagreements on inclusion/exclusion were resolved by discussion or by a third investigator. In addition, trials with 3 or more arms were examined for appropriateness of all arms for inclusion. For example, data from any active arm that did not include a wearable activity device were not abstracted for inclusion in the analysis.

Table 1. Inclusion and Exclusion Criteria

Study Characteristic	Inclusion Criteria	Exclusion Criteria
Population	· Adults 18 years of age and older	· Elite athletes · Children · Inpatient populations · Pregnant women
Interventions	· Studies will be included if at least one of the groups used wearable activity devices that provide objective feedback on physical activity to the wearer (*eg*, non-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	· Pedometer-based (only) studies · Non-wearable systems · 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 (*eg,* drugs) on ability to perform physical activity
Comparators	· Usual care/standard of care, waitlist control · Pedometer-based interventions · Other active comparator focused on enhancing physical activity (*eg,* educational or behavioral interventions	· Validation studies of head-to-head comparisons of different wearable physical activity devices used to assess validity of devices
Outcomes	· Change in physical activity behavior (*eg*, total steps, total activity, proportion of participants at activity goal) · Change in weight, body mass index, change or proportion of participants at goal · Patient satisfaction with healthcare	· Any outcomes not listed
Timing	· ≥3 months postrandomization	· <3 months postrandomization

Study Characteristic	Inclusion Criteria	Exclusion Criteria
Setting	· Outpatient general medical settings (geriatrics, family medicine, general internal medicine, integrative medicine) · Specialty medical care clinics (*eg*, orthopedic, rheumatology, endocrine, cardiology) · Community settings	· Intervention delivered primarily in hospital inpatient setting · Studies where monitoring of physical activity is confined to a supervised setting
Study design	· RCTs, n>20	· Not a clinical study (*eg*, editorial, nonsystematic review, letter to the editor, case series) · Prospective and retrospective observational studies · Measurement or validation studies
Publication type	· English-language only · Peer-reviewed articles · Published from 2000 forward	· Non-English articles · Abstracts only

Abbreviations: GPS=global positioning system; RCTs=randomized controlled trials

DATA ABSTRACTION

Data from included articles were abstracted into a customized database by a trained investigator and confirmed by a second investigator. Data elements included date of publication, sample size, location of study, intervention/exposure details, descriptors to assess applicability, quality elements, and outcomes. Key population and activity device characteristics abstracted were age, sex, chronic medical illness status, type of wearable activity monitor (*eg*, brand, location worn on body), type of adjunctive interventions (*eg*, behavioral weight management strategies, physical activity education) adherence to use of measurement device, and duration and frequency of intervention. Disagreements were resolved by consensus or by obtaining a third investigator's opinion when consensus could not be reached.

QUALITY ASSESSMENT

We used the key quality criteria described in the Cochrane Collaboration Risk of Bias Tool (CCRBT). The CCRBT was designed to evaluate the risk of bias (ROB) in RCTs.[27] It evaluates 6 different domains: (1) adequacy of random sequence generation; (2) allocation concealment; (3) blinding of participants and study personnel; (4) incomplete outcome data; (5) reporting bias due to selective outcome reporting; and (6) other forms of bias such as differences in relation to baseline measures, reliable primary outcomes, or protection against contamination. The Cochrane Collaboration provides guidelines to score each item. Each domain is evaluated as low ROB, unclear ROB, or high ROB. To draw conclusions about the overall ROB within trials we summarized assessments across items in the CCRBT and used the approach outlined in Table 2.

Table 2. Approach to Formulating Summary Risk of Bias for Each Outcome Across Domains

Risk of Bias	Interpretation	Criteria
Low ROB	Bias, if present, is unlikely to alter the results seriously	Adequacy of random sequence generation, allocation concealment, and blinding scored as low ROB, and no important concerns related to the other domains
Unclear ROB	ROB that raises some doubts about the results	One or 2 domains are scored "not clear" or "not done"
High ROB	Bias may alter the results seriously	More than 2 domains are scored as "not clear" or "not done"

Abbreviations: ROB=risk of bias

DATA SYNTHESIS

When meta-analysis was feasible, we computed summary estimates of effect. We aggregated outcomes when there were at least 3 studies with the same outcome. For KQ 1, analyses were conducted separately for wearable activity device interventions versus inactive controls (*eg*, waitlist, usual care) and wearable activity device interventions versus active comparators (*eg*, group weight loss, counseling). Three trials had more than one intervention arm.[28-30] Two of these trials compared different adjunctive interventions to continuous monitoring via accelerometers.[28,29] For these 2 studies, we selected the intervention conditions with the less-intensive adjuncts (*eg*, monthly counseling vs weekly counseling). The third trial tested the impact of continuous versus intermittent accelerometer feedback.[30] For this study, we selected the comparisons between continuous accelerometer use and control, as this was the type of accelerometer use evaluated in all other studies.

Continuous outcomes (difference in change from baseline to follow-up between intervention and control) were analyzed using standardized mean differences (SMDs) for physical activity outcomes and mean differences (MDs) for weight outcomes in a random-effects model with the Knapp-Hartung correction to confidence intervals. The method we used to interpret the SMD as an effect size was as follows: small effect size, SMD=0.2; medium, SMD=0.5; and large, SMD ≥0.80.[31] We used R (R Foundation for Statistical Computing, Vienna, Austria) with the metafor package[32] to calculate the summary estimates of treatment effect. We evaluated for statistical heterogeneity using visual inspection and the I^2 statistic. Publication bias was assessed using findings from the ClinicalTrials.gov search.

We explored potential sources of heterogeneity including characteristics of the population (*eg*, chronic medical illness status), adherence to the use of the wearable activity device, and characteristics of the device defined as location worn on body. We aimed to assess the differential impact of type of adjunctive interventions (*eg*, behavioral weight management intervention, physical activity education, goal-setting) as a source of potential heterogeneity. Because type and quantity of adjunctive interventions varied greatly from study to study, we operationalized this moderator as the role of the wearable activity device (*ie*, major vs minor component of intervention). To be categorized as being a major component of the intervention, the wearable activity device needed to be the central motivational enhancement intervention intended to improve the primary outcome of the study. Other adjunctive interventions might be included but had to play a minor role in enhancing physical activity. To be categorized as being a

minor component of the intervention, the wearable activity device needed to be an integrated component of a suite of other motivation enhancement interventions, such as a structured exercise program, diet or chronic disease counseling/education/monitoring, self-management techniques, or monetary or nonmonetary incentives. Two independent investigators categorized the role of the device, and any discrepancies were reconciled by the co-principal investigators.

If a quantitative synthesis was not feasible, we analyzed the data qualitatively. We gave more weight to the evidence from higher-quality studies with more precise estimates of effect. We focused on documenting and identifying patterns of the intervention across outcome categories. We analyzed potential reasons for inconsistency in treatment effects across studies by evaluating differences in the study population, intervention, comparator, and outcome definitions.

RATING THE BODY OF EVIDENCE

The strength of evidence (SOE) for each KQ was assessed using the approach described in the Agency for Healthcare Research and Quality (AHRQ)'s *Methods Guide for Effectiveness and Comparative Effectiveness Reviews.*[33] We focused on the 2 main outcomes of physical activity and weight. The AHRQ approach requires assessment of 4 domains: risk of bias, consistency, directness, and precision. Additional domains are used when appropriate: coherence, dose-response association, impact of plausible residual confounders, strength of association (magnitude of effect), and publication bias. These domains were considered qualitatively, and a summary rating of high, moderate, or low SOE was assigned after discussion by 2 investigators. In some cases, a rating of high, moderate, or low was impossible or imprudent to make. In these situations, a rating of insufficient was assigned. This 4-level rating scale consists of the following definitions:

- High—High confidence that the evidence reflects the true effect. Further research is very unlikely to change our confidence in the estimate of effect.
- Moderate—Moderate confidence that the evidence reflects the true effect. Further research may change our confidence in the estimate of effect and may change the estimate.
- Low—Low confidence that the evidence reflects the true effect. Further research is likely to change the confidence in the estimate of effect and is likely to change the estimate.
- Insufficient—Evidence either is unavailable or does not permit estimation of an effect.

PEER REVIEW

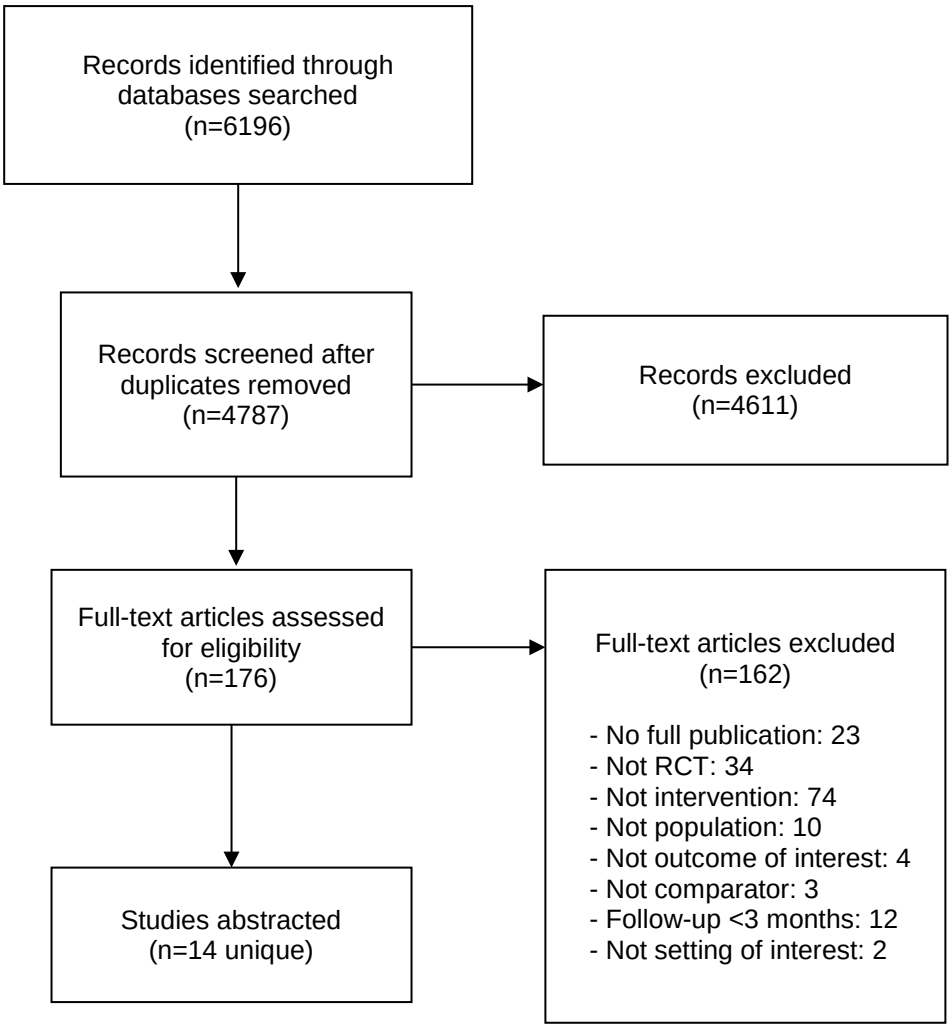
A draft of this report was reviewed by technical experts and clinical leadership. A transcript of their comments and our responses is provided in Appendix B.

RESULTS

LITERATURE FLOW

The literature search (Figure 1), which was limited to RCTs published between January 1, 2000, and January 6, 2015, identified 4787 unique citations from a combined search of MEDLINE (via PubMed; n=3334), Embase (n=839), CINAHL (n=265), SPORTDiscus (n=245), and Cochrane CENTRAL (n=104). After applying inclusion/exclusion criteria at the title-and-abstract screening level, 176 full texts were retrieved for further review. Of these, papers describing 14 unique RCTs were retained for data abstraction.

Figure 1. Literature Flow Chart



CHARACTERISTICS OF INCLUDED STUDIES

Within the 14 included trials, women comprised 62.5% of the populations, median age was 49.7 years (range 28.7 to 79.8 years), and only 4 trials reported race. The majority of trials were conducted in the United States (n=8) and were sponsored either wholly or partially by government agencies (n=9). Study sizes ranged from 20 to 544 participants (median 62), with the majority of studies (n=8) randomizing fewer than 70 participants. All included studies were published in the last 10 years, indicating the relatively new use of these activity devices in studies aimed at promoting physical activity. While we searched for any wearable nonpedometer devices, all identified trials used some form of accelerometer-based motion sensing technology. Characteristics of the individual studies are described in Appendix C. A search of ClinicalTrials.gov identified one completed but unpublished trial that we believe would meet our inclusion criteria (NCT00544245), revealing a small degree of publication bias.

Twelve studies reported on outcomes related to physical activity,[30,34-44] and 11 on outcomes related to weight.[28-30,35-41,43] No studies assessed the outcome of satisfaction with healthcare. Four trials were conducted on older adults, 5 on overweight/obese/sedentary adults, 3 on participants with a chronic medical illness, and 2 on healthy volunteers. We did not identify any studies that were specific to Veterans. Comparators were active (*eg*, behavioral counseling) in 3 trials and inactive (*eg*, usual care, waitlist) in 11 trials. The accelerometer, usually worn on the waist (n=8 trials), was a major component of the intervention in 9 trials and a minor component in 5 trials. Only 4 trials examined adherence. Most studies (n=8) were judged to be at high ROB, with 4 studies at unclear ROB, and only 2 at low ROB.

Interventions varied widely. The duration of interventions ranged from 12 to 52 weeks, and the number of planned interactions with participants in the accelerometer conditions ranged from none to 52 weekly contacts. Trials used a wide variety of adjunctive interventions in conjunction with accelerometers, including intensive diet, weight, and physical activity behavioral counseling; tailored written feedback; and web-based supportive educational modules. Selected details of interventions and comparators for each study are provided in Table 3.

