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## Feasible but Not Yet Efficacious: A Scoping Review of Wearable Activity Monitors in Interventions Targeting Physical Activity, Sedentary Behavior, and Sleep

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### Abstract

**Purpose of Review**—The present review aimed to explore the range and characteristics of interventions that utilize WAM and descriptively summarize the efficacy of these interventions.

**Recent Findings**—A total of 65 articles (61 studies) were included in this review. Most of the WAM-based interventions (n=58) were designed to improve physical activity (PA). Interventions targeting sedentary behavior (SB) were much less common (n=12), and even less frequent were WAM-based sleep interventions (n=3). Most studies tested the feasibility of WAM-based interventions; hence, efficacy of these interventions in improving PA, SB, and/or sleep could not be conclusively determined. Nonetheless, WAM-based interventions showed considerable potential in increasing PA and decreasing SB.

**Summary**—WAM-based PA interventions exhibited preliminary efficacy in increasing PA. Although not as many interventions were focused on SB, current interventions also showed potential in decreasing sedentary time. Meanwhile, more evidence is needed to determine the utility of WAM in improving sleep. Major challenges with including WAM as part of interventions are reduced engagement in using the devices over time and the rapid changes in technology resulting in devices becoming obsolete soon after completion of an efficacy trial.

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## Keywords

wearable activity monitors; fitness trackers; physical activity; sedentary behavior; sleep

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## Introduction

The market for wearable activity monitors (WAM), devices worn to track physical activity (PA), sleep, and other movement-based behaviors [1], has seen exponential growth over recent years. According to the International Data Corporation, 34.2 million units were sold during the second quarter of 2019 alone [2]. Similarly, a nationwide survey of US adults reported that 12.5% of its respondents were current users of WAM [3]. Advances in sensor technology and improvements in the algorithms used to analyze sensor data have made WAM more accurate [4]. The popularity of these wearable devices, coupled with their increasing capabilities, lend themselves well to clinical research.

Several systematic reviews have examined the validity and reliability of WAM in terms of measuring PA and sleep [1, 5–8]. Overall, WAM were accurate and reliable at counting steps and measuring activity duration [1, 5, 6]. In terms of sleep, WAM were highly correlated with polysomnography in measuring total sleep time [7]. In addition to validation studies, feasibility studies have shown that WAM were generally well-accepted by the intended users [9, 10].

Given the improvements in the validity and reliability of WAM and their acceptability across a wide range of users, it is not surprising that the use of WAM in clinical trials is increasing [1]. However, the majority of these studies utilized WAM as a more convenient and cost-effective alternative to research-grade instruments to collect data [4]. The effect of WAM as the intervention or as a supplement to the intervention are largely unknown. Therefore, the purpose of this scoping review is to examine the effect of WAM as the main intervention or as a supplement to the intervention on PA, sedentary behavior (SB), and/or sleep. Specifically, this review (1) explores the range (e.g., study population, target condition) and characteristics of interventions that utilized WAM, and (2) descriptively summarizes the preliminary efficacy of these interventions.

## Methods

This review was conducted following the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines [11].

## Search Strategy

PubMed, CINAHL Plus, and Embase were systematically searched for relevant studies with the guidance of a reference librarian. The database search was conducted in October 2019. Full search strategies for each database are described in the Online Resource 1.

## Study Selection

After eliminating duplicates, articles were screened in a 3-step process: by title, by abstract, and by full text. Articles were included if they met the following eligibility criteria: (1) used a randomized-controlled trial or quasi-experimental design, (2) tested an intervention using direct-to-consumer WAM (by itself or as a component of the study intervention), (3) had a measure of PA, SB, or sleep as an outcome variable, (4) was published between January 2009 and September 2019, and (5) was written in English. An article was excluded if it: (1) was only available as an abstract, (2) was only a study protocol, (3) used only a mobile application (app), (4) used only a pedometer, or (5) used only a WAM to evaluate the intervention.

The primary author reviewed the titles and abstracts. At least two independent reviewers assessed the full texts for inclusion (MIC/CCI/CEK/EJB). In case of disagreement regarding the inclusion of a study, a third person (LEB) decided whether the study was included in the scoping review.

## Data Charting

To aid in summarizing the findings, information on *study characteristics* (i.e., authors, year published, country, study design, study/intervention duration, target population, sample size, outcome variables); *device characteristics* (i.e., brand, model, location worn, activities measured); *intervention characteristics* (i.e., components, control condition); and *study outcomes* pertaining to PA, SB, and sleep were collected using an electronic data abstraction form. The primary author abstracted the data, which were then checked by another author (CCI/CEK/LEB) for accuracy.

## Results

### Search Result

A total of 65 articles, representing 61 studies—one article reported the findings from two studies [12] and 5 studies were used for multiple articles (10 in total) [13–22]—were included in this scoping review (Figure 1).

