Do Activity Monitors Increase Physical Activity in Adults with Overweight or Obesity? A Systematic Review and Meta-Analysis

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Objective: To systematically assess contemporary knowledge regarding behavioral physical activity interventions including an activity monitor (BPAI+) in adults with overweight or obesity.

Methods: PubMed/MEDLINE, Embase, CINAHL, PsycINFO, CENTRAL, and PEDro were searched for eligible full-text articles up to 1 July 2015. Studies eligible for inclusion were (randomized) controlled trials describing physical activity outcomes in adults with overweight or obesity. Methodological quality was independently assessed employing the Cochrane Collaboration's tool for risk of bias.

Results: Fourteen studies (1,157 participants) were included for systematic review and 11 for meta-analysis. A positive trend in BPAI+ effects on several measures of physical activity was ascertained compared with both wait list or usual care and behavioral physical activity interventions without an activity monitor (BPAI−). No convincing evidence of BPAI+ effectiveness on weight loss was found compared with BPAI−.

Conclusions: Behavioral physical activity interventions with an activity monitor increase physical activity in adults with overweight or obesity. Also, adding an activity monitor to behavioral physical activity interventions appears to increase the effect on physical activity, although current evidence has not yet provided conclusive evidence for its effectiveness.

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Introduction

Worldwide, 1.46 billion adults were overweight and 502 million had obesity in 2008 (1). The global rising prevalence of these conditions is expected to further increase both the health and economic burdens in the following decades (2). Overweight and obesity are frequently caused by a chronic imbalance involving dietary and physical activity patterns (3). Behavioral interventions involving alterations in both physical activity and diet can lead to clinically important weight loss (≥5% of baseline weight) in adults with overweight or obesity (4). Physical activity should be facilitated in intervention programs to enhance the likelihood of not only successful weight loss and weight maintenance but also for health benefits regardless of weight loss (5). A recent systematic review concluded that physical activity was included in 88% of studies that achieved clinically important weight loss, whereby behavioral training (such as self-monitoring) was included in 92% of these studies (6).

Over the previous decades, there has been increasing interest in the therapeutic application of objective measures of self-monitoring. One of the first objective measuring instruments for physical activity was introduced in 1965 with the release of the Japanese manpo-kei pedometer, meaning ''10,000 steps meter'' (7). Currently, devices such as triaxial accelerometers, gyroscopes, and global positioning systems are combined to create activity monitors that are more accurate (8,9) and even integrate behavior change techniques (BCTs) such as social support, prompts/cues, rewards, and behavioral outcome self-monitoring (10). Pedometer employment has been shown to increase physical activity in adults with type 2 diabetes,

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musculoskeletal diseases, and several other outpatient populations (11-14). Furthermore, pedometer-based walking interventions have assisted in achieving moderate weight loss in adults (11,13,15). Although a recent meta-analysis regarding the effects of activity monitors indicated positive outcomes on physical activity, HbA1c, systolic blood pressure, and body mass index (BMI) in patients with type 2 diabetes (16), no systematic review regarding the effects of activity monitor-based interventions on physical activity in adults with overweight or obesity is yet available. Therefore, the aim of this systematic review was twofold. The first aim was to establish whether receiving a behavioral physical activity intervention with an activity monitor (BPAI+) increases physical activity in adults with overweight or obesity compared with both wait list and usual care (WL/UC). The rationale was to determine whether offering a BPAI+ has clinical relevance when increasing physical activity is targeted. The second aim is to establish the added value of activity monitoring in existing interventions on increment of physical activity. Therefore, BPAI+ was compared with behavioral physical activity interventions without an activity monitor (BPAI−). Additionally, the BPAI+ effect on body weight compared with BPAI− will be examined.

Methods

The protocol for this systematic review and meta-analysis was based on the PRISMA-P statement (17) and registered at PROSPERO (CRD42015024086) (18). The review was executed according to the Cochrane Handbook for Systematic Reviews of Interventions (19) following the PRISMA statement (20).

Search strategy

Electronic databases were searched using the sensitivity-maximizing version of the Cochrane Search Strategy to filter for randomized controlled trials and controlled clinical trials (19). MEDLINE, Embase, CINAHL, PsycINFO, CENTRAL, and PEDro were searched for eligible articles published before 1 July 2015. The employed MeSH terms and keywords included overweight, obesity, accelerometry, actigraphy, physical activity, exercise, and energy expenditure. Furthermore, a reference tracking strategy was performed by searching the reference lists and citations of included articles in Web of Science and Scopus. The complete search strategy can be found in the protocol (18).

Study selection

Articles were eligible for inclusion if (a) they had a randomized controlled trial or controlled clinical trial design; (b) the majority of the participants were human adults with overweight or obesity (mean baseline BMI $\geq$27.0 kg/m^2 for Caucasians or $\geq$25.0 kg/m^2 for Asians); (c) the intervention included the application of activity monitors; (d) the control group was on a wait list, received usual care, or were provided with a similar physical activity intervention as that of the intervention group but without activity monitor feedback; (e) physical activity changes for both intervention and control groups were described; and (f) the full text of the article was available in English. Articles were excluded if (g) the document was a conference abstract, research letter, editorial note, or commentary; (h) the intervention included non-spontaneous physical activity or a workplace environment modification; (i) participants were primarily older adults (mean age $\geq$60 years) or pregnant women; (j) participants were possibly limited in the ability to modify physical activity due to serious comorbidity caused by a chronic disease or its treatment; or (k) the intervention period was $<$2 weeks.

Two independent content area experts (HJdV and TJMK) screened potentially eligible articles for inclusion based on titles and abstracts. Full-text articles were subsequently screened for final inclusion. Differences in appraisal were resolved by reaching consensus. The strength of inter-rater agreement was measured by Cohen's coefficient (19).

Methodological quality (risk of bias)

The risk of bias was scored by two independent reviewers (HJdV and TJMK) using the Cochrane Collaboration's tool (19). This tool reviews the random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other biases. Since the blinding of participants is practically infeasible in a self-monitoring intervention, this was not assessed and blinding of personnel was scored separately. Discrepancies between the raters were resolved in a consensus meeting. The strength of inter-rater agreement was measured by Cohen's coefficient (19).

Synthesis of results

Data extraction was performed by the reviewers utilizing a standard extraction form. Extracted data from the articles included: (a) first author, publication year, and study location, (b) participants age and BMI; (c) intervention characteristics; (d) outcome measures; and (e) study results. When multiple ($\geq$2) studies compared analogous groups and reported the same outcome measures, results were pooled in RevMan 5.3 software for random-effects meta-analysis using the Inverse Variance method. For statistical pooling, extracted data from intention-to-treat analyses was preferred over completer analyses and data measured by an objective instrument was favored over data from subjective instruments.