Table 3. Description of Interventions and Comparators

Study	Intervention	Comparator
Greene, 2013[39]	6 months of access to online social network to post about weight and physical activity progress + continuous accelerometer use and feedback	Inactive: Printed lifestyle guidelines on diet and exercise
Koizumi, 2009[42]	12 weeks of accelerometer with feedback + goal-setting	Inactive: 12 weeks of blinded accelerometer use

Study	Intervention	Comparator
Luley, 2014[28]	3-arm study (2 interventional): Intervention arm 1: 1-time 2-hour instruction on diet and physical activity + 12 months of accelerometer use + 52 weekly individual letters with feedback on weight, diet, and physical activity Intervention arm 2: 1-time 2-hour instruction on diet and physical activity + 12 months of accelerometer use + 12 monthly behavioral counseling calls	Inactive: 1-time 1-hour session, consisting of diet education, diet regimen, and physical activity education
Nicklas, 2014[35]	5-month weight loss intervention that included: hypocaloric diet (2 prepared meals a day) + 4 days/week supervised exercise + self-regulatory intervention that involved wearing an accelerometer, documenting activity, and 6 weekly sessions of behavioral counseling	Active: 5-month weight loss intervention consisting of diet education and regimen (individualized hypocaloric intake), physical activity education, structured exercise (supervised treadmill), and in-person counseling
Paschali, 2005[44]	12 weeks of continuous accelerometer use and feedback + 4 monthly in-person exercise behavioral counseling sessions + workbook	Active: 12-week blinded accelerometer use with 4 monthly in-person counseling sessions to review exercise diary, a 24-page information book and home-based walking plan with physical activity education, behavioral self-management, weight goal-setting, and chronic disease monitoring
Polzien, 2007[30]	3-arm study (2 interventional): Intervention arm 1: *Continuous* technology-based behavioral weight control program: 7 in-person individualized counseling sessions over 12 weeks + 12 weeks of continuous accelerometer use and feedback Intervention arm 2: *Intermittent* technology-based behavioral weight control program: 7 in-person individualized counseling sessions over 12 weeks + 3 weeks of accelerometer use and feedback over 12 weeks	Active: 7 in-person individualized counseling sessions consisting of diet education, diet regimen (1200 to 1500 kcal/day; dietary fat <20% of total energy intake), physical activity education, and weight goal-setting
Reijonsaari, 2012[41]	12 months of continuous accelerometer use and feedback + access to telephone counseling (frequency not defined)	Inactive: Explanation of results of physical exams and information on physical activity and occupational healthcare
Shrestha, 2013[40]	1-time 1.5-hour lifestyle instruction + 6 months of continuous accelerometer use and feedback	Inactive: Self-directed exercise and/or U.S. Army-mandated physical training

Study	Intervention	Comparator
Shuger, 2011[29]	4-arm study (3 interventional) : Intervention arm 1: Group-based behavioral weight loss: 14 group weight loss sessions + 6 individual phone calls + workbook over 9 months Intervention arm 2: Accelerometer alone: 9 months of continuous accelerometer use and feedback Intervention arm 3: Group-based behavioral weight loss + accelerometer use: 9 months of continuous accelerometer use and feedback + 14 group weight loss sessions + 6 individual phone calls + workbook	Inactive: Self-directed weight loss manual with diet education, physical activity education, and weight goal-setting
Slootmaker, 2009[43]	3 months of continuous accelerometer use + tailored physical activity feedback and motivational tips via web-based portal	Inactive: A single written brochure with brief physical activity recommendations
Tabak, 2014[34]	Self-directed technology-supported care program that included a tailored web-based exercise program, accelerometer-based activity senor and motivational messaging, COPD self-management module, and as needed web-portal teleconsultation conducted over 9 months	Inactive: Usual care
Thompson, 2014[38]	12 weeks of continuous accelerometer use and feedback + weekly brief counseling sessions on increasing activity + treadmill desk	Inactive: 12 weeks of blinded accelerometer use
Thompson, 2014[36]	24 weeks of continuous accelerometer use and feedback + weekly brief telephone counseling sessions focused on accelerometer feedback + 6 in-person brief counseling sessions	Inactive: 24 weeks of blinded accelerometer use
Wijsman, 2013[37]	12 weeks of continuous accelerometer use and feedback + personal website + personal e-coach who gives updates on activity status and advice via web portal	Inactive: 3-month waitlist control

Abbreviation: COPD=chronic obstructive pulmonary disease

KQ 1: AMONG ADULTS, WHAT IS THE EFFECTIVENESS OF WEARABLE MOTION SENSING TECHNOLOGIES ON: (A) PHYSICAL ACTIVITY LEVELS; (B) WEIGHT LOSS OR MAINTENANCE; (C) PATIENT SATISFACTION WITH HEALTHCARE?

Key Points

- We identified 12 studies (2 judged to be at low ROB, 2 at unclear ROB, and 8 at high ROB) that met eligibility criteria comparing an accelerometer intervention for increasing physical activity outcomes. The majority of the included studies (n=9) compared the accelerometer device against a weak inactive comparator consisting of usual care, waitlist controls, or one-time educational interventions.

- The overall summary estimate (SMD 0.26; 95% CI 0.04 to 0.49) demonstrated a small positive effect of accelerometer interventions on physical activity levels that was statistically significant. When stratified by comparator, a small statistically significant effect (SMD 0.29; 95% CI 0.03 to 0.55) was found for accelerometer interventions on the outcome of increasing physical activity when compared to an inactive control. An effect of smaller magnitude but same direction was found for the active comparator group, but the pooled estimate was not statistically significant (SMD 0.17; 95% CI -1.09 to 1.43).

- Eleven trials (2 judged to be at low ROB, 3 at unclear ROB, and 6 at high ROB) examined the impact of accelerometer interventions on weight loss or maintenance. Nine of these studies used a weak/inactive comparator. The overall pooled estimate demonstrated a small but statistically significant effect (MD -1.65 kg; 95% CI -3.03 to -0.28) of accelerometers on weight loss. Stratified results by inactive comparator mirrored the overall results but were not statistically significant (MD -1.44 kg; 95% CI -3.08 to 0.19). Only 2 studies used active comparators; both demonstrated a positive trend of weight loss, but only one study was statistically significant.

- The large number of trials at high or unclear ROB, small number of participants in the majority of the trials, and moderate to high heterogeneity across summary estimates limits the strength of evidence on the impact of accelerometers on physical activity levels and weight loss or maintenance.

Physical Activity (KQ 1a)

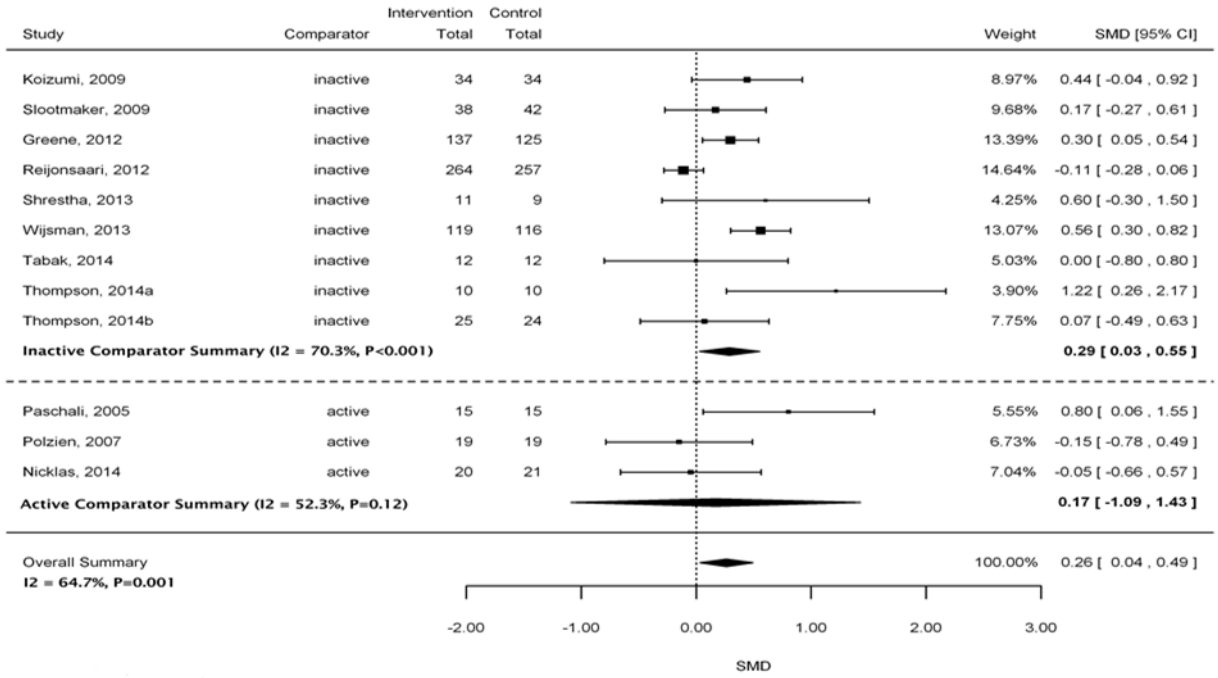
Synthesis of Findings

Twelve studies, (2 judged to be at low ROB,[37,41] 2 at unclear ROB,[34,38] and 8 at high ROB[30,35,36,39,40,42-44]) examined the impact of accelerometers on the outcome of physical activity. There was substantial variability in the mode and metrics of scales used to measure physical activity. Therefore, all summary estimates were calculated as SMDs. We stratified results by comparator type (inactive vs active) and present stratified and overall pooled estimates. The inactive comparator group contained 9 studies (1279 participants; 2 studies judged to be at low ROB,[37,41] 5 at high ROB,[36,39,40,42,43] and 2 at unclear ROB[34,38]). The active comparator group contained only 3 small studies, all judged to be at high ROB (n=109 participants).[30,35,44]

Figure 2 shows the forest plot of the meta-analysis examining the effect of accelerometers on physical activity with an overall pooled estimate and stratified pooled estimates by inactive and active comparator subgroups. The overall pooled estimate indicated a small, statistically significant effect for interventions using accelerometers to increase physical activity (SMD 0.26; 95% CI 0.04 to 0.49) with a high amount of heterogeneity (I^2=64.7%). A similar small effect was found for interventions using accelerometers to increase physical activity when compared to an inactive comparator (SMD 0.29; 95% CI 0.03 to 0.55). This summary estimate had high heterogeneity (I^2=70.3%). The high heterogeneity in these pooled estimates may be driven by several intervention characteristics including the duration of the interventions and the intensity of adjunctive interventions (*eg*, accelerometer only vs brief device-driven feedback vs intensive device-driven behavioral counseling and feedback), which underscore the overall heterogeneity across these intervention approaches.

There was also a very small positive overall effect (SMD 0.17; 95% CI -1.09 to 1.43) that was not statistically significant for accelerometer devices when compared to an active comparator. This summary estimate had moderate heterogeneity (I^2=52.3%). All of the studies included in this analysis were judged to be at high ROB.

Figure 2. Effect of Accelerometer Interventions on Physical Activity



Abbreviations: CI=confidence interval; SMD=standardized mean difference

Summary of Findings

We identified 12 studies that assessed the impact of accelerometer interventions on physical activity. Nine of these used weak controls consisting of usual care, waitlists, or one-time educational instruction and were categorized as using inactive comparators. The other 3 studies used more robust comparators and were classified as having active comparators. Compared to inactive control, the impact of accelerometer interventions on physical activity was similar to that observed in the overall summary estimate, favoring a small effect of accelerometer interventions on physical activity. Both the stratified and overall summary estimates displayed high heterogeneity as assessed by I^2 values >50%.

While the 3 trials with active comparators demonstrated a positive trend of increasing physical activity, the negligible pooled summary estimate (SMD 0.17; 95% CI -1.09 to 1.43) was not statistically significant. When compared to the inactive control summary estimate, these findings suggest that accelerometers may not have as substantial an impact on increasing physical activity when compared to a more robust and active comparator. However, the small number of studies, small sample sizes within these studies, and moderate to high heterogeneity limit conclusions that may be drawn.

