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Step Counter Use and Sedentary Time in Adults
A Meta-Analysis

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Abstract: Although step counters are increasingly being used in walking programmes to promote sedentary behavior changes in adults, their effectiveness remains unknown. The aim of this meta-analysis of randomized controlled trials (RCTs) was to assess the effectiveness of step counter use in reducing sedentary time among adults.

English-language RCTs from 3 databases were searched up to December 2014. Studies were included if they evaluated the effects of step counter use in adult populations and reported outcomes in sedentary time. Summary estimates (Cohen d with 95% confidence intervals [CIs]) were pooled using a random-effects model. Subgroup analyses and random-effects meta-regression analyses based on the characteristics of participants or interventions were conducted to explore their associations with sedentary time changes.

Fifteen RCTs with a total sample size of 3262 adults were included. Step counter use was associated with a small but significant overall effect in reducing sedentary time ($d = -0.20$, 95% CI -0.33 to -0.07), equating to a reduction in sedentary time of ~23 min/d compared with controls. Subgroup analyses showed that step counter use with a step goal was associated with significantly reduced sedentary time ($d = -0.32$, 95% CI -0.53 to -0.11), whereas without, it had only a trend. A greater reduction in sedentary time was observed among step counter users employing objective methods than those employing subjective methods for measurement ($P = 0.03$). Effects of covariates on sedentary time changes were generally unclear.

Step counter use is associated with reduced sedentary time among adults. Future studies are required to specify the step goal use and to employ objective as well as subjective methods for measuring both total and domain-specific sedentary time.

(*Medicine* 94(35):e1412)

Abbreviations: BMI = body mass index, CI = confidence interval, IPAQ = International Physical Activity Questionnaire, PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analyses, RCT = randomized controlled trial.

INTRODUCTION

Sedentary time, which refers to time spent sitting or reclining during waking hours while having an energy expenditure no >1.5 metabolic equivalents,[1] has emerged as an independent risk factor for obesity, metabolic syndrome, type 2 diabetes, cardiovascular disease, and cancer in adults.[2–5] A recent meta-analysis by Biswas et al[6] has also noted that prolonged sedentary time is independently associated with a greater risk for all-cause, cardiovascular, and cancer mortality, regardless of physical activity. However, more than one half of the waking time in adults is spent being sedentary,[7] even in those who already meet current physical activity recommendation of ≥150 min/wk of moderate-to-vigorous physical activity sustained in bouts lasting 10 minutes or longer.[8] These concerns therefore support the notion that the development and evaluation of effective interventions to reduce sedentary time in tandem with the traditional recommendation to increase physical activity in adults is a priority.

In recent years, step counters, such as pedometers and accelerometers, are increasingly being used in walking programmes in community and workplace settings to promote physical activity and to reduce sedentary time among adults.[9–24] Although it has been well documented that step counter use is associated with increased physical activity,[25,26] controversy still remains regarding its effectiveness in reducing sedentary time. Several randomized controlled trials (RCTs) pointed out that step counter use could significantly reduce sedentary time in adults;[11,19,23] however, others argued that there were only minor or no effects.[9,10] Moreover, previous meta-analyses have shown that having a step goal, such as 10,000 steps/d or an alternative step goal, is key to an increase in physical activity among step counter users.[25,26] Yet it is not known whether such a step goal use will also lead to a significant reduction in sedentary time, although there is some evidence that increased physical activity is positively associated with decreased sedentary time (that is, physical activity displaces sedentary time).[27]

Therefore, the aims of this meta-analysis of RCTs were to determine the association between step counter use and sedentary time, as well as to assess the importance of step goal setting in reducing sedentary time among adults.

MATERIALS AND METHODS

Data Sources and Searches

This study followed the procedures for a meta-analysis as documented in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Table, Supplemental Digital Content 1, http://links.lww.com/MD/A390, which shows the PRISMA checklist),[28] and reported with reference to a prospectively registered protocol in PROSPERO (CRD42015016888; Table, Supplemental Digital

Content 2, http://links.lww.com/MD/A390, which describes the registered protocol). Searches were restricted to peer-reviewed English-language research articles in the databases of PubMed, Web of Science, and the Cochrane Central Register of Controlled Trials from inception through December 12, 2014. Search strategies were built around 2 groups of text words or Medical Subject Heading terms related to step counters and sedentary time, along with entry terms associated with a sensitive search filter for RCTs (Table, Supplemental Digital Content 3, http://links.lww.com/MD/A390, which shows the search strategies).[29] In addition, manual searches of reference lists from relevant publications, systematic reviews, or meta-analyses were conducted to supplement the electronic searches. Gray literature such as dissertations and unpublished data were not sought because it was impractical to identify them from all authors and institutions around the world.