Results

Study selection

The search strategy identified 1,645 articles, of which 14 full-text articles (including 1,157 participants) that satisfied the inclusion criteria were identified and reviewed (21-34). Selection agreement between the reviewers was excellent ($\kappa = 0.75$) (19). A flowchart of the study selection process is depicted in Figure 1. Seven studies compared patients receiving BPAI+ with WL/UC (21-24,28,31,33), and seven different studies compared patients receiving BPAI+ with patients receiving BPAI− (25-27,29,30,32,34). Five studies comparing patients receiving BPAI+ with WL/UC used an objective measure to determine physical activity outcomes (21-23,31,33), and two used a self-administered questionnaire (24,28). Additionally, four studies comparing patients receiving BPAI+ with BPAI− used an objective physical activity measure (25-27,34) while three employed a questionnaire (29,30,32). Data from 11 studies (21-26,28-30,33,34) were pooled for meta-analysis including: steps per day, total moderate to vigorous physical activity (MVPA) minutes per time unit, walking MET-minutes per week, physical activity kilocalories per week, weight change in kilograms, relative weight change, and BMI change outcomes. No major adverse events related to the interventions were reported. Four studies executed a gender-specific intervention (23-26). All of the individual study characteristics can be found in Table 1.

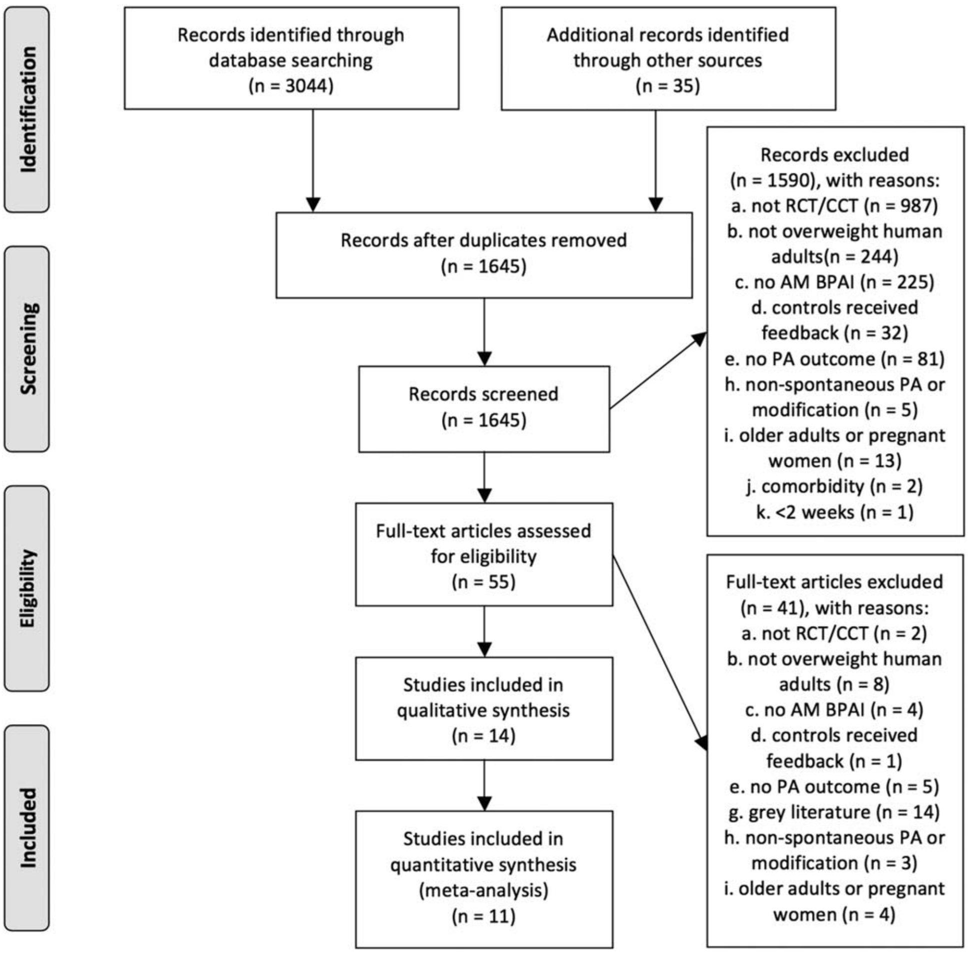

Figure 1 Flowchart of selected studies.

Methodological quality (risk of bias)

The agreement between the reviewers in the risk of bias assessment was fair ($\kappa = 0.52$) (19), however, consensus was reached. Among the 14 included studies, several increased risks of bias were assessed. One study (24) used a nonrandom component in the sequence generation process by randomizing work crews instead of individual participants (cluster randomized trial). It is unclear in seven studies (25,26,29,30,32-34) if random sequence generation was used and in 10 studies (22,24-30,33,34) whether allocation concealment was applied. Blinding of intervention personnel was absent in seven studies (21,22,24,27,30,31,33) and unclear in three studies (29,32,34). Blinding of outcome assessment was absent in one study (26) and unclear in seven studies (22,24,25,29,30,32,34). Three studies had a high risk of attrition bias due to incomplete outcome data (22,29,32) while the risk of attrition bias was unclear in two studies (30,34). Two studies had a high risk of reporting bias due to selective reporting (31,34). Another high risk of bias was introduced by two studies which allowed control group participants to register their own weekly step totals (25,26). Lastly, an unclear risk of bias may have been introduced by a study that removed outliers without being able to verify if the data was erroneous (31) and a study with a significant between-group age differences at baseline (34). The distribution of the risks of bias is graphically depicted in Figure 2.

Synthesis of results

BPAI+ versus WL/UC. A meta-analysis using the standardized mean difference (SMD) for steps per day was performed on four studies (21-23,33) comparing BPAI+ with WL/UC (Figure 3A). One study (23) that compared two relevant intervention groups to wait-list controls was entered twice. Another study that described a nonsignificant ($P = 0.167$) positive effect on steps per day could not be included, as steps per day outcomes were only graphically displayed (31). A significant ($P < 0.00001$) positive (SMD 0.90, 95% CI 0.61-1.19) intervention effect estimate with moderate (35) ($I^2 = 49\%$) but not significant ($P = 0.10$) heterogeneity was found. A meta-analysis using the SMD for total MVPA minutes per time unit was performed on three studies (22,24,28) comparing BPAI+ with WL/UC (Figure 3B). A significant ($P = 0.01$) positive (SMD 0.50, 95% CI 0.11-0.88) intervention effect estimate with substantial (35) ($I^2 = 74\%$) and significant ($P = 0.02$) heterogeneity was found.