Weight Loss or Maintenance (KQ 1b)

Synthesis of Findings

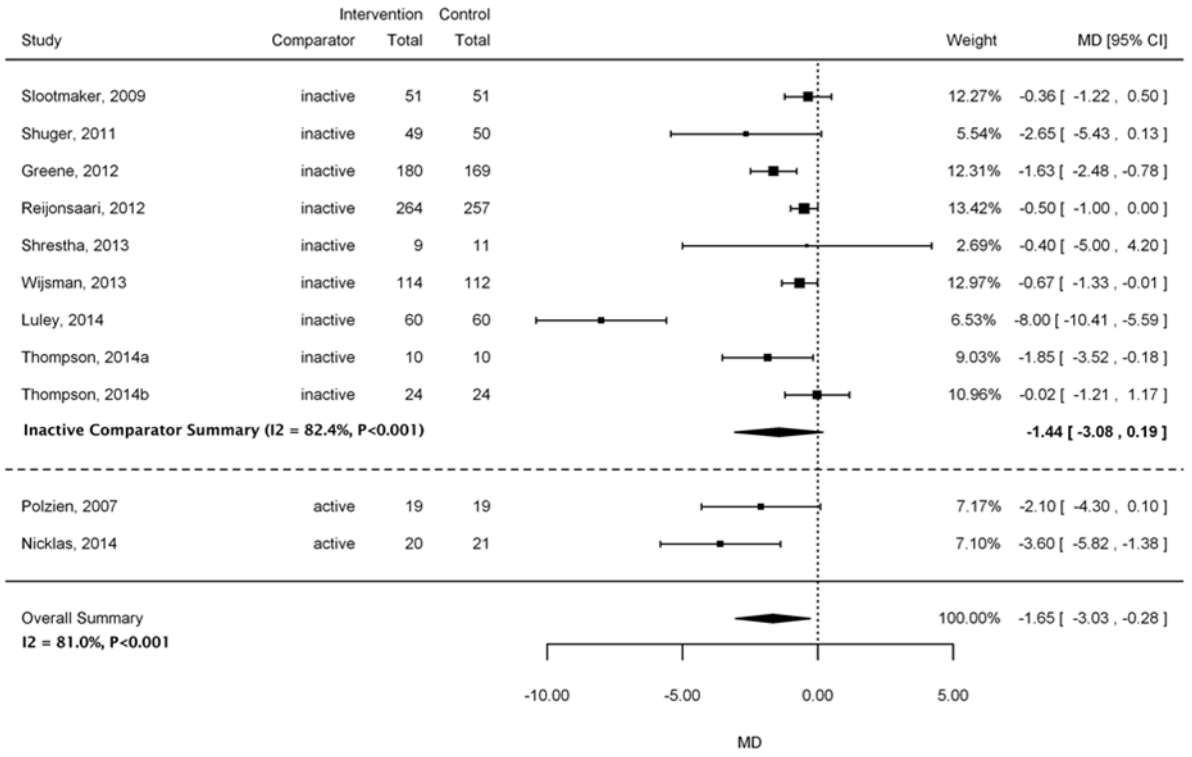
Eleven trials (2 judged to be at low ROB,[37,41] 3 at unclear ROB,[28,29,38] and 6 at high ROB[30,35,36,39,40,43]) examined the impact of accelerometers on weight loss or maintenance. All but one study reported weight changes in kilograms (kg). The other study[39] reported weight changes in pounds, which we converted to kilograms. Thus, all summary estimates were calculated as changes in weight expressed in kilograms. We stratified results by comparator type (inactive vs active) and present stratified and overall pooled estimates. The inactive comparator group contained 9 studies (n=1505 participants; 4 studies judged to be at high ROB,[36,39,40,43] 3 at unclear ROB,[28,29,38] and 2 at low ROB[37,41]). The active comparator group contained only 2 small studies judged to be at high ROB (n=79 participants).[30,35]

Figure 3 shows the forest plot of the meta-analysis examining the effect of the accelerometer interventions on weight loss or maintenance. Only the inactive comparator group had sufficient studies to be pooled. Compared to inactive controls, the impact of accelerometer interventions on weight loss was similar to that observed in the overall summary estimate (MD -1.44 vs -1.65 kg, respectively). Thus, both the overall and stratified estimate favored a small impact of accelerometer interventions on weight loss. However, the inactive pooled estimate was not statistically significant. Both the stratified and overall summary estimates displayed high heterogeneity as assessed by I^2 values >80%. High heterogeneity in these pooled estimates is likely driven by several intervention characteristics including the duration of the interventions and intensity of adjunctive interventions (*eg*, accelerometer only vs brief device-driven feedback vs intensive device-driven behavioral counseling and feedback) and underscores the overall heterogeneity across these intervention approaches.

Two small trials judged to be at high ROB compared interventions that used accelerometers with active comparators.[30,35] While both trials demonstrated a positive trend of weight loss (MD range

-3.60 to -2.10), only one study[35] was statistically significant. Differences in results are likely attributable to differences in the intensity of other intervention strategies used in conjunction with accelerometer use and in the duration of the interventions. The study with statistically significant findings[35] used structured and supervised exercise training, meal preparation twice daily, and behavior counseling delivered over 5 months. The study that did not produce statistically significant results was only 12 weeks long and used behavioral counseling only in conjunction with accelerometer use.[30]

Figure 3. Effect of Accelerometer Interventions on Weight Loss or Maintenance



Abbreviations: CI=confidence interval; MD=mean difference

Summary of Findings

We identified 11 studies that assessed the impact of accelerometer interventions on weight loss or maintenance. Nine of these used weak control conditions consisting of usual care, waitlists, or one-time educational instruction, and were categorized as using inactive comparators. Two studies used more robust comparators and were classified as having active comparators. While both trials with active comparators demonstrated a positive trend of weight loss (MD range -3.60 to -2.10), only one study was statistically significant. Differences in results are likely attributable to differences in the intensity of other intervention strategies used in conjunction with accelerometer use and in the duration of interventions. Compared to inactive controls, the impact of accelerometer interventions on weight loss was similar to that observed in the overall summary estimate, favoring a small impact of accelerometer interventions on weight loss. However, the inactive pooled estimate was not statistically significant. Both the stratified and overall summary estimates displayed high heterogeneity as assessed by I^2 values >80%. High

heterogeneity in these pooled estimates are likely driven by several intervention and population characteristics that underscore the overall variability across these studies.

In the active comparator group, most studies demonstrated a small weight loss that ranged from -0.36 to -2.65 kg. Yet, one study demonstrated a large weight loss of -8 kg (95% CI -10.41 to -5.59).[28] This trial evaluated the effects of telemonitoring for management of obesity over 12 months in patients with established metabolic syndrome. Both the control and intervention groups received dietary instruction at the beginning of the trial. The intervention group also received accelerometers and feedback via monthly behavioral counseling calls. Study authors posited that the magnitude of weight loss seen was secondary to the design of the intervention. The active interventions included key strategies associated with successful weight loss such as self-monitoring, counselor feedback and communication, social support, a structured program, and the use of an individually tailored program. Indeed, other studies included in the pooled analysis that included tailored feedback delivered by a coach or device were more likely to be associated with statistically significant weight loss.[36,37]

Patient Satisfaction (KQ 1c)

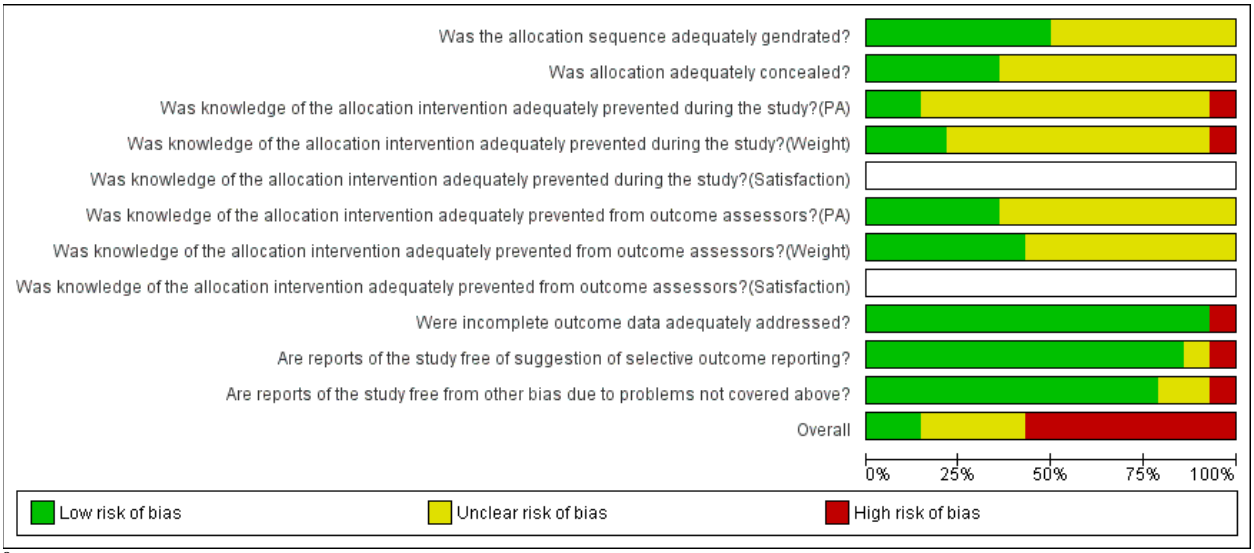
No studies reported on this outcome.

Quality of Evidence for KQ 1

Risk of Bias

Figure 4 presents a summary of the evaluation of the ROB, which shows an ROB graph with review authors' judgments about each ROB item presented as percentages across all included studies.

Figure 4. Risk of Bias Graph[a]



[a] For the overall score, low ROB required random sequencing, allocation concealment, and blinding in order to be scored low risk with no other important concerns; unclear ROB was assigned if 1 or 2 domains were scored not clear or not done; high ROB was assigned if >2 domains were scored not clear or not done.

Abbreviation: PA=physical activity

Selection Bias

Random Sequence Generation

Across all included studies, treatment allocation was described as random, and no studies were judged to be at high ROB in this domain. However, 7 of the 14 trials (50.0%) did not give details about the method for generating the random sequence, resulting in a rating of unclear ROB.

Allocation Concealment

In 5 of the 14 trials (35.7%), methods for allocation concealment were described in sufficient detail to determine whether the intervention allocation could have been foreseen in advance of or during enrollment, resulting in a judgment of low ROB. In the majority of trials (9 of 14 [64.3%]), there was an unclear ROB due to inadequate detail about allocation concealment provided by authors.

Performance Bias

For the outcome of physical activity, the blinding of participants and personnel was highly variable, as there are challenges to blinding physical activity interventions. Of the 12 trials measuring physical activity as an outcome, only 2 were judged to be at low ROB as a result of adequate reporting of blinding. In 7 of 12 trials (58.3%), there was an unclear ROB due to inadequate information regarding blinding. One study was judged to be at high ROB due to lack of blinding.

Similar to physical activity outcomes, for the weight outcome, the blinding of participants and personnel was highly variable, as there are challenges to blinding weight change interventions. Of the 11 trials measuring weight change as an outcome, 4 (36.4%) were judged to be at low ROB as a result of adequate reporting of blinding. In 6 of 11 trials (54.5%), there was an unclear ROB due to inadequate information regarding blinding. One study was judged to be at high ROB due to lack of blinding.

Satisfaction with healthcare was not identified as an outcome in any of the included studies. Therefore, no ROB is reported for this outcome.

Detection Bias

For the outcome of physical activity, in 5 of the 12 trials (41.7%) there was sufficient information provided by the authors regarding outcome blinding assessment to judge this domain as low ROB. In the remaining trials (7 of 12 [58.3%]), insufficient information regarding outcome blinding assessment was provided by authors, resulting in a judgment of unclear ROB.

For the outcome of weight, 6 of the 11 trials (41.7%) gave sufficient information provided by the study authors about outcome blinding assessment to judge this domain to be at low ROB. In the remaining trials (4 of 11 [36.4%]), insufficient information regarding outcome blinding assessment was provided by authors, resulting in a score of unclear ROB.

Satisfaction with healthcare was not identified as an outcome in any of the included studies. Therefore, no ROB is reported for this outcome.

Attrition Bias

All trials reported the numbers randomized to each group. The majority of trials (13 of 14 [92.9%]) reported complete outcome data that included information on attrition and exclusions from analysis. One trial did not disclose the reason for attrition/exclusion in sufficient detail, resulting in a judgment of high ROB.

Reporting Bias

The majority of trials (12 of 14 [85.7%]) reported details of the measured outcomes sufficient to be judged to be at low ROB.

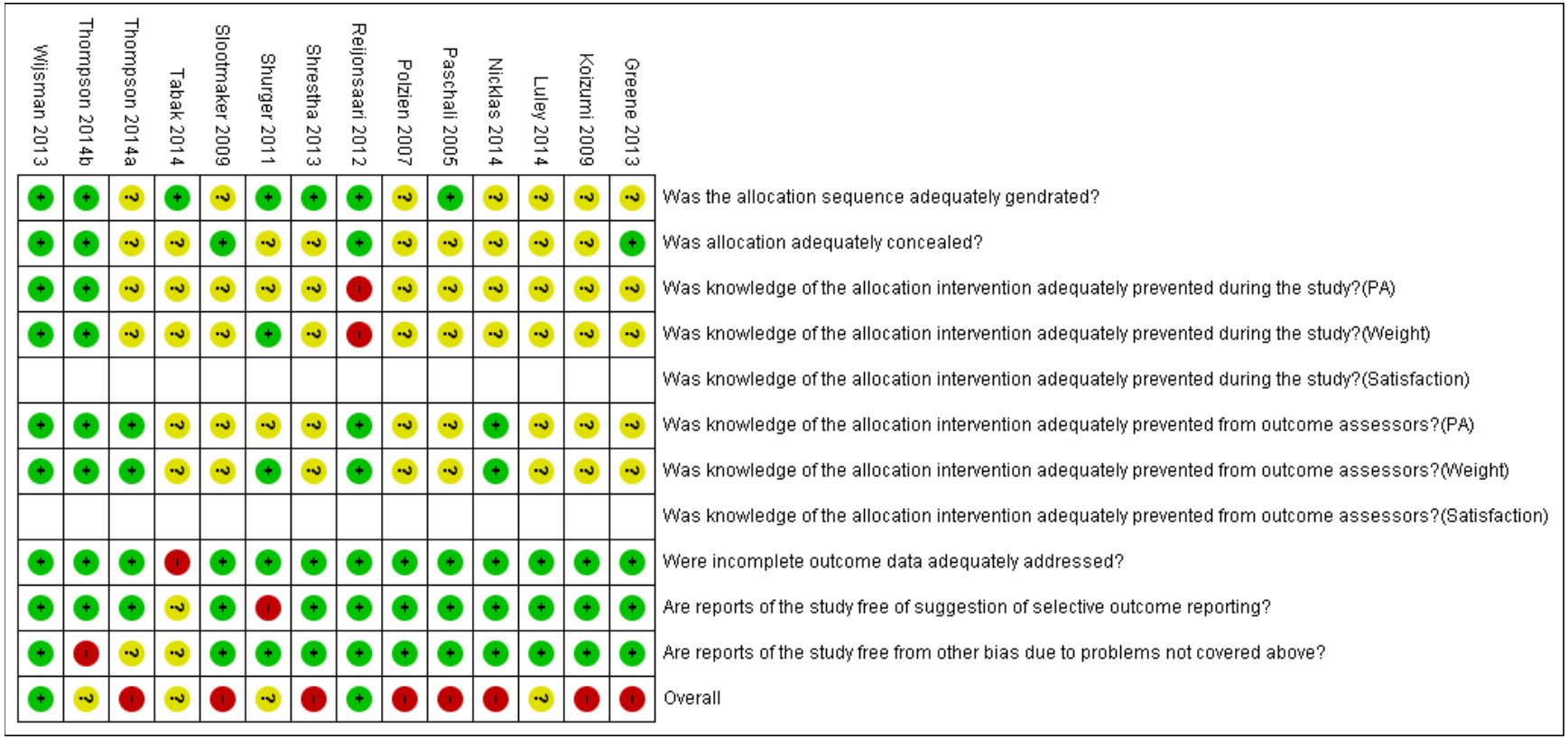
Other Bias

The majority of trials (11 of 14 [78.6%]) provided sufficient details not to raise concerns about bias of a nature not covered within the other domains mentioned. Two trials did not provide sufficient methodological detail to judge this domain and were given a judgment of unclear ROB, whereas one trial was judged to be at high ROB stemming from use of a questionable analytical approach during the interim analysis and stopping the trial due to insignificant results.