Study Selection

The criteria for inclusion were defined based on the "PICOS" principle, that is, participants, interventions, comparisons, outcomes, and study design. Studies were included if they included adult populations (mean ages ≥18 years), used step counters (eg, pedometers, accelerometers) as the intervention for physical activity motivation (eg, walking more), compared with control groups that received usual care, were asked to maintain current lifestyle, or received interventions that had nothing to do with physical activity or sedentary behavior, reported change scores or postintervention values of sedentary time (eg, time spent being sedentary or sitting) assessed by subjective (eg, International Physical Activity Questionnaire [IPAQ]) or objective methods (eg, accelerometers), and were RCTs. To assess the long-term effect of step counter use in reducing sedentary time among adults, the length of step counter intervention was restricted to 8 weeks or longer—a time window that is widely used for evaluating the intervention effects on health outcomes or metabolic profiles.[29,30]

Studies were excluded if they included children or adolescents, used step counters only for measuring physical activity or sedentary time, or had step counters sealed in the intervention groups or unsealed in the control groups. Studies were also excluded if they enrolled adults requiring to be hospitalized (eg, inpatients), were posters or nonrandomized studies, or did not report outcomes in sedentary time including the case that such information could not be obtained from the corresponding authors.

Data Extraction and Quality Assessment

All retrieved citations together with the abstracts were downloaded to EndNote X5 (Thompson Reuters, San Francisco, CA) and duplicates were removed using "duplicate" function or by hand. Following initial title and/or abstract screen, full-text articles were retrieved for any studies deemed appropriate or of uncertainty about their eligibility. Data were extracted from studies that met all inclusion criteria using a standardized data collection form, which included characteristics of study participants (including population sources, number of participants, mean ages, and body mass index [BMI] at entry, sex [proportion of women], and baseline mean sedentary time [unit, min/d]); characteristics of study interventions (including description of the interventions [eg, step goal use, components on sedentary behavior changes, methods for sedentary time measurement] and length of interventions); characteristics of control groups; outcomes of interest (changes in sedentary time

or postintervention values [unit, min/d]); details of study sources (including authors and date of publication). In addition, average baseline values and change scores of total walking steps (unit, steps/d) and physical activity (including light, moderate, vigorous, moderate-to-vigorous, and total physical activity [unit, min/d]) were also extracted.

The Cochrane risk of bias tool was used to assess the methodological quality within included RCTs.[31] For each RCT, 6 domains were judged to be of high, low, or unclear risk for bias: sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, and selective outcome reporting. These 6 domains assess the level of risk regarding selection bias, performance bias, detection bias, attrition bias, and reporting bias.

Two independent authors (S.Q. and X.C.) conducted the literature selection, data extraction, and quality assessment in an unblinded manner. When disagreements occurred, consensus was achieved through discussion with a third author (U.S.).

Data Synthesis and Analysis

Change scores from baseline or postintervention values of sedentary time expressed as means with standard deviations from studies using intention-to-treat or per-protocol analyses were entered in the same meta-analysis.[31] For studies that did not report means, they were imputed by using medians directly. For studies that did not report standard deviations, they were calculated from standard errors, 95% confidence intervals (CIs), interquartile ranges, or ranges.[31,32] For studies that had 2-step counter intervention or control groups, these groups were combined into 1 group to create a single pairwise comparison and to overcome a unit-of-analysis error.[31] Moreover, for studies that reported outcome variables at different time points within the intervention period, outcomes from the last time point were used for primary analyses.[31]