### Study Characteristics

The majority of the studies were conducted in the United States (n=40); 8 were conducted in Canada, 6 in Australia, 3 each in Singapore and South Korea, and one each in Germany and the Netherlands. Most of the interventions targeted PA (n=45), followed by interventions targeting both PA and SB (n=11), PA and sleep (n=2), SB (n=1), sleep (n=1), and only 1 targeted all 3 behaviors. Thirty-four of the studies used a randomized controlled trial design and 27 were quasi-experimental. Study duration ranged from 2 weeks to 12 months, while intervention duration ranged from one week to 10 months. The majority of the studies (n=50) recruited adult participants. Twenty-nine studies targeted populations with a health condition that could impact and/or was impacted by PA, SB, and/or sleep (e.g., cancer, arthritis, chronic pain, insomnia). Finally, sample sizes ranged from 10 to 800 participants (median: 53; mean: 99) (Table 1).

## Device Characteristics

As of November 2019, all but one of the WAM models included in this review have been discontinued. Two studies needed to use a different WAM after the original WAM was discontinued during the course of the study [23, 24]. The majority of the studies used Fitbit models (n=48), and most of the models were wrist-worn (n=14). Among the different attributes measured, 19 WAM recorded the number of steps taken, 17 calculated calories expended, 16 measured distance traveled, and 11 tracked the number of minutes spent in different PA intensities. Fifteen of the WAM recorded sleep duration and 11 provided a summary of sleep quality. Lastly, 5 of the WAM measured time spent being sedentary.

## Intervention Characteristics

Table 2 summarizes the various intervention strategies used in the reviewed studies. All but one study intervention [25] used at least two behavioral strategies, with self-monitoring being the most commonly used strategy (n=60). Self-monitoring was implemented using the WAM's display (if available) and/or the WAM's companion app or website. Two studies had a website specially designed for participants to monitor their activity and receive feedback [25, 26]. Similarly, 2 studies developed an app for self-monitoring and delivering feedback [27, 28] and one study provided participants with paper exercise diaries in addition to the WAM's companion app [29]. Only one study did not provide their participants access to the WAM's companion app or website to prevent any potential confounding with the intervention [17, 30].

Other commonly used intervention strategies were goal setting (n=54), providing education and/or health coaching (n=41), giving rewards/incentives (n=20), and providing social support. Goals were classified as adaptive (personalized to the participant's current level and/or adjusted to the participant's change in level over time) or static (unchanging, e.g. 10,000 steps/day). Only rewards that were meant to encourage the participants to meet PA/SB/sleep goals were considered. Process incentives (e.g., incentives given for completing the assessments, study completion incentives) were not considered. The majority of the interventions used gain-framed incentives, which is providing the reward after specific goals are achieved (n=18). Conversely, the loss-framed approach was only used in two interventions [31, 32]. Social support was provided in the form of encouraging feedback, motivational messages, and identification of barriers and solutions provided by a study team member through email (n=3), text messages (n=8), phone (n=7), and/or in person (n=1). Some interventions also used social support from an in-person (n=8) or online (n=9) community/partner. Another source of social motivation was provided in the form of friendly within-group competition. Interventions that utilized the principles of gamification mainly used the motivational potential of competition to bring about the desired behavioral change [31, 33–36].

## Study Outcomes

This scoping review focused only on outcomes related to PA, SB, and sleep (Table 2). Additionally, only objectively-measured findings were abstracted except in a few studies (n=4) that measured their outcomes using only self-report measures [37–40]. Among the studies that used objective instruments, 27 used a different accelerometer (research-grade)

from the one used in the intervention. A common strategy among studies that used the same WAM to measure their outcomes was to blind the participants during the baseline measurement (i.e., masking the display or not giving the participants access to their WAM accounts).

### Physical Activity Outcomes

**Steps.:** Out of the 44 studies with interventions that targeted step counts, 31 involved a control group and 13 did not include one. Of the studies with a control group, 25 resulted in a greater increase in steps (14 of which had a statistically significant difference at a *p-value of*  $< .05$ ) when compared to the control condition(s). However, 3 studies reported decreased steps at post-intervention—2 in which the pre- to post-intervention decrease in steps was less for the intervention group (*p*  $.05$ ) [12, 41] and one in which the intervention group decreased steps while the control group increased steps (*p*  $< .05$ ) [42]. Among the studies with a control group, 3 compared only the post-intervention step counts with the intervention groups showing greater step counts compared to the control groups (one of which had a statistically difference at a *p-value of*  $< .05$ ). Among the studies without a control group, 9 reported increased steps (4 of which had statistically significant difference at a *p-value of*  $< .05$ ) and 3 reported a non-significant decrease in steps [43–45]. Lastly, one study that did not have a control group performed a sub-group analysis, wherein the step counts for those who self-selected their group versus those who were assigned to a group were compared [19]. Those who self-selected their group had significantly greater step counts compared to those who were assigned to a group (*p*  $< .05$ ) [19].

**Moderate-to-vigorous physical activity (MVPA) time.:** Twenty-three interventions targeted time spent in MVPA; 16 of these 23 interventions included a control group. Of the studies with a control group, 13 resulted in a greater increase in MVPA time in at least one of the intervention groups compared to the control group (9 of which had statistically significant difference at a *p-value of*  $< .05$ ). One study reported a non-statistically significant greater increase in MVPA time in the control group compared to the intervention group [46]. However, 2 studies reported decreased MVPA time at post-intervention—one in which the pre- to post-intervention decrease in MVPA time was less for the intervention group (*p*  $.05$ ) [28] and one in which the decrease was greater for the intervention group (*p*  $.05$ ) [12]. Among the 7 studies that did not have a control group, 5 reported an increase in MVPA time at post-intervention (one of which had statistically significant increase at a *p-value of*  $< .05$  [47]) and 2 showed a non-significant decrease in MVPA time [45, 48].