TABLE 1 Characteristics of included studies, divided by comparison (BPAI+ vs. WL/UC and vs. BPAI−)

Study	Participants ($M \pm$ SD)	Control group	Intervention group	
			BPAI	Use of the AM
Comparison: BPAI+ vs. WL/UC				
Baker et al., Scotland (21)	Number (randomized): 80 (c: 40, i: 39). % Male (randomized): 20.3 (c: 20.0%, i: 20.5%). Age (randomized): 49.2 ± 8.8 (c: 51.2 ± 7.9, i: 47.3 ± 9.3). BMI (randomized): 29.0 ± 5.6[a] (c: 29.4 ± 6.3, i: 28.5 ± 4.8). Target group: community sample.	Wait-list control group.	Based on: transtheoretical model. Contact: one individual session at baseline (30 min). Behavioral components: discussion of motivation and barriers toward PA, individual goal setting, plan making. Additional feedback: - Resources: - Dietary advice: none. Duration: 12 wk.	AM: Omron HJ-109E Step-O-Meter. Instruction AM: participants were shown how to use the AM to monitor daily step count. PA goal: increase steps/d by 3,000 on 5 d/wk. This goal was reached with subgoals until week 7 and then maintained until week 12. AM feedback: daily steps + PA diary. Data recall from AM: 7 d
Bond et al., USA (22)	Number (randomized): 80 (c: 38, i: 42). % Male (randomized): 13.5 (c: 11.4, i: 15.0). Age (randomized): 46.0 ± 8.9 (c: 48.1 ± 8.1, i: 44.2 ± 9.2). BMI (randomized): 45.0 ± 6.5 (c: 44.4 ± 5.8, i: 45.6 ± 7.0). Target group: patients awaiting bariatric surgery.	Usual care: standard presurgical care; advice to adopt active lifestyle and engage in walking and similar activities but no formal prescription or strategies to change PA behavior.	Based on: transtheoretical model, theory of planned behavior, social cognitive and self-determination theory. Contact: six individual sessions (30-45 min). Behavioral components: increase knowledge, goal setting, action planning, PA cues, review of progress, problem solving. Additional feedback: -. Resources: Session handouts. Dietary advice: None. Duration: 6 wk.	AM: pedometer (unknown model). Instruction AM: record daily steps and bout-related walking minutes in a monitoring log. PA goal: (1) moderate-intensity walking in bouts ≥10 min for 30 min/d and (2) increase steps/d by 5,000/d. This goal was reached in smaller subgoals per week. AM feedback: daily steps + monitoring log. Data recall from AM: unknown.
Morgan et al., Australia (24)	Number (randomized): 110 (c: 45, i: 65). % Male (randomized): 100. Age (randomized): 44.4 ± 8.6 (c: 43.7 ± 9.1, i: 44.8 ± 8.3). BMI (randomized): 30.5 ± 3.6 (c: 30.2 ± 3.5, i: 30.7 ± 3.6). Target group: male shift workers.	Wait-list control group.	Based on: social cognitive theory. Contact: one individual session (75 min). Behavioral components: education, goal setting, use of a credible source, small financial incentives. Additional feedback: ≤7 individualized emails as response on weight, eating, and exercise diaries. Resources: CaloryKing website, website user guide, weight loss book. Dietary advice: education about diet and weight loss. Duration: 14 wk.	AM: pedometer (Yamax SW-200). Instruction AM: unknown. PA goal: individually discussed during first session, unknown whether the goal was specifically for steps. AM feedback: daily steps. Data recall from AM: 1 d.

TABLE 1. (continued).

Study	Participants ($M \pm$ SD)	Control group	Intervention group: BPAI	Intervention group: Use of the AM
Morgan et al., Australia (23)	Number (randomized): 159 (c: 52, i1: 54, i2: 53). % Male (randomized): 100. Age (randomized): 47.5 ± 11.0 (c: 48.0 ± 1.2, i1: 48.0 ± 10.8, i2: 46.5 ± 11.1). BMI (randomized): 32.7 ± 3.5 (c: 33.1 ± 3.9, i1: 32.4 ± 3.3, i2: 32.8 ± 3.4). Target group: men.	Wait-list control group.	*Resources group (i1)* Based on: social cognitive theory. Contact: none. Behavioral components: tailoring for men, self-selected goal setting, advice for social support strategies. Additional feedback: -. Resources: weight loss DVD, weight loss handbook and support book, tape measure, kilojoule counter book. Dietary advice: achieve a negative energy balance of 2,000 kJ/d. Seven diet-related weight loss messages. Duration: 3 mo. *Online group (i2)* Resources: same as resources group, with additional website use (Calory-King website) and website user guide. Online monitoring instead of paper-based logbook. Feedback: seven individualized feedback emails about food and exercise diary entries.	AM: pedometer (model unknown). Instruction AM: record pedometer-based steps for 4 d each week in the support books and to tick off a check box when goals are achieved. PA goal: one self-determined SMART goal per month. Two PA-related weight loss messages; increase daily steps and reduce sitting time. AM feedback: daily steps + i1: paper log-book, i2: online diary entries. Data recall from AM: unknown.
Patrick et al., USA (28)	Number (randomized): 441 (c: 217, i: 224). % Male (randomized): 100. Age (randomized): 43.9 ± 8.0 (c: 42.8 ± 8.0, i: 44.9 ± 7.8). BMI (randomized): 34.3 ± 4.1[a] (c: 34.3 ± 4.0, i: 34.2 ± 4.2). Target group: men.	Wait-list control group, with access to an alternate website containing general health information of interest to men but not likely to lead to changes in diet or PA (e.g., information on stress, hair loss, work site injury prevention).	Based on: social cognitive theory, BDM. Contact: orientation conversation with instruction of the website, email, or telephone contact to facilitate interaction with website and troubleshooting, discussion of goals with healthcare provider, optional email contact for health-related questions. Behavioral components: self-selected goal setting, tailoring of website	AM: pedometer (Yamax Digiwalker). Instruction AM: monitor daily steps and record the data on the website to assist with goal setting. PA goal: (1) $\geq$10,000 steps/d on $\geq$5 d/wk and (2) strength training $\geq$2 d/wk targeting $\geq$2 body areas. AM feedback: daily steps, online logbook, weekly graphical feedback of PA behaviors. Data recall from AM: 1 d.