Outcome estimates expressed as Cohen d and 95% CIs were assessed using a random-effects model, which better accounts for between-study heterogeneity than a fixed-effects model.[31] The reason for choosing Cohen d as the effect size rather than weighted mean differences was due to the different methods in measuring sedentary time (questionnaires versus instruments). Interpretation of the effect size was based on Cohen criteria, where $d < 0.40$ represents a small effect, 0.40 to 0.70 a medium effect, and >0.70 a large effect.[33] Statistical heterogeneity was assessed using the Cochrane Q test (considered the Q test with a $P < 0.10$ as heterogeneous) and the I^2 index (considered an I^2 value ≥50% as heterogeneous).[31]

Subgroup analyses based on step goal use (with versus without) and components focused on sedentary behavior changes (with versus without) were performed to evaluate their influences on outcome estimates. Another subgroup analyses on the basis of subjective and objective methods were conducted to compare their sensitivities or accuracies in determining sedentary time. Univariate, weighted random-effects meta-regression analyses were carried out to assess whether the changes in outcome estimates could be mediated by the following factors: baseline mean age (logarithmic transformation), BMI, sedentary time and physical activity, sex, length of intervention, and physical activity changes. Sensitivity analyses by removing each individual study from the meta-analysis were conducted to determine whether any particular study would significantly change the outcome estimates. Publication bias was evaluated using the Begg test and the Egger test at the $P < .10$ level of

significance. If publication bias was detected, the trim-and-fill computation was used to assess the effect of publication bias on the interpretation of the outcome estimates.[34] Unless otherwise specified, a $P < 0.05$ was considered significant. Statistical analyses were performed using STATA software (version 12.0; College Station, Texas, USA) and Review manager (version 5.2; the Nordic Cochrane Centre, Copenhagen, Denmark).

RESULTS

Study Characteristics

The literature search results and the study selection process are shown in Figure 1. In total, 1603 articles were identified, where 344 were from PubMed, 829 from Web of Science, 411 from the Cochrane Central Register of Controlled Trials, and 19 from identified systematic reviews or meta-analyses. After duplicate exclusion, title/abstract review, and full-text assessment, 15 studies met the inclusion criteria and were included in the final meta-analysis.[10–24]

The characteristics of the included studies are summarized in Table 1. A total sample size of 3262 participants (1649 as intervention participants and 1613 as controls) was pooled from the 15 studies. Most of the included participants were overweight or obese, and physically inactive or sedentary. The length of step counter intervention varied from 8 to 48 weeks.

All studies reported data on sedentary time, with 8 of them using subjective methods (6 with IPAQ and 2 with other questionnaires),[10,12–14,16,17,22,24] 6 using objective methods (3 with accelerometer [details not provided], 2 with ActivPAL [PAL Technologies, Glasgow, Scotland], 1 with StepWatch [Orthocare Innovations, Mountlake Terrace, WA]),[11,15,19–21,23] and 1 using both (IPAQ and accelerometer [details not provided]).[18] Five studies clearly indicated that the step counter interventions were conducted in workplace settings.[11,14,17,19,24] Seven studies reported adherence to step counter use among participants who completed the intervention, with an average rate of 79%. Eight studies had dropout rates <20%, while they were higher than 20% among the other studies except one that did not report.[24] Three studies were from the United States,[11,15,19] 9 from Europe,[10,14,17,18,20–24] and 3 from Australia.[12,13,16]