**Total PA time.:** Eleven interventions targeted time spent in PA; 8 of these 11 interventions included a control group. Of the 8 studies with a control group, 7 resulted in a greater increase in total PA time in the intervention group compared to the control group (5 of which had statistically significant difference at a *p-value of*  $< .05$ ). On the other hand, one study reported a non-significant decrease in total PA time for the intervention group relative to control [42]. Among the 3 studies without a control group, one reported a significant increase in total PA time [23], another had a non-significant increase [49], and one reported a non-significant decrease in total PA time [50].

## Sedentary Behavior Outcomes

**Sedentary time.:** Twelve interventions targeted sedentary time; 8 of these interventions included a control group. Of the 8 studies with a control group, 5 resulted in a greater decrease in sedentary time in the intervention group compared to the control group (2 of which had statistically significant difference at a *p-value of*  $< .05$ ). However, 2 studies reported a non-significant increase in sedentary time [46, 51]. One study that examined only post-intervention findings reported that intervention group spent significantly less time being sedentary compared to the control group [52]. Of the 4 studies without a control group, 3 reported a non-significant decrease in sedentary time [47, 49, 53] and one reported a non-significant increase in sedentary time [48].

**Sitting time.:** Only 2 studies explored sitting time. One reported a significant decrease in sitting time in the intervention group compared to the control group [39]. The other intervention also resulted in a greater decrease in sitting time for the intervention group; however, the difference was not significant [54].

## Sleep Outcomes

**Sleep duration.:** Three interventions targeted sleep duration; 2 of these interventions included a control group. Two interventions resulted in greater, albeit non-significant, increases in sleep duration in the intervention group compared to the control group [42, 55]. The other study reported a significant increase in sleep duration post-intervention compared to baseline [43].

**Sleep efficiency.:** Sleep efficiency (defined as the ratio of sleep duration to time spent in bed) was targeted in 2 studies. One study reported a non-significant increase in sleep efficiency in the intervention group compared to the control group [56]. The second study reported a non-significant decrease in sleep efficiency [42].

## Device Adherence

Out of the 61 studies, 28 provided information on device adherence. Device adherence was reported as the percentage of participants who wore their WAM, the proportion of days the participants wore their WAM, or a combination of the two. Similarly, valid “wear time” was also operationalized in numerous ways (e.g., 500 steps/day for 4 days, 10 hours/day for 5 days, 8 hours/day for 3 days), making synthesizing the findings a challenge. A descriptive summary of device adherence for the 28 studies is outlined in Online Resource 2.

## Discussion

The overwhelming majority of the WAM-based interventions focused on increasing PA, which was commonly operationalized using step count, MVPA time, and/or total PA time. Interventions designed to decrease SB were much less common, and even less frequent were interventions designed to improve sleep. Of the 44 studies that targeted step count, 18 resulted in statistically significant increases in steps post-intervention. Of the 23 studies that targeted MVPA time, 10 saw statistically significant increases in MVPA time post-intervention. Similarly, 6 of the 11 studies that targeted total PA time resulted in significant

increases in total PA time. Among the studies that targeted sedentary behavior, 2 of 12 studies resulted in significant decreases in sedentary time and 1 of 2 studies resulted in a significant decrease in sitting time. Among the studies that focused on sleep, 1 of 3 resulted in a significant increase in sleep duration; however, none of the studies significantly improved sleep efficiency. It should be noted that most of the studies examined the feasibility of WAM-based interventions and/or explored its preliminary efficacy; hence, the efficacy of the WAM-based interventions could not be conclusively determined. Nonetheless, WAM-based interventions exhibited considerable potential in increasing PA and decreasing SB across a diverse range of populations. This is especially true for multicomponent interventions that incorporated behavior change strategies, not only to encourage adoption of the desired behavior, but also to increase adherence to the intervention.

A quantitative synthesis of device adherence could not be performed due to the heterogeneous metrics used to determine device adherence. However, what was apparent is that a number of studies had issues with device adherence. Unfortunately, participants discontinued use of the WAM quite often, typically after a few months when the novelty of the WAM dissipated [57]. Novelty effect—defined as the individual's initial response to the technology rather than the pattern of use over time when habituation settles in [57]—was observed in several of the studies. After observing a significant initial increase in physical activity, a steady decline was noted in several studies. To minimize the potential bias from the novelty effect, one study included a run-in week to allow the participants to become accustomed to the WAM, and then excluded data collected during that week [31]. While this brief period provided a time to become comfortable with the device, it is not clear that one week is sufficient to remove the novelty effect. Further study needs to be done to examine what strategies can be implemented to provide more sustained use and engagement of these consumer friendly WAM. A recent editorial reported on this dilemma and suggested a novel approach to address this recurring issue [58].