Overall Risk of Bias

Overall ROB was assessed for each included study (Figure 5). The majority of studies (8 of 14 [57.1%]) were judged to be at high ROB, 4 (28.6%) were at unclear ROB, and only 2 studies (14.3%) were judged to be at low ROB.

Figure 5. Risk of Bias Summary: Review Authors' Judgments About Risk of Bias Items for Each Included Study[a]



[a] For the overall score, low ROB required random sequencing, allocation concealment, and blinding in order to be scored low risk with no other important concerns; unclear ROB was assigned if 1 or 2 domains were scored not clear or not done; high ROB was assigned if >2 domains were scored not clear or not done.

Abbreviation: PA=physical activity

KQ 2: AMONG ADULTS, DOES THE IMPACT OF WEARABLE MOTION SENSING TECHNOLOGIES VARY BY: (A) CHARACTERISTICS OF THE POPULATION; (B) TYPE OF ADJUNCTIVE INTERVENTIONS; (C) ADHERENCE TO USE OF THE DEVICES; OR (D) CHARACTERISTICS OF THE DEVICE?

Key Points

We explored the variable impact of wearable motion sensing technologies (activity devices) on physical activity and weight by multiple single factors that may contribute to heterogeneity (*ie*, recruited populations, role of device relative to other motivational enhancement strategies, location of device on body as a proxy for ease of use). None of these individual factors was a robust predictor of heterogeneity.

- Across 4 population subgroups (overweight/obese/sedentary, older adults, healthy volunteers, and chronic medical illnesses), there were no major subpopulation differences in the magnitude and direction of effect estimates on physical activity or weight. Only the older adult subgroup for physical activity and the overweight/obese/sedentary subgroups for weight displayed relatively lower heterogeneity.

- The impact of accelerometer interventions was not well-explained by the role of the device, operationalized as major role versus minor role of the accelerometer in the overall intervention approach. Pooled estimates mirrored the results of the overall summary estimate. The direction and magnitude of the effects were similar for both major and minor role groups; subgroups displayed moderate to high heterogeneity.

- Only 4 of 14 studies reported on adherence to the activity device, and these reports largely focused on the process measures related to accelerometer adherence (hours the device was worn, uploads to websites). The role of accelerometer adherence as a moderating factor of outcome remains to be fully examined in the literature.

- The predominant location of accelerometers was on the waist, followed by the arm. The impact of accelerometer interventions was not well explained by activity device characteristics operationalized as location of the device on the body. Pooled results on physical activity and weight were similar to the overall summary estimate.

Variation by Population Characteristics (KQ 2a)

Synthesis of Findings

We classified studies and organized findings by physical activity and weight. While satisfaction with healthcare was also an outcome of interest, no study reported on this outcome. We planned to perform meta-analytic regression to assess the impact of population characteristics on the outcomes of interest, but we had insufficient studies to perform these analyses. Thus, we categorized studies into population subgroups as determined by study trial recruitment criteria (*ie*, overweight/obese/sedentary, older adults, healthy volunteers, and chronic medical illnesses). For each subgroup with 3 or more studies, we calculated summary estimates. Other results are synthesized qualitatively.

Physical Activity

To assess whether the effects of accelerometer interventions vary by population characteristics, we conducted exploratory subgroup analyses based on study eligibility criteria. For the overweight/obese/sedentary population, there were 158 participants in 4 studies. All 4 studies were judged to be at high ROB.[30,38,40,43] For older adults, there were 393 participants in 4 studies, including one study judged to be at low ROB,[37] one at unclear ROB,[36] and 2 at high ROB.[35,42] For healthy volunteers, there were 783 participants in 2 studies, with one study each at low[41] and high[39] ROB. For chronic medical illnesses, there were 54 participants in 2 studies, with one study each at unclear[34] and high[44] ROB.

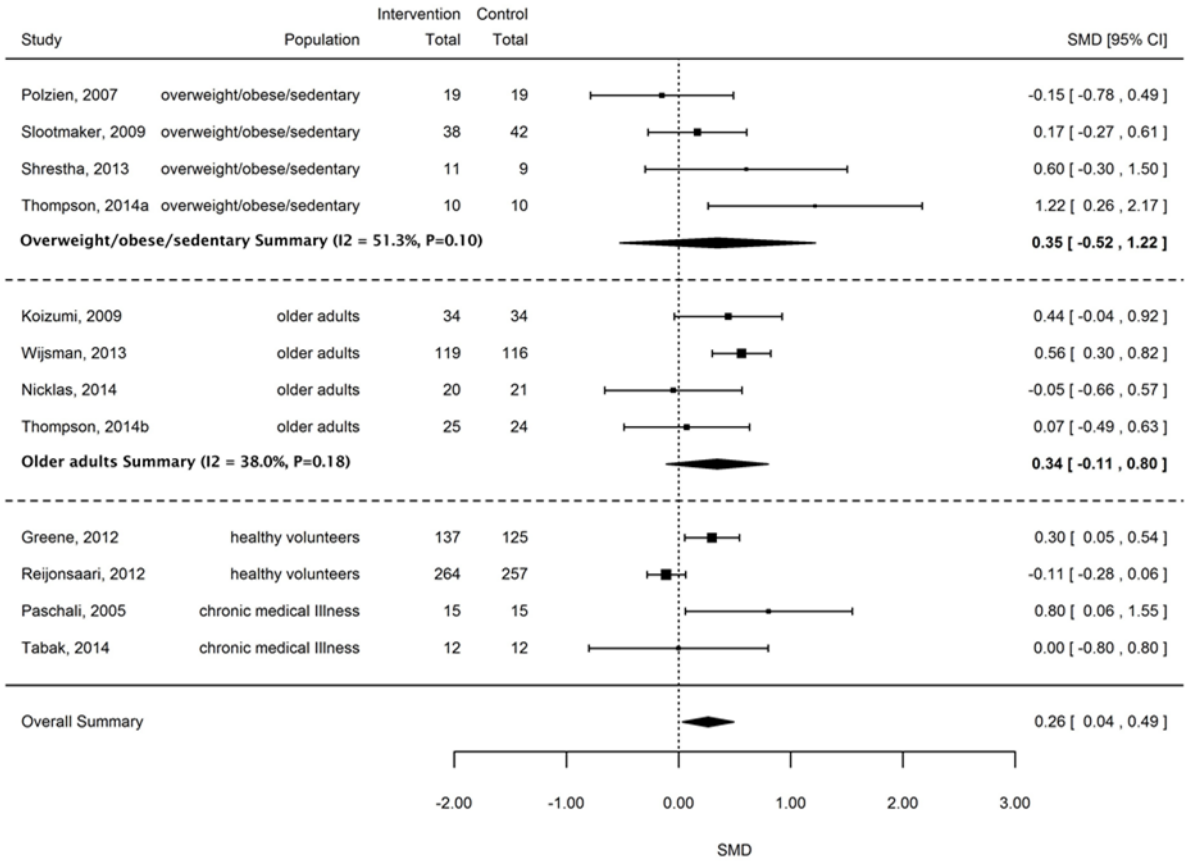
Figure 6 shows the forest plot of the meta-analysis examining the effect of accelerometer interventions on physical activity by the population subgroups. We had sufficient studies to pool effects for 2 population subgroups—the overweight/obese/sedentary population and older adults. Both subgroups displayed a similar magnitude and direction of effect—namely, a small positive effect of accelerometer interventions on increased physical activity—but neither estimate was statistically significant. The pooled SMD was 0.35 (95% CI -0.52 to 1.22) for the overweight/obese/sedentary group and displayed moderate heterogeneity (I^2=51.3%). For the older adult subgroup, the pooled SMD was 0.34 (95% CI -0.11 to 0.80), with low heterogeneity (I^2=38.0%).

Two additional subgroups—healthy volunteers[39,41] and those with chronic medical illnesses[34,44]—were evaluated in only 2 studies each and therefore could not be pooled. Results were mixed in the 2 studies in healthy volunteers. The differences between the 2 studies were likely due to differences in the population baseline activity levels and in participant interactions with adjunctive interventions. In a study at low ROB,[41] healthy insurance company employees (n=521 total) receiving a combined accelerometer and counseling intervention did not increase physical activity when compared to a control group (SMD -0.11; 95% CI -0.28 to 0.06). At baseline, the majority of employees in both arms met physical activity guidelines. In a study judged to be at high ROB,[39] there was a small effect indicating increased physical activity (SMD 0.30; 95% CI 0.05 to 0.54) in 262 healthy employees and family members of PeaceHealth Oregon who used an intervention containing an accelerometer plus an online social network versus an education-only control group. The level of social interaction was much greater in the intervention using an online social network compared with the intervention with online or telephone counseling.

For the 2 studies in chronic medical illness populations, accelerometer interventions produced no significant effect on physical activity in one study judged to be at unclear ROB[34] (SMD 0.00; 95% CI -0.80 to 0.80), and a moderate statistically significant effect on physical activity in the other study, which was at high ROB[44] (SMD 0.80; 95% CI 0.06 to 1.55). These differences were likely due to differences in populations (chronic obstructive pulmonary disease [COPD][34] vs type 2 diabetes[44]) and interventions, with one intervention more focused on physical activity.[44] In the COPD study[34] 24 participants received either usual care or a telehealth program where an accelerometer plus a smartphone activity coach was one of 4 components. The intervention arm did not increase physical activity; however, adherence to the physical activity portion of the program was low compared with the portion focused on COPD self-management. In the type 2

diabetes study (n=30 participants),[44] accelerometers plus counseling increased physical activity as compared to counseling alone.

Figure 6. Effect of Accelerometer Interventions on Physical Activity by Population Characteristics



Abbreviations: CI=confidence interval; SMD=standardized mean difference

Weight

For the outcome of weight, we conducted subgroup analyses by the following populations based on study eligibility criteria: overweight/obese/sedentary populations (1170 participants, 5 studies, with 4 at high ROB[30,38,40,43] and one at unclear ROB[29]); older adults (315 participants, 3 studies at low,[37] high,[35] and unclear[36] ROB); healthy volunteers (870 participants, 2 studies at high[39] and low[41] ROB); and chronic medical illness populations (120 participants, 1 study at unclear ROB[28]). There were insufficient studies to pool results for healthy volunteers and chronic medical illness populations.

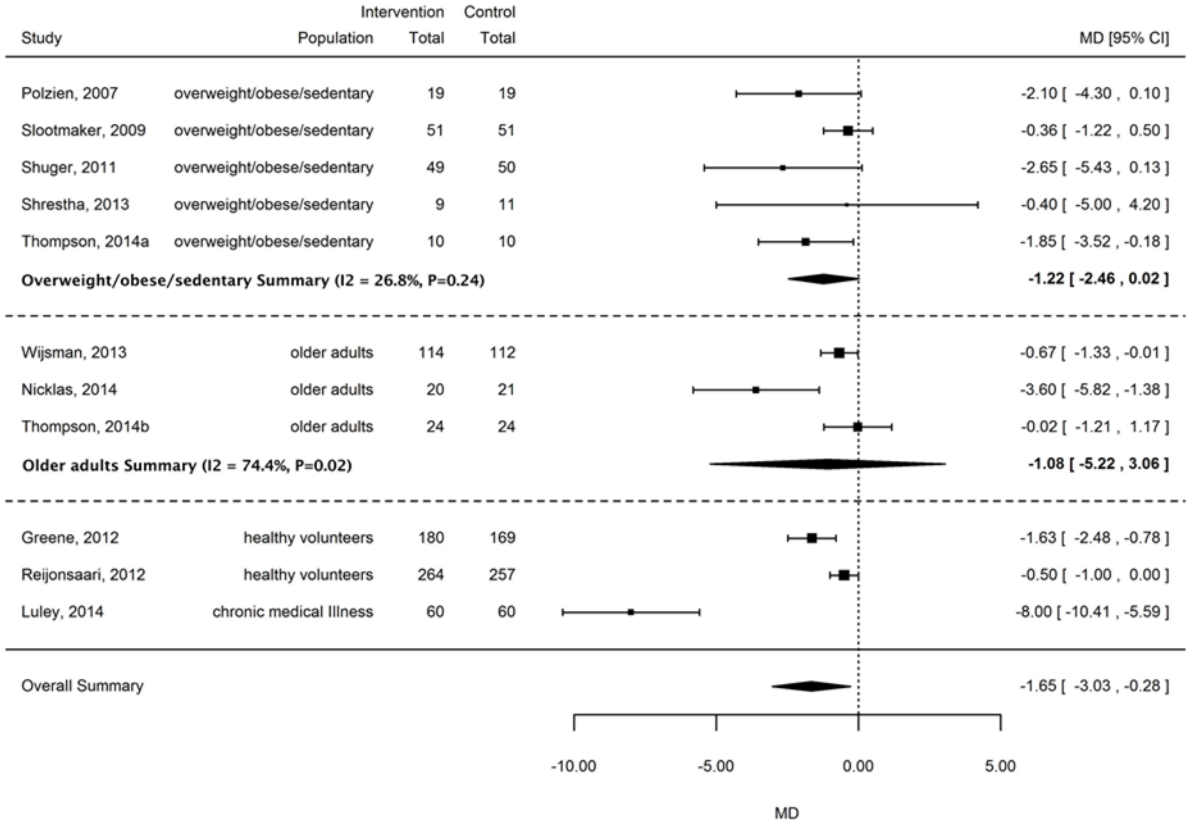
Figure 7 shows the forest plot displaying the effects of accelerometer interventions on weight by the population subgroups. Among overweight/obese/sedentary persons, 5 studies assessed the impact of accelerometer interventions on change in weight in kilograms. Compared with inactive and active control conditions combined, accelerometer interventions resulted in an MD of -1.22 kg (95% CI -2.46 to 0.02*)*. This estimate displayed relatively low heterogeneity (I^2=26.8%). In older adults, accelerometer interventions produced a decrease in weight of a similar magnitude. Again, the pooled effect estimate was not statistically significant (MD -1.08 kg; 95% CI -5.22 to

3.06) and displayed high heterogeneity (I^2=74.4%). This heterogeneity likely reflected populations somewhat different in age and other study eligibility criteria (*eg*, also recruiting for other comorbidities such as overweight).