TABLE 1. (continued).

Study	Participants ($M \pm$ SD)	Control group	Intervention group: BPAI	Intervention group: Use of the AM
			content (informed by assessed health behaviors), use of behavioral skills. Additional feedback: weekly graphical feedback of other health behaviors. Resources: Web-based learning. Dietary advice: dietary goals and information about a healthy diet through the website. Duration: 12 mo.	
Staudter et al., USA (31)	Number (randomized): 106 (c: 54, i: 52). % Male (completers): 20.2 (c: 27.3%, i: 13.3%). Age (completers): 50.0 ± 9.3 (c: 50 ± 8.4, i: 50 ± 10.1). BMI (completers): 32.5 ± 5.4 (c: 32.6 ± 6.2, i: 32.3 ± 4.6, $P = 0.915$). Target group: military beneficiaries.	Usual care: "Usual Lifestyle," no change in activity advised. During three data collection sessions, 30 min were spent on nutritional guidance, in order to minimize dietary biases.	Based on: theory of planned behavior. Contact: online message board, three data collection sessions at baseline, mid-study, and post-study. Behavioral components: encouragement, strategies for improvement through the online message board. Additional feedback: positive online feedback. Dietary advice: nutritional guidance, same as c. Resources: New Lifestyles website. Duration: 12 wk.	AM: pedometer (Yamax SW-200). Instruction AM: wear the pedometer daily and record daily steps on the website. PA goal: create weekly step goals, increasing by 500 to 1,000 steps/wk, until reaching ultimate walking goal of 10,000 steps/d. AM feedback: daily steps, online logbook. The website converted tracked steps into distance traveled on a virtual journey and provided targets to increase motivation. Data recall from AM: 1 d
Tudor-Locke et al., Canada (33)	Number (randomized): 60 (c: 30, i: 30). % Male (completers): 55.3 (c: 60.9%, i: 50%). Age (completers): 52.7 ± 5.2 (c: 52.5 ± 4.8, i: 52.8 ± 5.7). BMI (completers): 33.3 ± 5.6 (c: 32.5 ± 5.0, i: 34.1 ± 6.1). Target group: patients with type 2 diabetes.	Wait-list control group.	Based on: social cognitive theory, transtheoretical model. Contact: four group sessions in the first 4 wk. Behavioral components: goal setting and problem-solving exercises. Resources: First Step Program manual. Additional feedback: - Dietary advice: none. Duration: 16 wk.	AM: pedometer (model unknown). Instruction AM: use both pedometer and calendar for goal setting and self-monitoring. PA goal: unknown. AM feedback: daily steps and PA calendar. Data recall from AM: unknown.

TABLE 1. (continued).

Study	Participants ($M \pm$ SD)	BPAI−	Use of the AM in BPAI+
Comparison: BPAI+ vs. BPAI−			
Pal et al., Australia (25)	Number (randomized): 30 (c: 15, i: 15). % Male (randomized): 0. Age (completers): 43 ± 28.8^a (c: 44 ± 24.9^b, i: 42 ± 33.2^b, $P = 0.287$). BMI (completers): 29.3 ± 2.6^a (c: 28.6 ± 2.7^b, i: 29.9 ± 2.5^b, $P = 0.423$). Target group: women.	Based on: - Contact: review of PA guidelines at baseline. Behavioral components: - AM: sealed pedometer. Control participants wore this sealed pedometer for 12 wk with weekly recording. PA goal: set small achievable goals like 10 min walks, gradually increase goal weekly to ≥30 min/d. No step goals were set. Feedback: recording of total weekly steps. Resources: National Australian Physical Activity Guidelines. Dietary advice: maintain diet for duration of the study. Duration: 12 wk.	Based on: - Contact/behavioral components: same as c. AM: pedometer (Yamax SW-200). Instruction AM: monitor daily steps, record on a calendar. PA goal: set small achievable goals, weekly increase to (1) walking ≥30 min/d and (2) 10,000 steps/d. Feedback: daily steps and calendar. Data recall from AM: 1 d. Resources/dietary advice/duration: same as c.
Pal et al., Australia (26)	Number (randomized): 32 (c: 16, i: 16). % Male (randomized): 0. Age (completers): 43.5 ± 9.1 (c: 45.27 ± 8.4^b, i: 41.4 ± 9.8^b, $P > 0.05$). BMI (completers): 29.3 ± 4.1^a (c: 29.7 ± 4.1^b, i: 28.9 ± 4.3^b, $P > 0.05$). Target group: women.	Based on: - Contact: discussion at baseline about PA guidelines. Behavioral components: - AM: sealed pedometer. Participants recorded weekly steps. PA goal: ≥30 min/d walking on top of baseline activity. Feedback: recording of total weekly steps. Resources: National Australian Physical Activity Guidelines. Dietary advice: maintain normal diet. Duration: 12 wk.	Based on: - Contact/behavioral components: same as c. AM: pedometer (Yamax SW-200). Instruction AM: record steps/d on a calendar. PA goal: ≥10,000 steps/d. Feedback: daily steps and calendar. Data recall from AM: 1 d. Resources/dietary advice/duration: same as c.
Paschali et al., USA (27)	Number (randomized): 30 (c: 15, i: 15). % Male (randomized): 46.2 (c: 47%, i: 47%, $P > 0.05$). Age (randomized): 48.1 ± 7.1 (c: 47.0 ± 7.2, i: 48.8 ± 6.1, $P > 0.05$). BMI: unknown (inclusion: ≥30). Target group: community sample.	Based on: social cognitive theory. Contact: monthly counseling by behavior therapist (15 min). Behavioral components: basic behavioral self-management principles, discussion of goals, problems encountered, and problem solving. AM: triaxial accelerometer (BioTrainer), display turned off. PA goal: brisk walking or exercise of equivalent intensity ≥3 times per week. Feedback: paper diary with discussion of self-reported exercise. Resources: 24-page manual with exercise instructions and self-management. Dietary advice: none. Duration: 3 mo.	Based on: social cognitive theory. Contact/behavioral components: Same as c. AM: triaxial accelerometer (BioTrainer). Instruction AM: wear the AM daily and monitor daily steps. PA goal: brisk walking or exercise of equivalent intensity ≥3 times per week. Feedback: activity units accumulated on accelerometer, monthly history displayed graphically on a computer and printed, paper diary. Discussion of the accelerometer data. Data recall from AM: 28 d. Resources/dietary advice/duration: same as c.