Another common issue faced in the WAM-based interventions was the rapid turnover of the direct-to-consumer WAM. Since most of the WAM included in this review have already been discontinued, it is apparent that traditional research designs cannot keep up with the typical WAM lifecycle. This calls for more innovative designs and shorter study cycles to establish any efficacy of the WAM [59, 60].

While this scoping review was conducted following the PRISMA-ScR guidelines, it is not without limitations. First, the electronic search was limited to three databases, which could have introduced selection bias risk. To minimize this risk, a manual search was conducted to complement the electronic search and the electronic search strategy was formulated with the assistance of an experienced reference librarian. Additionally, critical appraisal of the risk of bias in the included studies was not undertaken. While optional for scoping reviews, formal assessment of bias increases the rigor of scoping reviews. However, there are also strengths to our review. First, we included studies that targeted very diverse population groups across the age span and range of disease or health conditions, and we reviewed studies that tested an array of wearable devices.



In conclusion, the efficacy of WAM-based interventions still needs to be established using rigorous study designs and adequate sample sizes. Further, WAM-based interventions targeting sleep are limited compared to interventions designed to improve PA and/or address SB. Nonetheless, based on the included studies, WAM-based interventions are feasible and acceptable for various populations, and show promising potential in increasing PA and reducing SB.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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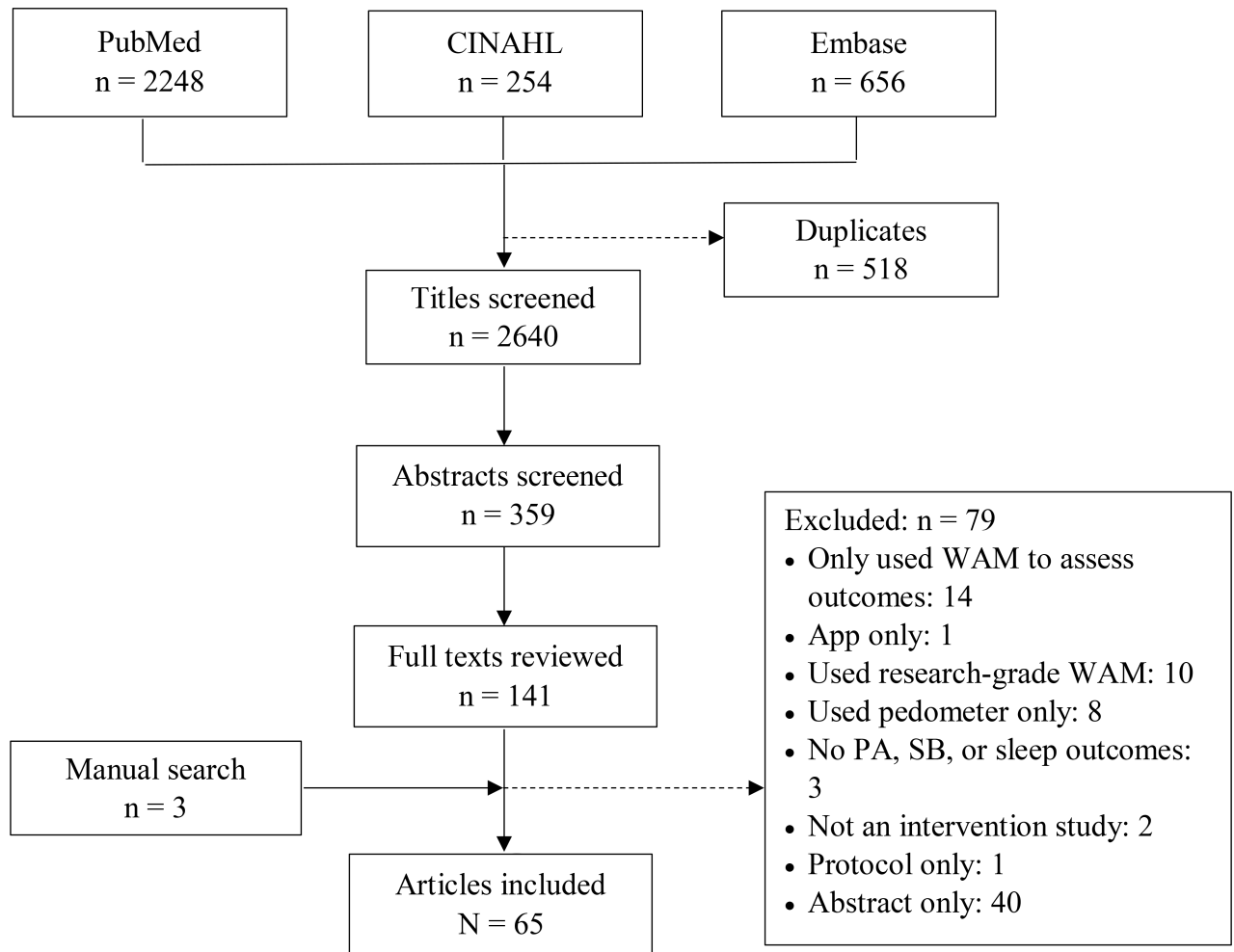
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**Figure 1.** Diagram of search and screening process. Acronyms: wearable activity monitor (WAM), physical activity (PA), sedentary behavior (SB)

Table 1.