We identified only 2 studies in healthy volunteers,[39,41] and both showed a small positive effect of accelerometer interventions on weight. In one study at high ROB,[39] 262 healthy employees and family members of PeaceHealth Oregon participated in an intervention with accelerometers where the major focus was on developing an online social network for sharing goal-setting and attainment. When compared to control, this intervention produced an MD of -1.63 kg (95% CI -2.48 to -0.78*).* In the other study, at low ROB,[41] when compared to a control intervention, a combined accelerometer and counseling intervention produced an MD of -0.50 kg (95% CI -1.00 to 0.00) in health insurance company employees. As above, baseline physical activity was higher in the latter study, and the intensity of the social component of the intervention was greater in the former.

One study judged to be at unclear ROB assessed the effect of accelerometer interventions on weight among study participants with chronic medical illnesses.[28] Persons with metabolic syndrome were randomized to a one-time education-only control or 12 months of accelerometer use plus weight, diet, and physical activity feedback via monthly telephone calls or weekly letters. More weight loss was observed in the accelerometer condition than in the control arm (MD -8.00 kg; 95% CI -10.41 to -5.59).

Figure 7. Effect of Accelerometer Interventions on Weight (in Kilograms) by Population Characteristics



Abbreviations: CI=confidence interval; MD=mean difference

Summary of Findings

Physical Activity

For subgroups where quantitative analyses were performed (overweight/obese/sedentary and older adults), pooled effect sizes were not statistically significant (SMD 0.35; 95% CI -0.52 to 1.22 and SMD 0.34; 95% CI -0.11 to 0.80), but were of similar magnitude and direction when compared to one another and to the overall summary estimate. For subgroups where only qualitative analyses could be performed (healthy and chronic medical illness), there were 2 studies each with mixed results. For both subpopulations, one study showed a small, statistically significant increase in physical activity, while the other showed little to no effect that was not statistically significant. Thus, taken together, all subgroups support a small positive effect, with no apparent differential effectiveness on physical activity.

Weight

For the outcome of weight loss, there were no major differences in effect sizes across the 4 population subgroups with the exception of the chronic medical illness subgroup, where a single study at high ROB showed a larger effect size (MD -8.00 kg; 95% CI -10.41 to -5.59). This difference might be attributed to the metabolic syndrome population studied, in which counseling convention strongly promotes lifestyle change above pharmacologic interventions.

Additionally, this intervention was focused on weight loss and included counseling and monitoring of nutrition—as well as physical activity and weight—over a 12-month period compared to a weak control of a one-time educational intervention.

Summary

Table 4 provides a summary of findings for KQ 2a.

Table 4. Summary of Findings: Variation by Population Subgroups (KQ 2a)

Outcome	Population			
	Overweight/Obese/ Sedentary	Older Adults	Healthy Volunteers	Chronic Medical Illnesses
Physical activity	4 studies: SMD 0.35 (95% CI -0.52 to 1.22)	4 studies: SMD 0.34 (95% CI -0.11 to 0.80)	2 studies: SMD range: -0.11 to 0.30	2 studies: SMD range: 0.00 to 0.80
Weight	5 studies: MD -1.22 kg (95% CI -2.48 to 0.02)	3 studies: MD -1.08 kg (95% CI -5.22 to 3.06)	2 studies: MD range: -1.63 to -0.50 kg	1 study: MD -8.00 kg (95% CI -10.41 to -5.59)

Abbreviations: CI=confidence interval; MD=mean difference; SMD=standardized mean difference

Variation by Activity Device Role (Major vs Minor; KQ 2b)

Synthesis of Findings

We classified studies and organized findings by physical activity and weight. While satisfaction with healthcare was also an outcome of interest, no study reported on this outcome. We categorized studies into subgroups as determined by activity device role (major or minor). A device was determined to have a major role if the device (accelerometer) was the only or central motivational enhancement intervention intended to improve the primary outcome of the study. In this case, other intervention components were centered on the feedback provided by the accelerometer. Other adjunctive interventions may have been included but played a minor role in enhancing physical activity or could not have been conducted without the feedback of accelerometer data. An activity device was determined to have a minor role if the accelerometer was an integrated component of a suite of other motivation enhancement interventions which may have included, but were not limited to, a structured exercise program, diet counseling/education, chronic disease counseling/monitoring, and/or self-management techniques.

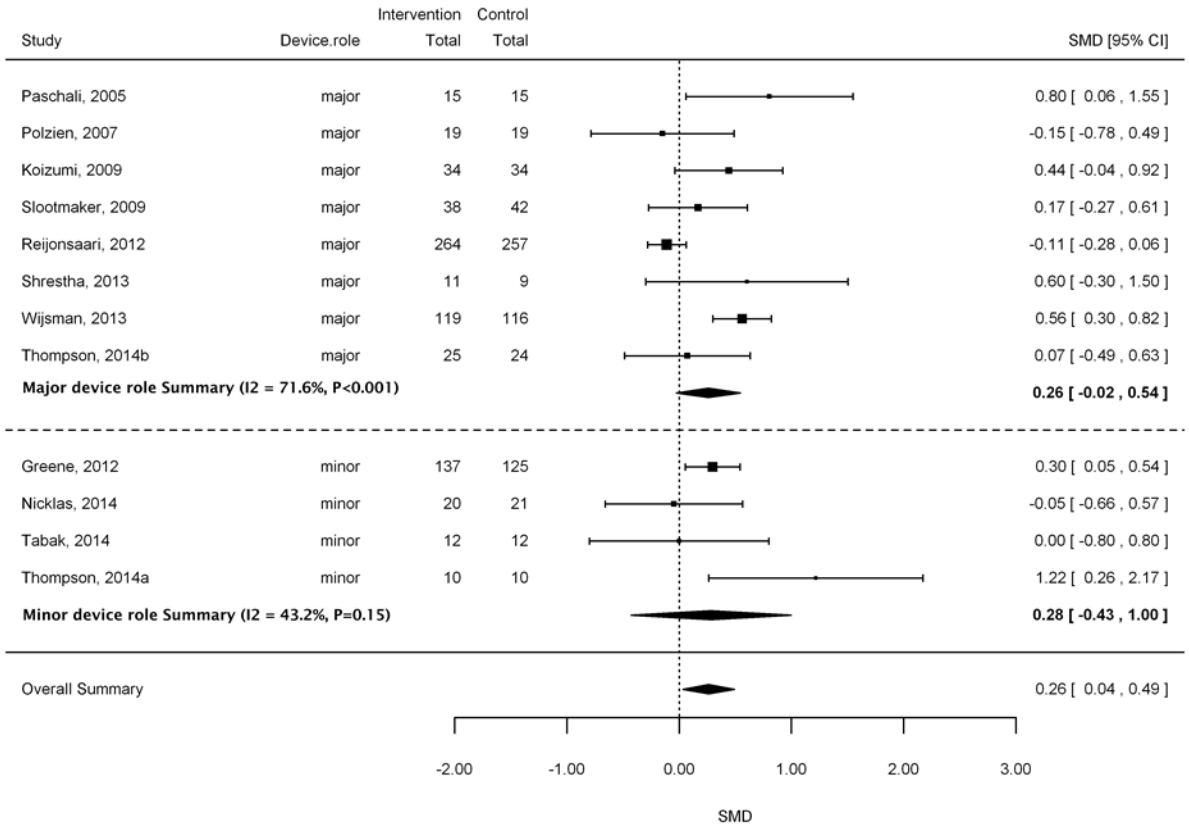
Physical Activity

To assess whether the effects of the accelerometer interventions on physical activity vary by activity device role, we conducted an exploratory subgroup analysis by major versus minor role of the device. The major role subgroup contained 8 studies (n=1041 participants), 5 judged to be at high ROB,[30,40,42-44] one at unclear ROB,[36] and 2 at low ROB.[37,41] The minor role subgroup contained 4 studies (n=374 participants), 3 at high ROB[35,38,39] and one at unclear ROB.[34]

Figure 8 shows the forest plot of the meta-analysis examining the effect of accelerometer interventions on physical activity by activity device role. Both subgroups displayed a similarly

small, positive effect size for accelerometer interventions on increased physical activity, but neither group was statistically significant. The pooled SMD was 0.26 (95% CI -0.02 to 0.54) for the major device role subgroup and displayed high heterogeneity (I^2=71.6%). The subgroup including studies where the activity device played a minor role showed a pooled SMD of 0.28 (95% CI -0.43 to 1.00), with moderate heterogeneity (I^2=43.2%).

Figure 8. Effect of Accelerometer Interventions on Physical Activity by Device Role



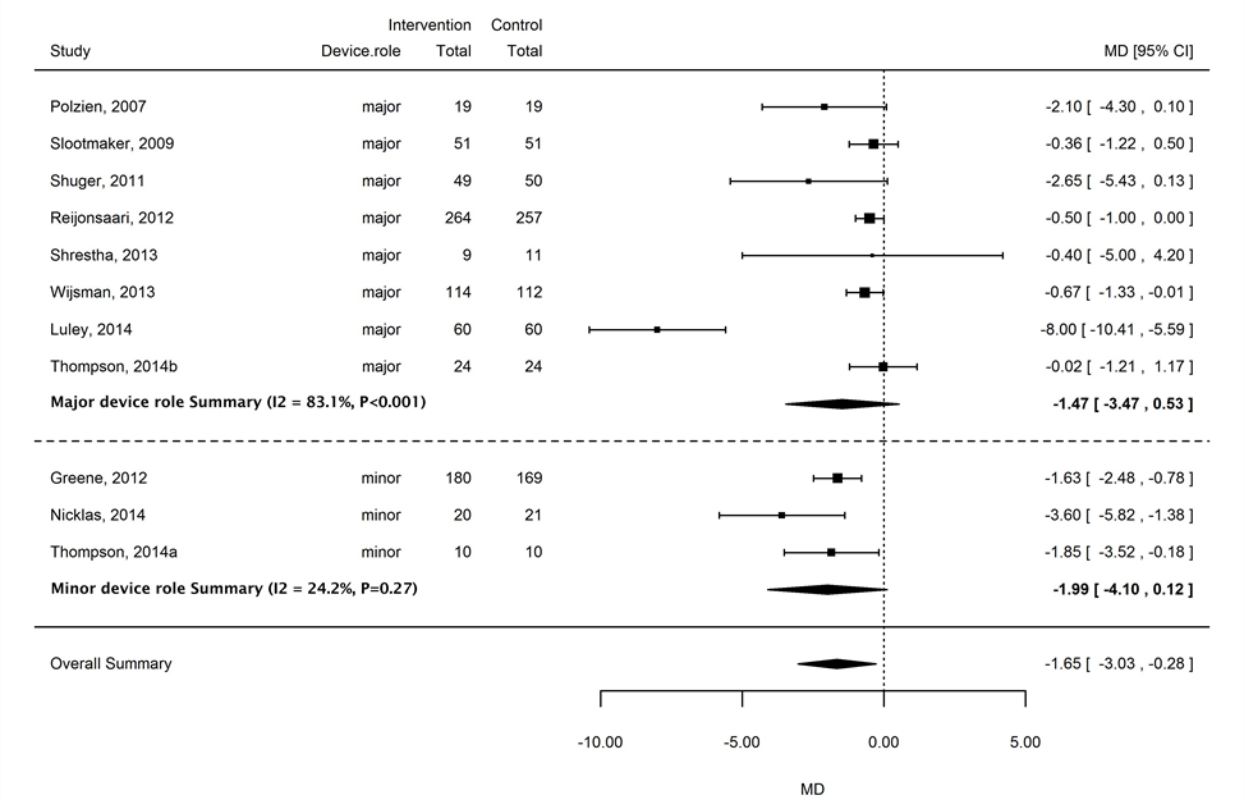
Abbreviations: CI=confidence interval; SMD=standardized mean difference

Weight

To assess whether the effects of the accelerometer interventions on weight vary by activity device role, we conducted an exploratory subgroup analysis by major role versus minor role of the device. In the major role subgroup, there were 8 studies (n=1174 participants), 3 judged to be at high ROB,[30,40,43] 2 at low ROB,[37,41] and 3 at unclear ROB.[28,29,36] In the minor role subgroup, there were 3 studies (n=410 participants), all at high ROB.[35,38,39]

Figure 9 shows the forest plot of the meta-analysis examining the effect of the interventions on weight by activity device role. The direction and magnitude of the effects were similar for both groups, favoring a small impact of less than 2 kg of weight loss, but neither group was statistically significant. Compared with inactive and active control conditions combined, the pooled MD was -1.47 kg (95% CI -3.47 to 0.53) for the major role subgroup and displayed high heterogeneity (I^2=83.1%). The minor role subgroup showed a pooled MD of -1.99 kg (95% CI -4.10 to 0.12) and displayed low heterogeneity (I^2=24.2%).