TABLE 1. (continued).

Study	Participants ($M \pm$ SD)	BPAI−	Use of the AM in BPAI+
Pellegrini et al., USA (29)	Number (randomized): 51 (c: 17, i1: 17, i2: 17). % Male (randomized): 13.7 (c: 0%, i1: 23.5%, i2: 17.6, $P = 0.12$). Age (randomized): 44.2 ± 8.7 (45.1 ± 9.4, i1: 43.3 ± 9.1, i2: 44.1 ± 8.1, $P = 0.85$). BMI (randomized): 33.7 ± 3.6 (c: 33.1 ± 3.8, i1: 34.7 ± 3.4, i2: 33.4 ± 3.6, $P = 0.42$). Target group: community sample.	*Standard behavioral weight loss (c)* Based on: - Contact: weekly meetings (three group meetings, one individual meeting per month). Behavioral components: behavioral strategies (not specified). AM: none. Feedback: paper diary (diet, PA, and weight), weekly written feedback from interventionist. PA goal: progressive engagement in moderate-intensity PA to 100-300 min/wk. Resources: - Dietary advice: reduce caloric intake to 1,200-1,800 kcal/wk and dietary fats to 20% of total calories. Elicit an energy deficit of 500 kcal/d. Duration: 6 mo.	*Standard behavioral weight loss plus technology-based system (i1)* Based on: - Contact/behavioral components: same as c. AM: BodyMedia Fit and additional digital display. Instruction AM: wear AM and digital display daily, download PA data on the website daily. PA goal: progressive engagement in moderate-intensity PA 100-300 min/wk. Feedback: digital display (real-time feedback), website, weekly feedback from interventionist. Data recall from AM: unlimited. Resources: website. Dietary advice/duration: same as c. *Technology-based system only (i2)* Same as i1 except: no weekly meetings but weekly mailed behavioral lessons. At baseline, one instruction and one weight loss information session.
Polzien et al., USA (30)	Number (randomized): 58 (c: 19, i1: 19, i2: 19). % Male (randomized): 1.6. Age (randomized): 41.3 ± 8.7 (c: 40.2 ± 8.0, i1: 41.1 ± 8.3, i2: 42.6 ± 10.0, $P = 0.71$). BMI (randomized): 33.1 ± 2.8 (c: 33.6 ± 2.7, i1: 33.4 ± 2.8, i2: 32.6 ± 2.7, $P = 0.51$). Target group: community sample.	*Standard in-person behavioral weight control program (c)* Based on: social cognitive theory. Contact: seven individualized counseling sessions. Behavioral components: Constructs of social cognitive theory (not specified). AM: none. PA goal: moderate-intensity exercise progressing from 20 to 40 min/d during 5 d/wk. Feedback: paper diary for self-monitoring of diet and PA behaviors. Resources: - Dietary advice: reduce energy intake to 1200-1500 kcal/d, reduce saturated fat to 20% of total intake. Duration: 12 wk.	*Intermittent technology-based behavioral weight control program (i1)* Based on: social cognitive theory. Contact/behavioral components: same as c. AM: Sensewear Pro armband (weeks 1, 5, and 9). Instruction AM: wear the AM, upload AM data on website. PA goal: moderate-intensity exercise increase from 20 to 40 min/d, 5 d/wk. Feedback: daily steps and EE, Internet monitoring of PA and diet (weeks 1, 5, 9), paper diaries during the other weeks. Data recall from AM: daily in weeks 1, 5, and 9. Resources: website. Dietary advice/duration: same as c. *Continuous technology-based behavioral weight control program (i2)*

TABLE 1. (continued).

Study	Participants ($M \pm SD$)	BPAI−	Use of the AM in BPAI+
			Same as i1 except: continuous availability of Sensewear Pro armband and Internet monitoring.
Stovitzet al., USA (32)	Number (randomized): 94 (c: 44, i: 50). % Male (randomized): 33.0, (c: 27.3, i: 38.0). Age (randomized): 40.9 ± 13.4 (c: 44.3 ± 13.8, i: 38.0 ± 12.4). BMI (randomized): 31.0 ± 8.5 (c: 31.5 ± 9.8, i: 30.5 ± 7.3). Target group: patients of a family medicine clinic.	Based on: - Contact: a brief scripted statement endorsing the benefits of increased PA (1 min), two phone calls (after week 1 and in week 5). Behavioral components: - AM: none. PA goal: increase PA level by 10% per week. Feedback: 9-wk calendar, with own recording of PA. Resources: one-page handout summarizing the benefits of PA. Dietary advice: - Duration: 9 wk.	Based on: - Contact/behavioral components: same as c. AM: Yamax DigiWalker SW-200 (pedometer). Instruction AM: wear AM daily, record daily steps in the PA calendar. PA goal: increase daily average of steps by 400 each week. Feedback: 9-wk calendar to use as step-log. Data recall from AM: 1 d. Resources: one-page handout summarizing benefits of PA. Dietary advice/duration: same as c.
Unick et al., USA (34)	Number (randomized): 29 (c: 14, i: 15). % Male (randomized): 18. Age (randomized): 41.5 ± 9.8[a] (c: 46.1 ± 9.1, i: 38.7 ± 9.3, $P = 0.04$). BMI (randomized): 45.0 ± 3.9. Target group: community sample.	Based on: - Contact: weekly group meetings. Behavioral components: behavioral approaches (not specified). AM: none. PA goal: progression toward 250 min/wk of exercise. Feedback: paper diary for self-monitoring PA and diet, weekly written feedback from interventionist. Resources: none. Dietary advice: reduce intake to 1,500 to 1,800 kcal/d. Duration: 6 mo.	Based on: - Contact/behavioral components: same as c. AM: BodyMedia Fit (armband, digital watch). Instruction AM: wear AM and upload data daily. PA goal: progression to 250 min/wk of exercise. Feedback: website where PA data was shown, and food intake and weight were recorded, weekly written feedback from interventionist. Data recall from AM: unlimited. Resources: website. Dietary advice/duration: same as c.

[a]SD was calculated based on the data from two separate groups using the formula in Cochrane Handbook section 7.7.a. (19).
[b]SD was calculated based on a SE using the formula in Cochrane Handbook section 7.7.3.2.
AM, activity monitor; BDM, behavioral determinants model; BPAI, behavioral physical activity intervention; c, control group; EE, energy expenditure; i, intervention group; MVPA, moderate to vigorous physical activity; PA, physical activity; WL, wait list; UC, usual care.