## Study Characteristics

Author	Study Design	Duration (Study/Intervention)	Physical Activity	Target Population	Sample Size
<b>2015</b>					
A Cadmus-Bertram LA et al.[13, 14]	RCT	16 weeks		Females, post-menopausal overweight, sedentary.	51 (49 completed)
Garde A et al.[33]	Quasi-experimental	2 weeks / 1 week		Children (8y–13y)	54 (44 analyzed)
Hayes LB and Camp CM[61]	Quasi-experimental	5 school weeks		Children	10 (6 analyzed)
Martin SS et al.[62]	RCT	5 weeks / 4 weeks		Adults (18y–69y)	48
<b>2016</b>					
Choi JW et al.[27]	RCT	12 weeks		Females, sedentary, pregnant (18y–40y)	30 (29 completed)
B Finkelstein EA et al.[16]	RCT	12 months / 6 months		Full-time employees (21y–65y)	800
Garde A et al.[34]	RCT, cross-over	4 weeks / 1 week		Children (9y–13y)	42
Hooke MC et al.[44]	Quasi-experimental	17 days / 5 days		Children with acute lymphoblastic leukemia (6y–18y)	17 (16 completed)
Le A et al.[63]	Quasi-experimental	~7 months / 6 months		Pediatric cancer survivor (>=15y)	19 (15 completed)
Poirier J et al.[25]	RCT	7 weeks / 6 weeks		Employees	265 (217 completed)
<b>2017</b>					
Abrantes AM et al.[23]	Quasi-experimental	12 weeks		Females with alcohol use disorder and depressive symptoms (18y–65y)	20
C Adams MA et al.[30]	RCT	4 months		Adults, overweight/obese, sedentary	96
Chung AE et al.[36]	Quasi-experimental	2 months		College students	12
Evans EW et al.[12]	Quasi-experimental	Study 1: 4 weeks Study 2: 6 weeks		5 <sup>th</sup> and 6 <sup>th</sup> graders	Study 1: 32 Study 2: 42
Gell NM et al.[45]	Quasi-experimental	4 weeks		Cancer survivors	26 (24 completed)
D Losina E et al.[20]	Quasi-experimental	26 weeks / 24 weeks		Adults, sedentary	300 (292 analyzed)
McMahon SK et al.[64]	RCT	8 months / 8 weeks		Older adults (>=70y)	102 (100 analyzed)
Patel MS et al.[31]	RCT	26 weeks / 12 weeks		Adult dyads	206 (200 analyzed)
Roite AE[65]	Quasi-experimental	~5 months / 10 weeks		College students	120 (56 analyzed)
Shin DW et al.[37]	RCT	12 weeks		Male college students, overweight/obese(19y–45y)	105 (98 analyzed)
Yeung J et al.[66]	Quasi-experimental	8 weeks / 4 weeks		Medical/Surgical residents	86 (26 completed)
Zhang XC et al.[67]	Quasi-experimental	26 weeks		Females with advance ovarian cancer	10



Author	Study Design	Duration (Study/Intervention)	Target Population	Sample Size
<b>2018</b>				
Bade BC et al.[68]	Quasi-experimental	12 weeks	Adults with lung cancer	35
Chokshi NP et al.[32]	RCT	24 weeks / 16 weeks	Adults with ischemic heart disease ( $\geq 18y$ )	105
DiFrancisco J et al.[69]	RCT	10 months	1 <sup>st</sup> year medical students (17y–50y)	120 (113 analyzed)
Duscha BD et al.[70]	RCT	12 weeks	Adults completing cardiac rehab	32 (25 completed)
Gremaud AL et al.[35]	RCT	10 weeks	Healthy adults with sedentary jobs	146 (144 analyzed)
Hacker ED et al.[50]	Quasi-experimental	~8 weeks / 6 weeks	Adults scheduled for hematopoietic stem cell transplantation ( $\geq 18y$ )	10
Heale LD et al.[71]	Quasi-experimental	5 weeks	Adolescents with juvenile idiopathic arthritis (12y–18y)	31 (28 analyzed)
Kooiman TJM et al.[72]	RCT	12 weeks	Adults with type 2 diabetes	72 (66 analyzed)
Liau AK et al.[73]	Quasi-experimental	5 weeks / 3 weeks	Adults (18y–50y)	85
McDermott MM et al.[74]	RCT	9 months	Adults with peripheral artery disease ( 50y)	200 (198 analyzed)
Nyrop KA et al.[75]	Quasi-experimental	6–12 weeks (during chemotherapy)	Females with early stage breast cancer (21y–64y)	127 (100 analyzed)
Ovans JA et al.[76]	Quasi-experimental	24 weeks / 12 weeks	Children/adolescents with brain tumors (7y–18y)	20 (11 completed)
Polgreen L.A et al.[41]	RCT	180 days	Adults with diabetes, obesity (19y–75y)	138
Vandelanotte C et al.[39]	RCT	3 months	Adults with overweight/obesity	243
Yoon SM et al.[77]	RCT	12 months / 6 months	Adults	79 (73 randomized)
<b>2019</b>				
Amorim AB et al.[28]	RCT	6 months	Adults with chronic lower back pain	68 (55 completed)
Cadmus-Bertram LA et al.[24]	RCT	12 weeks	Breast/colorectal cancer survivors + support partners	50 (47 survivors completed)
Cheung NW et al.[78]	RCT	38 weeks	Females who had gestational diabetes	60 (37 analyzed)
Christiansen MB et al.[79]	RCT	12 months / 6 months	Adults receiving outpatient PT for total knee replacement	43 (29 completed)
Deka P et al.[29]	RCT	8 weeks	Adults with heart failure	30
Janevic MR et al.[40]	RCT	8 weeks / 6 weeks	Older African Americans with chronic pain	50 (44 completed)
D Meints SM et al.[19]	Quasi-experimental	26 weeks / 24 weeks	Adults, sedentary	300 (225 analyzed)
C Phillips CB et al.	RCT	4 months	Adults, sedentary with overweight, obesity	96
Van Blarigan EL et al.[80]	RCT	84 days	Adults with non-metastatic colon/rectal cancer	42 (39 analyzed)
<b>2013</b>			<b>Physical Activity &amp; Sedentary Behavior</b>	
E Barwais FA et al.[38]	RCT	5 weeks / 4 weeks	Adults, sedentary	33
<b>2015</b>				