Figure 9. Effect of Accelerometer Interventions on Weight (in Kilograms) by Device Role



Abbreviations: CI=confidence interval; MD=mean difference

Summary of Findings

The impact of accelerometer interventions on physical activity and weight were not well-explained by the role of the activity device, operationalized as major role versus minor role of accelerometer in the overall intervention approach. These estimates mirrored the results of the overall summary estimate. For physical activity, 8 studies were categorized as using accelerometers as the major intervention strategy,[30,36,37,40-44] and 4 were categorized as using accelerometers as a minor component in the overall intervention approach.[34,35,38,39] For weight loss, 8 studies were categorized as major[28-30,36,37,40,41,43] versus 3 categorized as minor.[35,38,39] The direction and magnitude of the effects were similar for both subgroups, favoring a small positive impact on increasing physical activity and decreasing weight that mirrored the overall summary estimate. Yet neither group was statistically significant. Across physical activity and weight loss, the major subgroups displayed high heterogeneity. High heterogeneity in the major role of device subgroup is likely driven by several intervention characteristics that underscore the overall variability in the intervention approaches included in this subgroup. For example, studies in this group ranged from accelerometer-alone strategies[29] to interventions that included in-person behavioral counseling and accelerometer-driven feedback used to enhance the self-monitoring and motivational aspects of device feedback.[30] In general, interventions that included an accelerometer as a major component of the intervention and that capitalized on the self-monitoring and tailored device-driven feedback capabilities of these devices were associated with a greater decrease in weight (see Figure 9).[28-30] The same trend was not seen for greater

increases in physical activity with better implementation of activity device feedback and self-monitoring functionality.

Table 5 provides a summary of findings for KQ 2b.

Table 5. Summary of Findings: Variation by Device Role (KQ 2b)

Outcome	Role of Accelerometer	
	Major Role	Minor Role
Physical activity	SMD 0.26 (95% CI -0.02 to 0.54)	SMD 0.28 (95% CI -0.43 to 1.00)
Weight	MD -1.47 kg (95% CI -3.47 to 0.53)	MD -1.99 kg (95% CI -4.10 to 0.12)

Abbreviations: CI=confidence interval; MD=mean difference; SMD=standardized mean difference

Variation by Adherence to Use of the Activity Device (KQ 2c)

Synthesis of Findings

The primary aim of KQ 2c was to examine accelerometer adherence as a moderator of the outcomes of physical activity, weight loss, and satisfaction with healthcare. Only 4 of 14 studies reported any measure of accelerometer adherence.[30,35,41,43] Across these 4 studies, adherence to the activity device was defined variably by total arm-band time use, categorical measure of time the device was worn (*eg*, often vs regularly), percentage of days device was worn at least 10 hours per day, and change in web-based service use at 2 time points. In light of dropout rates (range of 12% to 31%), adherence data were reported only on study completers. While these 4 studies assessed physical activity levels and body weight as outcome measures, only one of these studies examined accelerometer adherence relationship to these outcomes (weight only). Satisfaction with healthcare was not assessed as an outcome in any of these studies. Individual determinants of accelerometer adherence were not examined in any of these studies. The synthesis of findings presented here combines results for physical activity and weight loss outcomes.

A large worksite physical activity promotion study judged to be at low ROB[41] randomized 544 employees to either 12 months of continuous accelerometer use and distance counseling (by phone or the web) or a control group that received baseline fitness results only. Participants in the intervention arm were instructed to enter their physical activity score from the accelerometer manually to the web-based service. Use of the web-based service was assessed as a proxy of accelerometer adherence in this study. Overall, use of the web-based service was low among participants in the intervention arm, averaging just 15 logins during the last 6 months of the trial (0.6 logins per week). Comparisons of the 0- to 6-month versus 6- to 12-month time periods of the study show that use of the web-based service also decreased over the trial for both participants and coaches. Participants entered fewer days of physical activity scores (14% of days vs 9% of days), coaches sent fewer messages to participants (7.2 vs 6.1 messages), and participants sent fewer messages to coaches (4.3 vs 1.7 messages). This study did not examine the impact of accelerometer adherence on physical activity or weight loss outcomes.

A second, smaller worksite physical activity promotion study judged to be at high ROB[43] randomized 102 healthy young employees to either 3 months of continuous accelerometer use and tailored web-based support or a control group that received a single brochure with brief activity recommendations at baseline. Participants in the intervention arm were encouraged to

enter their physical activity score from the accelerometer manually to the web-based service. Uploaded accelerometer scores were paired with automatic, tailored physical activity advice and motivational tips. Seventy-three percent of those in the intervention arm reported wearing the accelerometer "regularly" or "often" and accessed the web-based service on average nearly once per week to upload accelerometer data. Fifty-two percent of intervention arm participants set a personal goal using the web-based service. However, 41% of participants found the tailored advice on the website unappealing. Barriers to compliance included a limited menu of preferred personal activities on the web-based service, and physical activity advice not relevant to the participant's preferred personal activity. This study did not examine the impact of accelerometer adherence on physical activity or weight loss outcomes.

In a small 12-week behavioral weight-loss study judged to be at high ROB,[30] 57 healthy adult participants were randomized to: (1) standard in-person weight control program; (2) standard program + continuous technology-based behavioral program (continuous armband-accelerometer wear and feedback); or (3) standard program + intermittent technology-based behavioral program (3 weeks of armband accelerometer wear and feedback). Average total accelerometer wear time was low in both the intermittent and continuous groups (63.8 minutes/week and 71.0 minutes/week, respectively) and was highly variable (range 51 to 350 minutes/week). Adherence to the accelerometer, defined as total arm band time, declined significantly across all 4-week time periods in the continuous technology group. Self-monitoring of exercise also decreased across the intervention period in the standard and intermittent groups. This was the only study to examine the relationship between accelerometer adherence and weight loss. Significant correlations were reported between change in body weight and total accelerometer wear time in both the intermittent ($r=-0.68$, $p<0.01$) and continuous ($r=-0.71$, $p<0.01$) technology arms.

In a pilot study (high ROB) of spontaneous physical activity and weight loss,[35] 48 older adults were randomized to a 5-month weight loss intervention that included a hypocaloric diet and aerobic exercise or the same weight loss intervention plus a self-regulatory intervention (which included an accelerometer) to promote spontaneous physical activity. Following post-weight loss assessments at 5 months, both groups transitioned to a self-directed diet and exercise program during a 5-month follow-up period. Adherence to the accelerometer was high (see Table 6). Eighty-five percent of participants (n=17) submitted accelerometer data for the entire 10 months of the study, of which 87% wore the accelerometer for the prescribed ≥10 hours per day. Eighty-one percent of participants met the daily spontaneous physical activity goal recorded by the accelerometer. Reported barriers to accelerometer wear compliance included device malfunction/battery change (13%), illness/health (9%), forgot to wear the monitor (7%), and too busy/time conflict (7%). The transition from the 5-month, intensive intervention to the self-monitored program also seemed to pose a barrier for some who stopped wearing the monitor (15%). This study did not examine the impact of accelerometer adherence on physical activity or weight loss outcomes.

Summary of Findings

Only 4 of 14 studies provided any data on adherence to the activity device. Although our primary aim was to examine accelerometer adherence as a moderator of physical activity, weight loss, and satisfaction outcomes, none of these studies reported such analyses. Instead, these studies focused largely on the process measures related to accelerometer adherence. Despite the major

role played by the accelerometer in 3 of these studies, a consistent pattern of decline in participants' use of the device was evident over study duration, and generally low levels of adherence over time were reported. Two studies conducted in workplace settings showed significant participant disengagement expressed in low levels of self-motivated, self-initiated, stated goals to be achieved during the study time period. In summary, we are unable to determine from this literature whether accelerometer adherence has an effect on the outcomes of interest when accelerometers are used as part of behavioral interventions.

Table 6 provides a summary of findings for KQ 2c.

Table 6. Summary of Findings: Accelerometer Adherence Across Individual Studies of Physical Activity and Weight Loss (KQ 2c)

Study	Role of Accelerometer	Accelerometer Adherence Description
Nicklas, 2014[35]	Minor	· 85% of participants submitted accelerometer data for entire 10 months · 87% of days completers wore accelerometer at least 10 hours/day · 81% of days spontaneous physical activity goal met · Barriers to compliance: device malfunction/battery change (13%), illness/health (9%), forgot to wear (7%), too busy/time conflict (7%)
Polzien, 2007[30]	Major	· Accelerometer wear time was low and highly variable in both continuous and intermittent technology groups · Significant decline in total accelerometer wear time use by continuous technology group across all 4-week time periods · Standard and intermittent groups decreased self-monitoring of exercise across the 12-week intervention period · Longer total accelerometer wear time was significantly associated with greater weight loss in both the continuous and intermittent technology groups
Reijonsaari, 2012[41]	Major	· Use of web-based service decreased with time (comparing 0 to 6-month vs 6- to 12-month study periods) for both participants and coaches · Declines in web-based service across time included entries of participant physical activity scores (14% of days vs 9% of days); coach communication to participants (7.2 vs 6.1 messages); participant communication to coaches (4.3 vs 1.7 messages)
Slootmaker, 2009[43]	Major	· 73% of participants wore accelerometer "often" or "regularly" · 52% of participants set personal goal on web-based service · Barriers to compliance: Limited menu of preferred, personal activities on web-based service; physical activity advice not relevant to participant-preferred, personal activity; 41% found advice on website unappealing

Variation by Characteristics of the Activity Device (Body Location; KQ 2d)

Synthesis of Findings

We classified studies and organized findings by physical activity and weight. While satisfaction with healthcare was also an outcome of interest, no study reported on this outcome. We categorized studies into subgroups as determined by characteristics of the activity device, operationalized as location of the device on the body. Locations of interest were waist, arm, wrist, and multisite. One study that did not specify device location was not included. We had sufficient studies to pool effects only for one subgroup (waist); other results are synthesized qualitatively.

Physical Activity

To assess whether the effects of the accelerometer interventions on physical activity vary by device characteristics, we conducted exploratory subgroup analysis by the following device location sites: waist (n=809 participants; 7 studies, 5 judged to be at high ROB,[35,38,42-44] one at low ROB,[41] and one at unclear ROB[36]); arm (n=38 participants; 2 studies, both at high ROB[30,40]); wrist (n=235 participants; one study at low ROB[37]); and multisite (n=24 participants; one study at unclear ROB[34]).

Figure 10 shows the forest plot examining the effect of the interventions on physical activity by activity device location. The pooled estimate displayed a weakly positive association regarding effect of location of accelerometer at the waist on increasing physical activity (SMD 0.24; 95% CI. -0.15 to 0.63) and moderate heterogeneity (I^2=62.3%). This effect was similar in direction and magnitude to the overall summary estimate.

Three additional subgroups—arm, wrist, and multisite—contained fewer than 3 studies and could not be pooled. The 2 studies where the device was worn on the arm[30,40] showed mixed results, neither of which was statistically significant. Of the 2 studies, one (at high ROB)[30] showed a negative impact on physical activity (SMD -0.15; 95% CI -0.78 to 0.49). The second (also at high ROB)[40] showed a small positive effect on physical activity (SMD 0.60; 95% CI -0.30 to 1.50). The differences in the 2 studies were likely due to differences in the duration of the intervention (12 vs 24 weeks), comparator arms (active vs weak or active vs active), and overall analytic strategy of each study. Of note, both studies had high dropout rates, but only one study specifically stated that they used an intention-to-treat analysis. In Shrestha et al[40] an accelerometer paired with an interactive website versus usual care did not show a statistically significant mean change in total physical activity between groups. The lack of difference in effect on physical activity was attributed to low initial recruitment (28 participants total) and a high dropout rate (attrition 64% at 6 months). Polzien et al[30] used a technology-based program added to an in-person behavioral weight loss program. Although each group showed a significant increase in leisure time physical activity, there was no statistically significant difference between the active intervention arms.

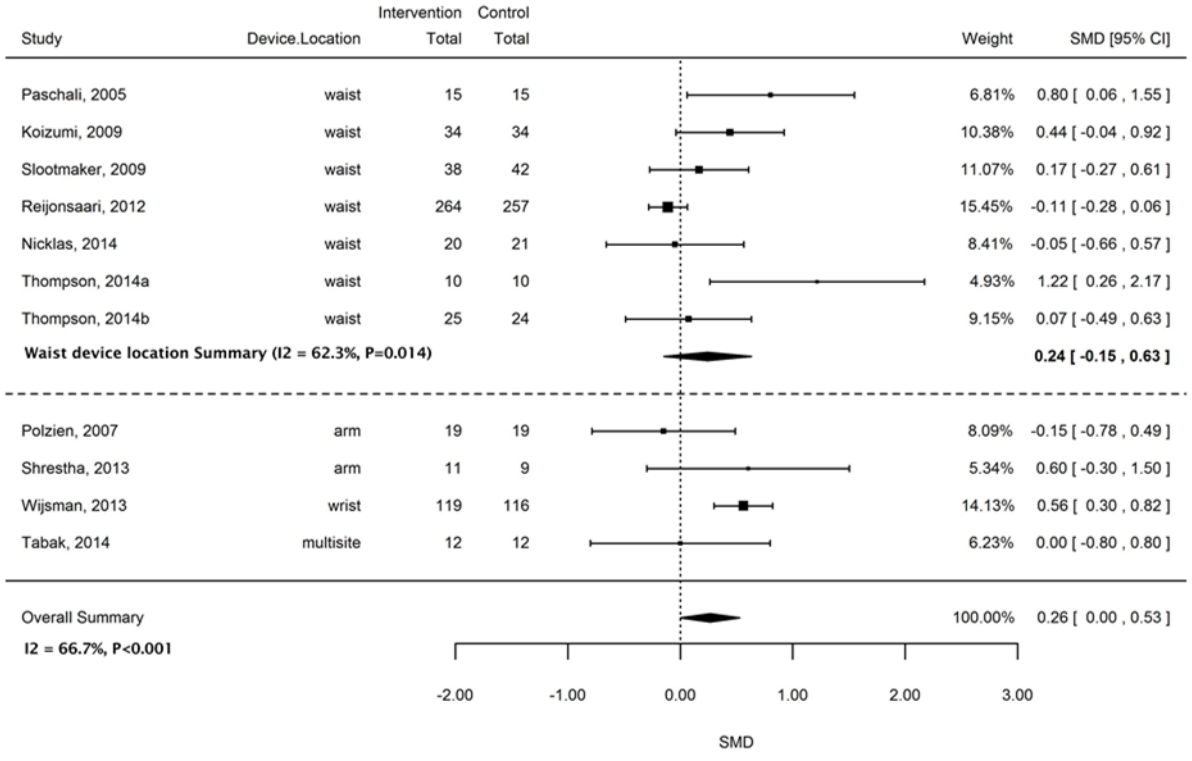
For one study where the accelerometer was worn on the wrist (low ROB),[37] the intervention produced a modestly statistically significant increase in physical activity (SMD 0.56; 95% CI 0.30 to 0.82). In this study, 119 adults were randomized to receive a 12-week web-based physical activity program focused on increasing daily activity. The intervention was composed

of 3 elements: an accelerometer-based activity monitor, a personal website, and a personal e-coach who gave feedback about ways to increase physical activity. After 13 weeks, daily physical activity increased in the intervention versus control group (11% vs 5%, p <0.11).