BPAI+ versus BPAI−. A meta-analysis using the SMD for total MVPA minutes per time unit was performed on three studies (25,26,34) (Figure 4A). A positive (SMD 0.43, 95% CI 0.00-0.87) but not significant ($P = 0.05$) intervention effect estimate of moderate quality (Table 2) without heterogeneity ($I^2 = 0\%$, $P = 0.66$) was found. A meta-analysis using the mean difference (MD) for walking MET-minutes per week was performed on two studies (25,26) (Figure 4B). A significant ($P = 0.002$) positive (MD 282.00 walking MET-minutes per week, 95% CI 103.82-460.18) intervention effect estimate and low (35) ($I^2 = 4\%$), not significant ($P = 0.31$) heterogeneity was found. The two studies included had a 100% female sample. One study (33) reported insufficient data on walking MET-minutes per week to be included in meta-analysis. They used the nonparametric Mann-Whitney *U* test and found a significant ($P = 0.03$) BPAI+ effect on total walking MET-minutes per week compared with BPAI−. A meta-analysis using the SMD for physical activity kilocalories per week was performed on two studies (29,30) (Figure 4C). One study (30) that compared two relevant BPAI+ groups with a similar BPAI− group was entered twice. A significant ($P = 0.02$) positive (SMD 0.45, 95% CI 0.07-0.83) intervention effect estimate without heterogeneity ($I^2 = 0\%$, $P = 0.57$) was found. Meta-analyses using MD were also performed for studies comparing BPAI+ with BPAI− that reported outcomes for changes in body weight. All analyses found a positive but not significant intervention effect estimate with low to moderate (35) but not significant heterogeneity. Three studies (25,29,30) reported outcomes for weight change in kilograms (MD −0.86, 95% CI −2.93 to 1.20, $P = 0.41$ and $I^2 = 45\%$, $P = 0.14$), two (30,34) for relative weight change in percentage (MD −0.75, 95% CI −3.10 to 1.59, $P = 0.53$ and $I^2 = 46\%$, $P = 0.16$), and three (25,26,29) for BMI change (MD −0.39, 95% CI −1.53 to 0.75, $P = 0.51$ and $I^2 = 27\%$, $P = 0.26$).

Results of individual studies

Aside from the outcomes that were pooled for meta-analysis, significant positive BPAI+ effects on several other physical activity outcomes were described. No statistically significant negative effects on physical activity outcomes were found. Baker et al. (21) used the nonparametric Mann-Whitney *U* test to find a positive BPAI+ effect on leisure MVPA− ($P = 0.04$) and sitting minutes per week ($P = 0.02$) compared with WL/UC. Bond et al. (22) found a positive 6-week BPAI+ effect on bout-related MVPA ($P = 0.001$) compared with WL/UC. Morgan et al. (24) described a positive 14-week BPAI+ effect on current physical activity ($P < 0.001$) compared with WL/UC. Pal et al. (26) found a significant ($P = 0.045$) between-group 12-week effect of BPAI+ on steps per day compared with BPAI−. Pellegrini et al. (29) measured self-reported changes in physical activity in kilocalories per week in two BPAI+ groups and one BPAI− group. They found a significant positive time effect ($P < 0.001$) but no significant group ($P = 0.225$) and group × time ($P = 0.246$) effects. Lastly, Stovitz et al. (32) described a positive BPAI+ effect on frequency of walking short trips ($P < 0.05$).

Discussion

Activity monitors may serve as a tool to enhance self-awareness of daily physical activity and to support individual behavioral physical activity interventions. To the authors' knowledge, this is the first systematic review (including meta-analysis) that describes the effects of a BPAI+ in adults with overweight or obesity. The first aim was to establish whether receiving a BPAI+ increases physical activity in adults with overweight or obesity compared with both WL/UC. A positive effect of BPAI+ on physical activity was ascertained when compared with WL/UC, which demonstrates that offering adults with overweight or obesity a BPAI+ has clinical relevance when increasing physical activity is targeted. However, clinical diversity within the included populations and applied interventions resulted in statistical heterogeneity. This heterogeneity makes it difficult to attribute the causes of the positive effects of BPAI+, including the added value of activity monitors. The second aim was to establish the added value of an activity monitor in existing interventions on increment of physical activity. A positive effect was determined based on a positive trend in the performed meta-analyses and results of individual studies comparing BPAI+ with BPAI−. The magnitude of this effect remains uncertain due to wide confidence intervals in all analyses as a result of the low number of studies that could be pooled for meta-analysis. Although conclusive evidence cannot be derived from these results, all results generally indicate a positive effect in favor of the use of activity monitors. Additional insight, study limitations, and clinical implications will be discussed below.

The small number of studies included in this meta-analysis could not be amended. Only 0.85% of the studies identified by the search strategy (14 out of 1,645) could be included as the search funnel was likely sensitive. Analysis on funnel plot asymmetry in order to detect publication bias was not feasible as the number of studies that could be included in the five individual meta-analyses was insufficient (<10) (19). The search strategy identified seven conference abstracts (36-42), one research letter (43), and one commentary article (44) describing studies without a full article publication; these were excluded. Although publication bias appears to be present based on these excluded studies, their results are in accordance with the results of this systematic review and meta-analysis. Positive BPAI+ effects on steps per day have also been meta-analyzed in healthy adults (11), in adults with type 2 diabetes (12,16) and patients with musculoskeletal disorders (14), as well as being based on pooled data from all available populations (45). The small number of studies that could be included in our meta-analyses can be further explained by the apparent lack of consensus on a preferred physical activity outcome measure and the limited number of studies reporting physical activity outcomes as 81 studies could not be included for those reasons (Figure 1). As a result, the effect sizes of the performed meta-analyses, particularly those of analyses comparing BPAI+ with BPAI−, were associated with relatively wide confidence intervals, meaning the accuracy of the estimated effect sizes are low. Therefore, future clinical studies are encouraged to report physical activity outcomes and preferably include objectively measured MVPA and steps per day as these have clinical relevance regarding both current international physical activity guidelines and the feedback provided by activity monitors. To establish the isolated effect of activity monitors, future clinical studies should also consider simply issuing their intervention participants an activity monitor with regular consumer instructions or to compare a well-described BPAI+ with an identical intervention without the activity monitor by mimicking either consumer use or the added value for existing clinical programs.