Author	Study Design	Duration (Study/Intervention)	Target Population	Sample Size
<i>E</i> Barwais FA et al.[22]	Secondary analysis focusing on the IG	5 weeks / 4 weeks	Adults, sedentary	20 (18 analyzed)
<b>2017</b>				
Gilson ND et al.[49]	Quasi-experimental	28 weeks / 20 weeks	Male truck drivers	26 (19 completed)
Mendoza JA et al.[81]	RCT	13 weeks / 10 weeks	Pediatric cancer survivors (14y–18y)	60 (59 analyzed)
<b>2018</b>				
Buchele Harris H and Chen WY[52]	Quasi-experimental	7 weeks / 4 weeks	5 <sup>th</sup> graders	116
Ezeigwu VE et al.[53]	Quasi-experimental	16 weeks / 8 weeks	Adults discharged from inpatient stroke rehab	34
Li LC et al.[82]	RCT	6 months / 2 months	Adults with knee osteoarthritis ( 50y)	61
Olsen HM et al.[48]	Quasi-experimental	6 weeks	Employees	113 (30 completed)
Pope ZC et al.[46]	RCT	10 weeks	Breast cancer survivors ( 21y)	30 (20 analyzed)
<b>2018</b>				
Trinh L et al.[47]	Quasi-experimental	24 weeks / 12 weeks	Prostate cancer survivors	46
<b>2019</b>				
Lynch BM et al.[54]	RCT	24 weeks / 12 weeks	Breast cancer survivors	83 (72 analyzed)
Muellmann S et al.[26]	RCT	12 weeks / 10 weeks	Older adults (60y–80y)	589 (405 completed)
<b>2018</b>				
Guitar NA et al.[83]	Quasi-experimental	8 weeks	Employees	22
<i>B</i> Sloan RA et al.	RCT	12 months / 6 months	Full-time employees (21–65y)	800
<b>2017</b>				
Kang SG et al.[56]	RCT	4 weeks	Adults with insomnia disorder (18–65y)	19
<b>2016</b>				
Crowley O et al.[43]	Quasi-experimental	12 months / 9 months	Employees	565 (510 analyzed)
Melton BF et al.[42]	RCT	14 weeks / 6 weeks	Female African American college students (18–24y)	69 (50 completed)
<b>2018</b>				
Choi JY et al.[55]	Quasi-experimental	9 weeks	College students, sedentary	70 (63 analyzed)

Note:

A, B, C, D, E Two articles on the same study, reporting on different outcomes. RCT – randomized-controlled trial.

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Table 2.

Intervention Characteristics and Study Outcomes

Author	Goal-Setting	Social Support	Reward	Education/Training	Comparison	Findings
<b>Physical Activity</b>						
<b>2015</b>						
A Cadmus-Bertram LA et al.[13, 14]	Both	--	--	--	◆	Step count: between study groups ↑ MVPA: between study groups ↑ Light PA: between study groups ↓
Garde A et al.[33]	--	Community, Competition	Digital reward	--	◆	Step count: between study groups ↑ Total PA: between study groups ↑
Hayes LB and Camp CM[61]	Adaptive	In-person	In-kind	--	N/A	Step count: pre/post-intervention ↑
Martin SS et al.[62]	Static	Text messages	--	--	◆	Step count: between study groups ↑ Total PA: between study groups ↑*
<b>2016</b>						
Choi JW et al.[27]	Both	App	--	One-on-one	◆	Step count: between study groups ↑
B Finkelstein EA et al.[16]	Static	--	Cash/Charitable donation	Printed material	◆	Step count: between study groups ↑*
B Sloan RA et al.[51]	--	Community, Competition	Digital reward	--	Not specified	MVPA: between study groups ↑ Sedentary time: between study groups ↓
Garde A et al.[34]	--	Community, Competition	Digital reward	--	Not specified	Step count: between study groups ↑ Total PA: between study groups ↑*
Hooker MC et al.[44]	Both	Email	--	--	N/A	Step count: pre/post-intervention ↓
Le A et al.[63]	Static	--	--	Not specified	N/A	MVPA: pre/post-intervention ↑
Poirier J et al.[25]	Adaptive	Community*, Competition*	Digital reward	--	○	Step count: between study groups ↑*
<b>2017</b>						
Abrantes AM et al.[23]	Adaptive	Phone	--	One-on-one	N/A	Step count: PP ↑* MVPA: pre/post-intervention ↑ Total PA: pre/post-intervention ↑*
C Adams MA et al.[30]	Both	Text messages	Cash	Printed material	◆	Step count: between study groups ↑* (Adaptive Goal > Static Goal; Immediate Reward > Delayed Reward)
C Phillips CB et al.[17]	Adaptive	Community, Competition	In-kind	Twitter	NA	MVPA: between study groups ↑* (IR>DR); ↑ (SG>AG) PA goal: only 58% reached daily step goal