Finally, a pilot study (at unclear ROB)[34] showed no effect on physical activity of an accelerometer that could be worn at multiple sites as compared to a usual care group (SMD 0.00; 95% CI -0.80 to 0.80). The intervention arm included 4 modules: a web-based exercise program for home exercising, an activity coach with real-time feedback, self-management of COPD exacerbations via diary on web portal, and teleconsultation. The activity coach consisted of an accelerometer-based sensor and a smartphone that displayed cumulative activity and sent motivational cues based on activity already performed. Objective activity at baseline and 3 months for the intervention group (n=15) was 536.3 (standard error of the mean [SEM] 42.6) and 511.0 (SEM 44.1), respectively. Objective activity at baseline and 3 months for usual care (n=14) was 360.5 (SEM 44.7) and 335.2 (46.3), respectively. The notable baseline difference may be influenced by the poorer clinical characteristics including a higher prevalence of dyspnea among usual care (p=0.03) despite computerized randomization distributed in sealed envelopes.

The lack of difference in physical activity based on multisite location is likely secondary to very low use of the exercise module by physiotherapists and low use and adherence to the exercise module and activity coach by participants. Of note, median adherence to prescribed exercise schemes was 21%.

Figure 10. Effect of Accelerometer Interventions on Physical Activity by Device Location



Abbreviations: CI=confidence interval; SMD=standardized mean difference

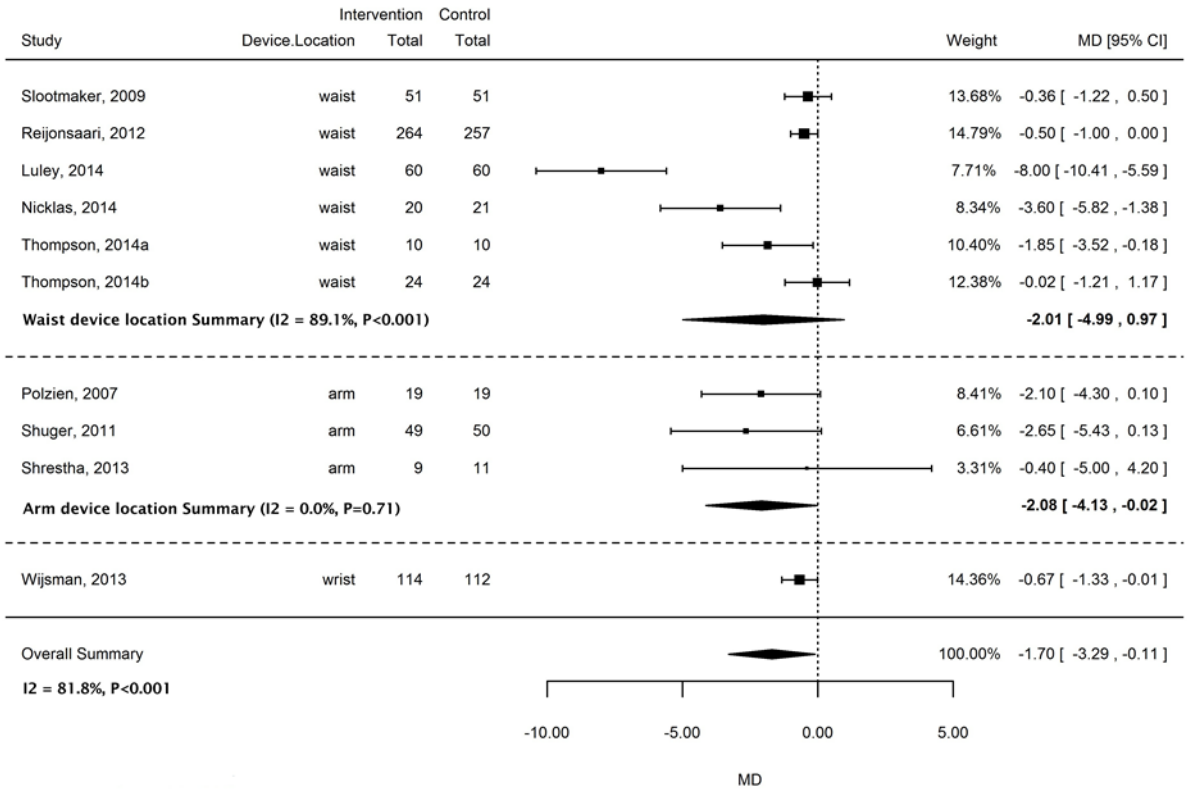
Weight

To assess whether the effects of the accelerometer interventions on weight vary by device characteristics, we conducted exploratory subgroup analysis by the following device location sites: waist (n=852 participants; 6 studies, 3 judged to be at high ROB,[35,38,43] one at low ROB,[41] and 2 at unclear ROB[28,36]); arm (n=157 participants; 3 studies, 2 at high[30,40] and one at unclear[29] ROB); and wrist (n=226 participants; one study at low ROB[37]).

Figure 11 shows the forest plot of the meta-analysis examining the effect of the interventions on weight by device location. The overall pooled estimate demonstrated a small statistically significant effect on weight (MD -1.65 kg; 95% CI -3.03 to -0.28), with high heterogeneity (I^2=81%). We had sufficient studies to pool effects for 2 subgroups (waist and arm). Both produced effects of the same direction and magnitude, which mirrored those of the overall summary estimate. Compared with control conditions, the pooled MD was -2.01kg (95% CI -4.99 to 0.97) for the waist subgroup and displayed high heterogeneity (I^2=89.1%). High heterogeneity in the waist subgroup is likely driven by differences in intervention approach (self-monitoring vs self-monitoring plus individualized counseling/feedback), intensity (weekly counseling via phone calls or letters vs self-driven interaction with device/website), and length of follow up (range 3 to 12 months). The arm location subgroup showed a similar pooled MD of -2.08 kg but was statistically significant (95% CI -4.13 to -0.02), with low heterogeneity (I^2=0.00%).

One additional subgroup, wrist, contained fewer than 3 studies and could not be pooled but demonstrated small positive impacts on weight loss. In the one study (low ROB) where the accelerometer was worn on the wrist,[37] the intervention produced a small impact on weight (MD -0.67 kg; 95% CI -1.33 to -0.01). In this study, 119 adults were randomized to receive either a 12-week web-based physical activity program focused on increasing daily activity or a 3-month waitlist control. The intervention was composed of 3 elements: an accelerometer-based activity monitor, a personal website, and a personal e-coach who gave feedback about ways to increase physical activity.

Figure 11. Effect of Accelerometer Interventions on Weight (in Kilograms) by Device Location



Abbreviations: CI=confidence interval; MD=mean difference

Summary of Findings

The predominant location of accelerometers was the waist, followed by the arm. The impact of accelerometer interventions was not well explained by where the device was worn on the body; pooled estimates mirrored those of the overall summary estimate. For physical activity, activity devices worn on the waist (n=7 studies) produced effects that ranged from negative and not statically significant to modest positive effects that were statistically significant. Of note, only one small (n=20) study of a waist-worn device, judged to be at high ROB, produced positive and statistically significant effects on physical activity.[38] Activity devices worn on the arm (n=2 studies) also displayed mixed results. One study (at low ROB) including a wrist-worn device[37] produced a positive and statistically significant impact on physical activity, while a study that allowed multisite use[34] showed no impact on physical activity.

For weight loss, activity devices worn on the waist (n=6 studies) produced effects that ranged from no effect to positive and statistically significant effects. High heterogeneity in the waist subgroup is likely driven by differences in intervention approach (self-monitoring vs self-monitoring plus individualized counseling/feedback), intensity (weekly counseling via phone calls or letters vs self-driven interaction with device/website), and differences in length of follow up (range 3 to 12 months). Activity devices worn on the arm (n=3 studies) displayed modestly positive effects on weight that were statistically significant and displayed low heterogeneity. One study including a wrist-worn device produced a small positive and statistically significant effect

on weight. This was the only device location that produced positive and statistically significant effects on both physical activity and weight, but this group included only one study (low ROB).[37]

Table 7 provides a summary of findings for KQ 2d.

Table 7. Summary of Findings: Variation by Characteristics of the Device (KQ 2d)

Outcome	Location of Accelerometer			
	Waist	Arm	Wrist	Multisite
Physical activity	7 studies: SMD 0.24 (95% CI -0.15 to 0.63)	2 studies: SMD range: -0.15 to 0.60	1 study: SMD 0.56 (95% CI 0.30 to 0.82)	1 study: SMD 0.00 (95% CI -0.80 to 0.80)
Weight	6 studies: MD -2.01 (95% CI -4.99 to 0.97)	3 studies: MD -2.08 (95% CI -4.13 to -0.02)	1 study MD -0.67 (95% CI -1.33 to -0.01)	No studies

Abbreviations: CI=confidence interval; MD=mean difference; SMD=standardized mean difference

Quality of Evidence for KQ 2

The same 14 studies were included for KQs 1 and 2. The quality of evidence is discussed above, under KQ 1.

SUMMARY AND DISCUSSION

Physical activity is universally endorsed as a cornerstone for maintaining optimal physical and cognitive health.[45,46] Increased physical activity is also considered an important therapeutic modality for patients with many chronic conditions including diabetes,[47] arthritis,[48] various cancers,[49] obesity,[50] and depression.[51] Despite the proven benefits and widespread public health and clinical calls to increase physical activity, sedentary behavior has proven difficult to change.

Self-monitoring is a key behavioral strategy to increase physical activity, and objective self-monitoring, as opposed to self-report, is considered the gold standard.[52] Pedometers have been found to be associated with significant increases in physical activity and significant decreases in both body mass index and blood pressure.[53] Although pedometers are a cost-effective tool, they are increasingly being replaced by accelerometers. Accelerometers offer the advantage of assessing accelerative movements, in all directions. In addition, accelerometers can detect differences in intensity[13] and can be tethered with other electronic devices to provide real-time, tailored feedback. Therefore this review sought to identify and summarize the evidence on the use of accelerometers on 2 major outcomes associated with many chronic conditions: physical activity and weight loss or maintenance. In addition, we sought to examine the effects of accelerometer use on satisfaction with healthcare.

We identified 14 unique RCTs that assessed the impact of accelerometers on physical activity and weight loss or maintenance. All included studies were published in the last 10 years, indicating the relatively new use of motion sensing devices in studies aimed at promoting physical activity or weight loss. Although we searched for wearable motion sensing technologies in general, no studies included newer wearable motion sensing technologies (*eg*, GPS, hand gesture, eye gesture, hand swipe) beyond an accelerometer. Twelve studies assessed the impact of accelerometers on physical activity and 11 on weight. No identified studies reported on the impact of accelerometers on satisfaction with healthcare. Four trials explicitly recruited older adults, 5 recruited obese/sedentary adults, 3 recruited participants with a chronic medical illness (diabetes, metabolic syndrome, COPD), and 2 recruited healthy volunteers. No studies specifically recruited Veterans.

STRENGTH OF EVIDENCE

Table 8 presents an overview of findings and strength of evidence (SOE) by major outcomes. We found moderate SOE for small increases in physical activity level (SMD 0.29; 95% CI 0.03 to 0.55) and small decreases in weight (MD -1.44 kg; 95% CI -3.08 to 0.19) over 3- to 12-month periods (median 5.5 months) when interventions that integrated accelerometers were compared with weak or inactive controls. We found low SOE for very small increases in physical activity levels (SMD 0.17; 95% CI -1.09 to 1.43) and small decreases in weight (MD range -3.60 to -2.10 kg) for accelerometer interventions compared with active control conditions.