When compared with WL/UC, the effect of BPAI+ on steps per day (SMD 0.90, 95% CI 0.61-1.19) is larger than on MVPA (SMD 0.50, 95% CI 0.11-0.81). In the analysis comparing the effects

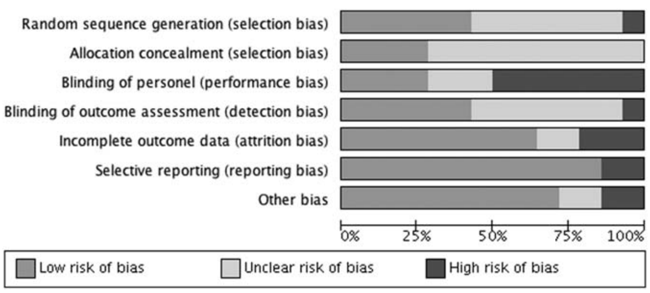

Figure 2 Risk of bias graph for included studies (*n* = 14).

BPAI+ with BPAI−, a positive trend on different MVPA outcomes was ascertained with moderate SMDs. Unfortunately, no studies could be pooled for meta-analysis comparing the effect of BPAI+ on steps per day with BPAI−. All steps per day outcomes were objectively measured, but two out of three studies included in both MVPA meta-analyses used a subjective measure. This increases the likelihood that the effect on steps per day is indeed larger than on MVPA because adults with obesity tend to overestimate their physical activity in subjective measures (46). Only one study (22) measured both steps and MVPA within the same study population. Therefore, it is unknown whether there are actual differences in the effect of BPAI+ on steps per day and MVPA or if the differences were caused by the presence of the various study populations and designs. For both MVPA and steps per day, two broad accepted physical activity norms are available. The current American College of Sports Medicine guideline recommends that adults perform 30 min of MVPA per day for at least 5 days per week (47). Another norm prescribes 10,000 steps per day, which can be obtained by both low intensity physical activity and MVPA. The 10,000 steps per day recommendation corresponds to that of 30 min of MVPA per day when at least 3,000 of the taken steps are taken at MVPA intensity (48). Modern activity monitors are able to determine if steps are taken at a moderate to vigorous intensity. These modern activity monitors also include BCTs such as social support, prompts/cues, and rewards (10), all of which are all associated with positive physical activity changes in obese adults (49). Since modern activity monitors can objectively measure the quantity and intensity of physical activity in the context of physical activity guidelines and incorporate BCTs that have proven to be effective, they should be preferred over older models for future studies and clinical use.

This study found no convincing evidence of an effect on changes in bodyweight when an activity monitor is added to the behavioral intervention (BPAI+ vs. BPAI−). This accords to that of other studies that found only modest effects of pedometer interventions on weight loss in adults with both overweight or obesity and type 2 diabetes (15). A possible explanation for the limited effect on body weight changes is that lower intensity physical activity is associated with less impact on weight loss (50), although it remains ambiguous if the use of an activity monitor does indeed particularly increase low intensity physical activity such as steps per day that are not taken at a moderate to vigorous intensity. However, more factors could have influenced the lack of effect found on body weight. First, only five studies described effects on body weight or BMI, limiting generalization. Second, in addition to inactivity, a variety of other factors are related to the onset and retaining of obesity, such as ethnicity, pre-birth health, eating habits, and sleeping patterns (51). It should also be noted, however, that higher levels of physical activity and fitness are favorably associated with biomarkers and anthropometric markers in adults with overweight or obesity, even causing

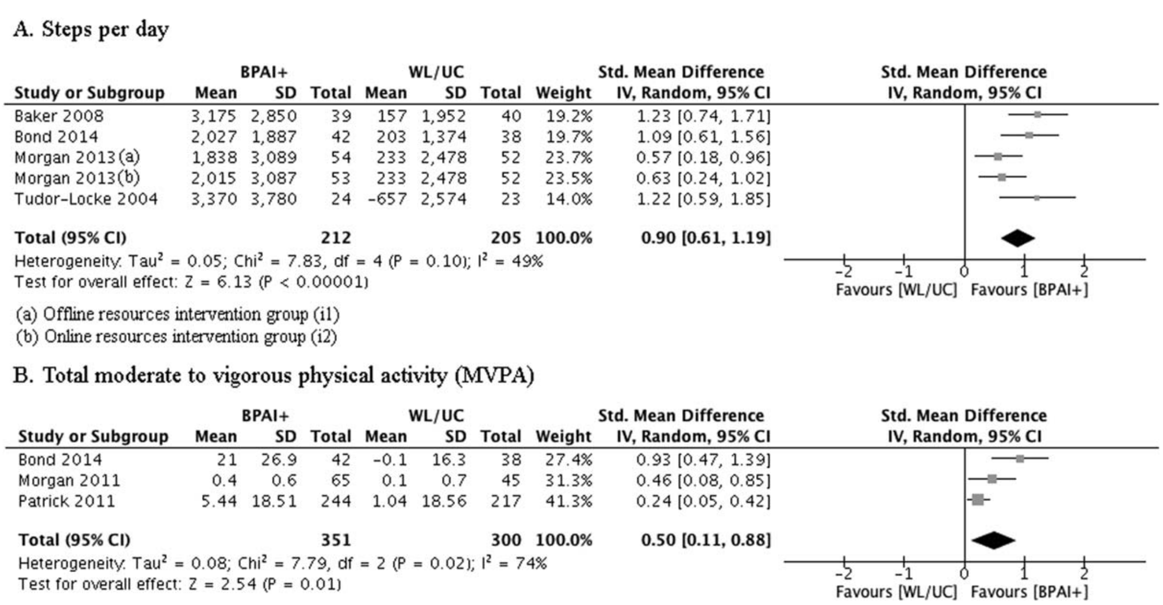

Figure 3 Forrest plot of standardized mean differences of (**A**) steps per day and (**B**) total moderate to vigorous physical activity in studies comparing patients receiving a behavioral physical activity intervention with an activity monitor (BPAI+) to patients on a wait list or receiving usual care (WL/UC).