Author	Goal- Setting	Social Support	Reward	Education/Training	Comparison	Findings
Evans EW et al.[12]	Static	--	In-kind	Printed material	N/A	Step count: pre/post-intervention ↑
Gell NM et al.[45]	Static	Competition	Cash, In-kind	Group session	◆ ○	Step count: between study groups ↓ MVPA: between study groups ↓
D Losina E et al.[20]	Adaptive	Phone, Text messages	--	Printed material, Health coaching	N/A	Step count: pre/post-intervention ↓ MVPA: pre/post-intervention ↓
D Meints SM et al.[19]	Adaptive	Community	Cash	--	N/A	Step count: between study groups ↑*
McMahon SK et al.[64]	Adaptive	Community, Competition	--	Group session	◆ ◆ ◆	Step count: between study groups ↑
Patel MS et al.[31]	Both	Community	In-kind	--	◆	Step count: between study groups ↑*
Rote AE[65]	--	--	--	--	◆ ○	Step count: between study groups ↑*
Shin DW et al.[37]	Static	--	Cash	One-on-one, Printed material	◆ ◆	Total PA: between study groups ↑*
Yeung J et al.[66]	Static	--	--	--	N/A	Step count: pre/post-intervention ↑*
Zhang XC et al.[67]	Both	Phone	--	Video, exercise training	N/A	Step count: pre/post-intervention ↑* MVPA: pre/post-intervention ↓ Light PA: pre/post-intervention ↑ Moderate PA: pre/post-intervention ↑*
<b>2018</b>						
Bade BC et al.[68]	Adaptive	Text messages	--	One-on-one	◆	Step count: between study groups ↑
Chokshi NP et al.[32]	Both	--	Cash	--	◆	Step count: between study groups ↑*
DiFrancisco J et al.[69]	Both	--	--	--	◆ ○	Step count: BET ↑*
Duscha BD et al.[70]	Adaptive	Phone, Text messages	--	Phone	◆	Step count: between study groups ↑ MVPA: between study groups ↑*
Gremaud AL et al.[35]	Adaptive*	Competition	Digital reward	--	◆	Step count: between study groups ↑ Total PA: between study groups ↑
Hacker ED et al.[50]	Adaptive	--	--	One-on-one	N/A	Step count: pre/post-intervention ↑ Total PA: pre/post-intervention ↓
Heale LD et al.[71]	Adaptive	--	--	--	N/A	MVPA: pre/post-intervention ↑
Kooinan TJM et al.[72]	Both	--	--	Video, Online	○	Step count: IG>CG (post-int only) MVPA: between study groups ↑*
Liau AK et al.[73]	Static	--	--	Online	◆	Step count: between study groups ↑*

Author	Goal- Setting	Social Support	Reward	Education/Training	Comparison	Findings
McDermott MM et al.[74]	Both	Phone	--	Exercise training	■	Exercise: between study groups ↑* PA goal: post-int, only 19% achieved goal
Nyrop KA et al.[75]	Static	--	--	Printed material	N/A	Step count: pre/post-intervention ↑
Ovans JA et al.[76]	Adaptive	--	--	One-on-one, Phone	N/A	Step count: between study groups ↓
Polgreen LA et al.[41]	Adaptive	--	--	Printed material	◆	MVPA: between study groups ↑* Total PA: between study groups ↑* Sitting time: between study groups ↓*
Vandelande C et al.[39]	Adaptive	--	--	Online	■	Exercise: between study groups ↓*
Yoon SM et al.[77]	--	--	--	Email	■	Step count: between study groups ↑ MVPA: between study groups ↓ Light PA: between study groups ↑
<b>2019</b>						
Amorim AB et al.[28]	Adaptive	Phone	--	Printed material, Health coaching	■	Step count: between study groups ↑* MVPA: between study groups ↑* Step count: IG>CG (post-int only)
Cadmus-Bertram LA et al.[24]	Both	Email, Community	--	One-on-one, Printed material	■	Step count: between study groups ↑* MVPA: between study groups ↑*
Cheung NW et al.[78]	Both	Text messages	--	One-on-one, Phone	■	Step count: between study groups ↑* MVPA: between study groups ↑*
Christiansen MB et al.[79]	Both	--	--	Printed material	■	Exercise: between study groups ↓
Deka P et al.[29]	Static	Community	--	Printed material, Online	◆	Walking: between study groups ↑ Step count: between study groups ↑ MVPA: between study groups ↑
Janevic MR et al.[40]	--	--	--	--	O <sup>w</sup>	
Van Blarigan EL et al.[80]	Static	--	--	Printed material	■ <sup>w</sup>	
<b>Physical Activity &amp; Sedentary Behavior</b>						
<b>2013</b>						
<i>E</i> Barvais FA et al.[22, 38]	Adaptive	Email	--	--	ns	Light PA: between study groups ↑* Moderate PA: between study groups ↑* Vigorous PA: between study groups ↑* Exercise: between study groups ↑* Sedentary time: between study groups ↓*
<b>2017</b>						
Gilson ND et al.[49]	Adaptive	Community, Competition	Cash	Group session, Printed material	N/A	Total PA: pre/post-intervention ↑ Sedentary time: pre/post-intervention ↓