Table 8. Summary of Intervention Effects and Strength of Evidence Ratings

Outcome and Comparison	Number of Studies (Subjects)	Domains and Ratings Pertaining to SOE	SOE and Summary Effect Estimate (95% CI)
Physical Activity: Inactive Comparator	9 (1279)	Risk of Bias: All RCTs, but some limitations due to poor study quality. Majority of RCTs were judged to be at high (n=5) or unclear (n=2) ROB. This domain was not rated as high ROB because 2 of the larger studies were at low ROB, and a large proportion (59.1%) of the weight for the subgroup summary estimate was generated from these 2 studies.	Moderate SMD 0.29 (0.03 to 0.55)
		Consistency: Some inconsistency. The individual study estimates for the most part had the same direction of effect as the subgroup summary estimate. One study, which was the largest and judged to be at low ROB, had an individual effect size on the opposite side of the null value. The magnitude of effect sizes varied across individual studies (SMD range -0.11 to 1.22).	
		Directness: Direct	
		Precision: Some imprecision. Most of the included studies had small sample sizes. The subgroup summary estimate was precise and similar to the overall summary estimate. The impact of bias on heterogeneity was inconclusive, as there was no consistency in the relationship between studies of variable ROB and direction of effect, and the effect estimate from the largest study, scored at low ROB, was on the opposite side of the null.	
Physical Activity: Active Comparator	3 (109)	**Risk of Bias:** All RCTs, but all studies judged to be at high ROB.	**Low** SMD 0.17 (-1.09 to 1.43)
		Consistency: Minor inconsistency. Two of the 3 individual estimates had a similar effect size, but the range of individual effect sizes varied substantially from -0.05 to 0.80.	
		Directness: Direct	
		Precision: Imprecise. All of the included studies had small sample sizes. The subgroup summary estimate and the overall summary estimate had wide confidence intervals. The impact of bias on heterogeneity could not be ruled out, as one of the individual estimates was on the opposite side of the null and was judged to be at high ROB. This may have influenced heterogeneity and subsequently the overall summary estimate confidence interval.	

Outcome and Comparison	Number of Studies (Subjects)	Domains and Ratings Pertaining to SOE	SOE and Summary Effect Estimate (95% CI)
Weight: Inactive Comparator	9 (1505)	**Risk of Bias:** All RCTs, but some limitations due to poor study quality. Most studies were judged to be at high (n=4) or unclear (n=3) ROB. This domain was not rated as high ROB because 2 of the larger studies were scored at low ROB, and a large proportion (49.6%) of the weight for the subgroup summary estimate was generated from these 2 studies.	**Moderate** MD -1.44 kg (-3.08 to 0.19)
		Consistency: Consistent in direction and magnitude. The individual estimates for the active comparator group were on the same side of the null value. Aside from one study, the MDs were consistent in magnitude when compared to the subgroup summary estimate.	
		Directness: Direct	
		Precision: Precise. A few of the included studies had small sample sizes, which contributed to imprecision. The subgroup summary estimate was precise and similar to the overall summary estimate. The impact of bias on heterogeneity is possible, as one study judged to be at unclear ROB was outside the MD range of other included studies in this subgroup.	
Weight: Active Comparator	2 (79)	**Risk of Bias:** Both studies RCTs, but both judged to be at high ROB.	**Low** MD range: -3.60 kg (-5.82 to -1.38) to -2.10 kg (-4.30 to 0.10)
		Consistency: Minor inconsistency. The individual studies had similar MDs on the same side of the null value.	
		Directness: Direct	
		Precision: Some imprecision. Both included studies had small sample sizes.	

Abbreviations: CI=confidence interval; MD=mean difference; SMD=standardized mean difference; RCTs=randomized controlled trials; ROB=risk of bias; SOE=strength of evidence

SUMMARY OF EVIDENCE BY KEY QUESTION

Overall, we found a small positive effect of accelerometers on increasing physical activity and decreasing weight. Twelve studies provided estimates for the effect of accelerometers on level of physical activity. Pooled estimates demonstrated a small and favorable impact on increasing physical activity levels (SMD 0.26; 95% CI 0.04 to 0.49) with moderate heterogeneity (I^2=64.7%). In stratified analysis by type of comparator, the effects versus the inactive comparator were similar; however, no significant effect was found when accelerometers were compared with an active comparator. A similar pattern was observed for the 11 studies that provided estimates for the effect of accelerometers on weight loss. The overall pooled estimates demonstrated a small and favorable impact on weight (MD -1.65 kg; 95% CI -3.03 to -0.28) but exhibited high heterogeneity (I^2=81%). In stratified analysis by type of comparator, effects were muted when accelerometer interventions were compared with more robust controls than with weaker controls. The moderate to high heterogeneity in these pooled estimates may be driven by

several intervention characteristics, including the duration of the interventions, intensity of adjunctive interventions (*eg*, accelerometer only vs brief device-driven feedback vs intensive device-driven behavioral counseling and feedback) and study design features that resulted in most studies being judged to be at high or unclear ROB. For physical activity outcomes, an additional source of heterogeneity may stem from the substantial variability in the mode (self-report vs objectively measured) and metrics (step counts per day vs minutes per day active) used to measure this outcome.

We also sought to explore the variable impact of wearable activity devices on physical activity and weight by multiple single factors that may contribute to heterogeneity (recruited populations, role of device relative to other motivational enhancement strategies, location of device on body as a proxy for ease of use). None of these individual factors was a robust predictor of heterogeneity. Thus, the variability in pooled estimates is likely due to a combination of factors related to underlying differences in populations, comparators, interventions, and study design and quality issues. However, other quantitative patterns were observed. In general, interventions that capitalized on the self-monitoring and tailored activity device-driven feedback capabilities of these devices were associated with greater decreases in weight loss. Effects were even greater when these strategies were paired with behavioral counseling focused on device feedback. The same trend was not consistently seen for greater increases in physical activity with better implementation of device feedback and self-monitoring functionality. Lastly, while we sought to explore the role of adherence to the activity device as a moderator of effects, only 4 studies provided any data on adherence to the device, and none of these studies reported such analyses. Instead, these studies focused largely on the process measures related to accelerometer adherence. In general, these studies reported a consistent pattern of decline in participants' use of activity devices over time.

CLINICAL AND POLICY IMPLICATIONS

Commercially available wearable activity devices have surged in popularity in recent years, including accelerometers marketed for their ability to assist individuals who want to increase their physical activity. Accelerometers have proven to be a valid and reliable means of tracking step counts and activity levels; however, their effectiveness as an agent of behavior change has been less clear. Also it is unclear whether accelerometers offer additional advantages over pedometers as a means of self-monitoring physical activity.

The results of this review provide important new information by demonstrating a small positive effect of wearable accelerometers on increasing physical activity and decreasing weight. These findings are important for both clinician and policymakers who may be considering programs to encourage more widespread use of these technologies as a public health strategy to improve health and well-being. Although we found small but significant effects related to activity device use, the heterogeneity of the included studies precludes firm conclusions about how they can be deployed most effectively in clinical practice as a tool to facilitate increased physical activity. Furthermore, we did not find any studies that sought to integrate physical activity data from wearable accelerometers into the patient's medical records to facilitate ongoing primary care and chronic disease management. Such research could be of real value to clinicians and policymakers.

No studies actively recruited Veterans and, germane to the VA healthcare system, we found surprisingly few trials (n=3) that focused on chronic disease populations. Use and effectiveness of wearable accelerometers may differ among participants who are motivated to use these devices to achieve different goals; for example, those who are trying to increase physical activity to reduce pain from osteoarthritis compared to participants whose goal is to lose weight. Thus, it is unclear if these devices should be offered to all patients or a subset of patients who may derive the most benefits from increased physical activity.

For accelerometers to function optimally, patients need to wear the devices and understand the information they receive from them. In this review, we found limited data on activity device adherence. Other research suggests that more than half of individuals who purchase a wearable activity device stop using it; of these, one-third stop in the first months.[54] Future research should (1) measure how often participants wear accelerometers; (2) measure how participants interact with their generated data; and (3) explore facilitators and barriers to adoption of wearable technologies. This would be valuable for clinicians, policymakers, and organizations by helping programs target individuals who are most likely to wear and therefore benefit from these devices. Last, accelerometers are more costly than traditional pedometers, which may impact decisions regarding purchase and usage. In this review, we were unable to assess whether accelerometers increase physical activity beyond pedometers.

LIMITATIONS

Our review has a number of strengths, including a protocol-driven design, a comprehensive search, and careful quality assessment. We conducted both quantitative and qualitative synthesis when possible. Our review—and the literature—have limitations: the number of studies is small; many had design limitations (8 of 14 were judged to be at high ROB); the range of interventions evaluated was diverse; and the number and reporting of studies precluded any analyses of variability in accelerometers by more than one variable at a time. Our review was limited to English-language publications, but the likelihood of identifying relevant data unavailable from English-language sources is low.

The small sample sizes of most included trials and the populations recruited also limited our findings and may have resulted in a type II error as a result. No studies actively recruited Veterans, yet we did identify 3 studies among those with chronic medical illnesses, 5 studies among overweight/obese/sedentary populations, and 4 studies among older adults. It is likely that the results of these studies are highly applicable to the VA, because these conditions and populations are common among the patients seen in the VA healthcare system. However, having so few studies with large sample sizes leaves unanswered questions of feasibility of integrating accelerometers into clinics and healthcare systems with large, heterogeneous patient populations and multiple providers.

Many of our pooled analyses suggested moderate to high heterogeneity. While we conducted subgroup analysis to explore multiple single factors that may contribute to heterogeneity (recruited populations, role of activity devices relative to other motivational enhancement strategies, location of device on body as a proxy for ease of use), none of these individual factors was a robust predictor of heterogeneity. Thus, the observed heterogeneity is likely attributable to a combination of factors that relate to underlying differences in populations, comparators,

interventions, and study design and quality issues. The overall low number and small size of included trials per outcome precluded us from conducting multivariable analyses.

RESEARCH GAPS/FUTURE RESEARCH

This comprehensive review of the literature identified several gaps in the current evidence that warrant future investigation. We used the framework recommended by Robinson et al[55] to identify gaps in evidence and classify why these gaps exist (Table 9). This approach considers the PICOTS (population, intervention, comparator, outcome, timing, and setting) to identify gaps and classifies them as due to (1) low strength of evidence or imprecise information, (2) biased information, (3) inconsistency or unknown consistency, and (4) not the right information. VA and other healthcare systems should consider their clinical and policy needs when deciding whether to invest in research to address gaps in evidence.

Table 9. Evidence Gaps and Future Research

Evidence Gap	Reason	Type of Studies to Consider
Population		
· Absence of trials that actively recruited Veterans · Limited studies (n=3) among those with chronic medical illnesses	Insufficient information	· RCTs · Quasi-experimental studies · Prospective cohort studies
Interventions		
· What are the optimal adjunctive interventions that enhance functionally of accelerometers in motivating behavior change? · How does intensity or dose of adjunctive interventions enhance functionally of accelerometers in motivating behavior change? · How is adherence to use of the activity device associated with key outcomes? Are there strategies to enhance adherence? · How do aspects of the activity device (location on body, ease of use, ability to pair with other technologies) impact physical activity and weight? · Is accelerometer-based feedback inferior, equivalent, or superior to pedometer-based feedback for increases in physical activity or decreases in weight?	Insufficient information	· RCTs of head-to-head comparisons of different types of adjunctive intervention packages · Stepped and adaptive trial designs
Comparators		
· Relatively few studies that used active or more robust comparators · No studies that assessed accelerometers vs pedometers	Insufficient information	· RCTs · RCTs of head-to-head comparisons of accelerometers and pedometers
Outcomes		
Uncertain effects on: · Patient satisfaction with healthcare Limited information on:	Insufficient information	· RCTs · Prospective cohort studies · Non-randomized controlled

Evidence Gap	Reason	Type of Studies to Consider
· Physical activity · Weight loss or maintenance · Adherence to devices over time		before-and-after studies · Secondary analyses of existing trial data
· None of these studies examined factors that impact accelerometer adherence. Future research aimed at identifying individual characteristics associated with accelerometer adherence will inform efforts to create a hierarchy of who is more likely to adhere to these devices. · Determine how participants interact with their generated data as feedback. · Explore facilitators and barriers to adoption of wearable activity devices.	Insufficient information	· RCTs · Prospective or retrospective cohort studies · Non-randomized controlled before-and-after studies · Qualitative studies · Secondary analyses of existing trial data
Setting		
· No studies that recruited through clinical settings	Insufficient information	· RCTs · Prospective or retrospective cohort studies · Nonrandomized controlled before-and-after studies

Abbreviation: RCTs=randomized controlled trials

CONCLUSIONS

Overall this review found low to moderate strength of evidence that the use of wearable accelerometers produces small positive effects on physical activity and weight. These changes, however, may not result in clinically significant changes to health-related outcomes. The small number of studies with small sample sizes and the moderate to high heterogeneity limit the conclusions that may be drawn. What appears evident is that accelerometers may be necessary—but not sufficient—to change behavior. Unfortunately, the data available for this review did not allow us to determine the most effective means of using wearable accelerometers to facilitate behavior change. Nevertheless, we observed qualitatively that studies with more robust effects used adjunctive interventions (*eg*, tailored feedback and behavioral counseling) to foster motivation, had longer intervention durations, and compared accelerometers to weaker controls. Focusing on specific goals, using evidence-based strategies, personalizing designs, and integrating social support are additional, critical components for achieving increased physical activity or reduced weight. Stepped and adaptive trial designs, as well as those that incorporate patient preferences, may be particularly well-suited to address questions about the effectiveness of accelerometers within the context of complex behavioral interventions to increase physical activity and other related health outcomes.[56,57]

The overall paucity of studies that used accelerometers and the generally low quality of the included trials may be due, in part, to the only recent availability of accelerometers with visible displays to allow for self-monitoring and the ability to interface with behavioral programs (*ie*, ability to collect and share data in real time). This review raises a number of important questions and illuminates key gaps in the evidence. This includes a need to understand whether accelerometers outperform traditional pedometers, how activity device features may enhance adherence and outcomes, and the effects on long-term outcomes. The relatively low response rates and attrition trends over time from the included studies in this report underscore the

importance of integrating these devices in tailored, patient-focused behavioral interventions that offer dynamic content, real-time and personalized behavioral counseling, and progressive goal-setting.

These findings are important for both clinicians and policymakers who may be considering programs to encourage more widespread use of these technologies as a public health strategy to improve health and well-being. Although we found small significant effects related to activity device use, the heterogeneity of the included studies precludes firm conclusions about how they can be deployed most effectively in clinical practice as a tool to facilitate increased physical activity. Furthermore, we did not find any studies that sought to integrate physical activity data from wearable accelerometers into the patient's medical records to facilitate ongoing primary care and chronic disease management.

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