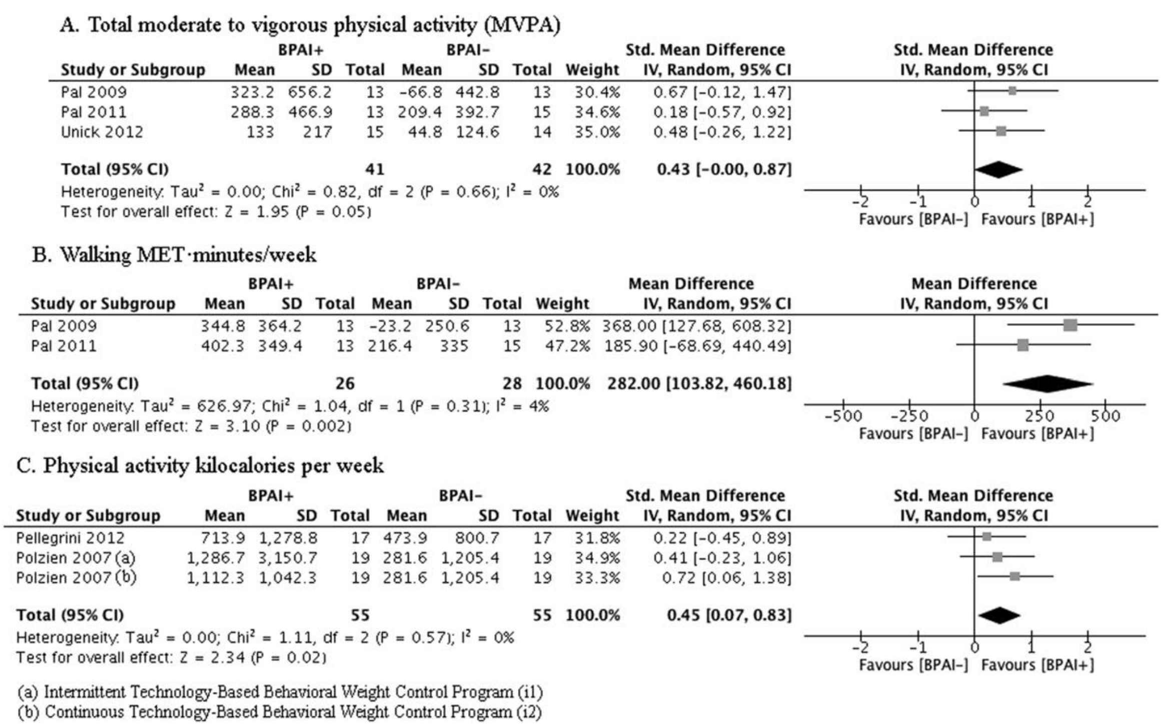

Figure 4 Forrest plots of (**A**) the standardized mean difference in minutes of moderate to vigorous physical activity, (**B**) the mean difference in walking MET-minutes per week, and (**C**) the standardized mean difference in physical activity kilocalories per week in studies comparing patients receiving a behavioral physical activity intervention with an activity monitor (BPAI+) with patients receiving a behavioral physical activity intervention without an activity monitor (BPAI−).

overweight adults to have similar cardiovascular profiles to their normal weight counterparts; the so-called ‘‘fat but fit’’ paradigm (52). Because of the strong evidence for reduced rates of multiple disease outcomes and a variety of health benefits (53), increasing physical activity has clinical relevance and should be stimulated for inactive adults with overweight or obesity, even if it has no effect on body weight.

As described in Table 1, three studies included subpopulations with a specific characteristic in patients awaiting bariatric surgery (22), patients with diabetes mellitus type 2 (33), and military beneficiaries (31). While it cannot be precluded that these characteristics could have influenced the study outcomes, either positively (the characteristic as an extra motivator) or negatively (the characteristic as a limitation to increase physical activity levels), we do not expect that the inclusion of these participants has influenced the drawn conclusions. This systematic review excluded original contributions that aimed at increasing the physical activity levels of older adults. This exclusion was necessary because lower effect sizes are typical in intervention studies comprising older adults (mean age $\geq$60 years) due to a lower compliance with BCTs that are often applied in BPAI+, such as setting behavioral goals, prompting self-monitoring of behavior, planning for relapses, providing normative information, and providing feedback on performance (54).

TABLE 2 Summary of findings for studies used in meta-analysis (BPAI+ vs. WL/UC and vs. BPAI−)

Outcome	No. participants (studies)	Anticipated absolute effect of BPAI+ (95% CI)
Comparison: BPAI+ vs. WL/UC		
Steps per day	417 (4 RCTs)	SMD 0.9 more (0.61 more to 1.19 more)
Total MVPA minutes per week	651 (3 RCTs)	SMD 0.5 more (0.11 more to 0.88 more)
Comparison: BPAI+ vs. BPAI−		
Total MVPA minutes per week	83 (3 RCTs)	SMD 0.43 more (0 to 0.87 more)
(Brisk) walking minutes per week	54 (2 RCTs)	MD 282 more (103.82 to 460.18 more)
Kilocalories per week	110 (2 RCTs)	SMD 0.45 more (0.07 more to 0.83 more)

CI, confidence interval; MD, mean difference; SMD, standardized mean difference; RCT, randomized controlled trial; MVPA, moderate to vigorous physical activity; BPAI, behavioral physical activity intervention; WL, wait list; UC, usual care.

Although additional well-designed studies are needed to improve the accuracy of our findings, the apparent positive effect of activity monitor use in behavioral physical activity interventions in patients with overweight or obesity is consistent with findings in other patient populations. Even more so, a natural transition to the use of an activity monitor appears to be ongoing as an increasing number of patients are using activity monitors to self-monitor physical activity (55). Based on both the indications of a positive effect of activity monitor use and the growing popularity of consumer-available activity monitors, clinicians are advised to develop methods to incorporate activity monitor feedback into their behavioral physical activity interventions. Specifically, we advise to use modern activity monitors that can determine if physical activity was executed at moderate to vigorous intensity and include BCTs which have been substantiated to successfully improve physical activity. Several studies included in this meta-analysis also indicate the importance of goal-setting that can preferably be monitored by the activity monitor feedback (e.g., 10,000 steps per day in pedometer interventions) and can be achieved by an incremental increase of physical activity (21,22,25,26). Also, Morgan et al. (24) mention that the increase in physical activity should be placed in the context of weight loss. For example, when using energy expenditure data in combination with caloric intake data, the patient can learn about the caloric balance and amount of physical activity that is necessary to lose weight. One or more physical activity consultations may be needed to discuss individual goal setting, self-efficacy, and physical activity barriers (21,22), especially for adults who experience difficulties with self-management. In addition, healthcare providers might simply advise their patients to use an activity tracking application on their smartphones when purchasing an activity monitor is a barrier (28).

Conclusion

Behavioral physical activity interventions with an activity monitor increase physical activity in adults with overweight or obesity. Also, adding an activity monitor to behavioral physical activity interventions seems to increase the effect on physical activity, although current evidence does not yet provide conclusive evidence for its effectiveness. O

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