Author	Goal- Setting	Social Support	Reward	Education/Training	Comparison	Findings
Mendoza JA et al.[81]	Both	Text messages, Community, Competition	Digital reward	--	■	MVPA: between study groups ↑ Sedentary time: between study groups ↓
<b>Physical Activity &amp; Sedentary Behavior</b>						
<b>2018</b>						
Bachele Harris H and Chen WY[52]	Both	--	--	Video	◆	<i>Post-intervention only:</i> Step count: IG>CG* Light PA: IG>CG Moderate PA: IG>CG* Vigorous PA: IG>CG* Sedentary time: IG<CG*
Ezeugwu VE et al.[53]	Static	Phone	--	One-on-one	N/A	Step count: pre/post-intervention ↑ Sedentary time: pp ↓
Li LC et al.[82]	Adaptive	--	--	One-on-one or Video	○ <sup>w</sup>	Step count: between study groups ↑* MVPA: between study groups ↑* Sedentary time: between study groups ↓
Olsen HM et al.[48]	Not specified	Community	--	Group session, Printed material	N/A	MVPA: pre/post-intervention ↓ Light PA: pre/post-intervention ↑ Sedentary time: pre/post-intervention ↑
Pope ZC et al.[46]	--	Community	--	Facebook	■	Step count: between study groups ↑ MVPA: between study groups ↑ Light PA: between study groups ↑ Sedentary time: between study groups ↑
Trinh L et al.[47]	Adaptive	--	Charitable donation, In-kind	App	N/A	Step count: pre/post-intervention ↑* MVPA: pre/post-intervention ↑* Light PA: pre/post-intervention ↓ Sedentary time: pre/post-intervention ↓
<b>2019</b>						
Lynch BM et al.[54]	Not specified	--	--	One-on-one	○ <sup>w</sup>	Step count: between study groups ↑ MVPA: between study groups ↑* Sitting time: between study groups ↓
Muellmann S et al.[26]	Static	Community	Digital reward	Group session, Printed material	■ ○ <sup>w</sup> only	MVPA: between study groups ↑ Sedentary time: between study groups ↓
<b>Sedentary Behavior</b>						
<b>2018</b>						
Guitar NA et al.[83]	Static	--	--	One-on-one or Video	N/A	Mean no. of sit-to-stand in an 8hr-workday (goal=16): 12 ( <i>post-intervention only</i> )



Author	Goal-Setting	Social Support	Reward	Education/Training	Comparison	Findings
<b>Sleep</b>						
<b>2017</b> Kang SG et al.[56]	Adaptive	--	--	Video, App	■	Sleep efficiency: between study groups ↑
<b>Physical Activity &amp; Sleep</b>						
<b>2016</b> Crowley O et al.[43]	Adaptive	--	Charitable donation, In-kind, Digital reward	--	N/A	Step count: pre/post-intervention ↓ Sleep duration: pre/post-intervention ↑*
Melton BF et al.[42]	--	--	--	--	■ <sup>W</sup>	Step count: between study groups ↓* Total PA: between study groups ↓ Sleep duration: between study groups ↑ Sleep efficiency: between study groups ↓
<b>Physical Activity, Sedentary Behavior, &amp; Sleep</b>						
<b>2018</b> Choi JY et al.[55]	Adaptive	Community Competition	Cash	One-on-one, Group session, Printed material, Exercise training	◆	Step count: between study groups ↑* Total PA: between study groups ↑* Sedentary time: between study groups ↓* Sleep duration: between study groups ↑

Note:

A, B, C, D, E: Two articles on the same study, reporting on different outcomes.

**Comparison:** ◆ - comparison group (CG) received a WAM; ■ - CG received a 'control intervention' without a WAM; ○ - CG did not receive anything or received usual care only; ■<sup>W</sup> - CG received a 'control intervention', then after the intervention period was given the WAM; ○<sup>W</sup> - CG did not receive anything, then after the intervention period was given the WAM; N/A - not applicable (no comparison group)

**Findings:** between study groups – difference in the mean change between the IG and CG(s); pre/post-intervention – change at post-intervention from baseline; ↑ – increase; ↓ – decrease

\* – statistically significant (p<.05);