The risk-of-bias assessment for each study is described in Supplemental Digital Content 4, http://links.lww.com/MD/A390. The largest risk of bias came from attrition bias, with 7 of the included studies using improper methods in dealing with incomplete outcome data.[11,13–17,19] Because of the nature of step counter intervention, which requires unsealed step counters to promote physical activity and to reduce sedentary time, complete blinding of participants and personnel is impossible and unnecessary, and therefore, the risk of performance bias was judged to be low.
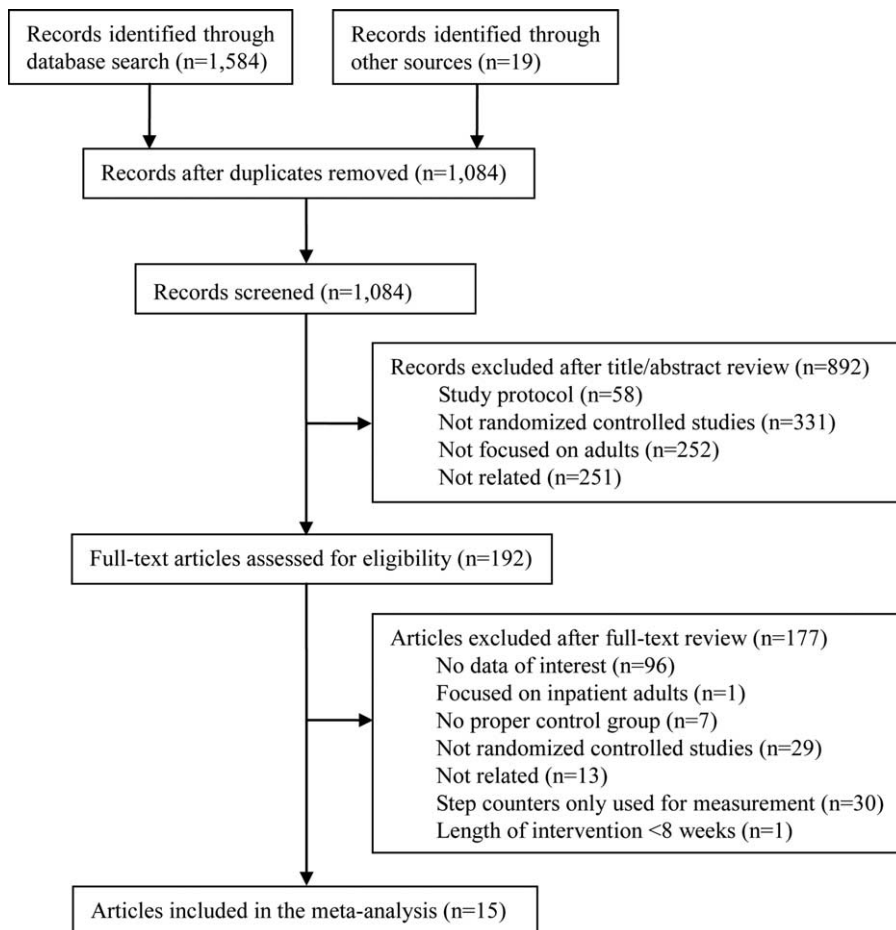

FIGURE 1. Flow diagram of literature search and study selection.

TABLE 1. Characteristics of Each RCT

Author, y	Population	Intervention and Control Description	Duration, wk*	Step Goal	Elements on SB	ST Measurement
Petersen et al,[10] 2012	Inactive adults	Intervention: received a pedometer-based walking program including a pedometer, a book with a pedometer-based goal-setting program, and a logbook. Control: received leaflets describing benefits of physical activity	12	Self-set goal	No	IPAQ
Kozey Keadle et al,[11] 2014†	Inactive overweight/obese adults	Intervention: received ST reduction strategies and pedometers for self-monitoring of behavior. Control: were asked to maintain current lives	12	Other goal	Yes	ActivPAL
Morgan et al,[12] 2013	Overweight/obese men	Intervention: received Self-Help, Exercise and Diet programmes, which included the pedometer use aimed to increase exercise. Control: were asked to maintain normal lives	12	Self-set goal	Yes	Sitting Questionnaire
Lane et al,[13] 2013	Inactive women	Intervention: received tailored physical activity booklets including pedometers for physical activity promotion. Control: received healthy eating leaflets	9	Not stated	No	IPAQ
Aittasalo et al,[14] 2012	Inactive employees	Intervention: received a pedometer-based intervention including emphasis on stairs use, walking leaflets, pedometers, logbooks, and monthly email messages. Control: were asked to maintain normal lives	24	Self-set goal	No	IPAQ
Suboc et al,[15] 2014‡	Sedentary older adults	Intervention: received a pedometer intervention with motivational messages and weekly physical activity counseling. Control: were asked to maintain normal lives	12	10,000 steps/d	No	Accelerometer
Burke et al,[16] 2013	Adults with insufficient activity	Intervention: received a home-based program supported by an exercise chart, calendar, bimonthly newsletters, resistance band, pedometer, phone calls, and emails. Control: were asked to maintain normal lives	24	Not stated	No	IAPQ
Verweij et al,[17] 2012	Employees with unhealthy lifestyle behaviors	Intervention: received guideline-based care including behavioral change counseling, goal-setting, and behavior monitoring on physical activity and nutrition by using a toolkit contained a pedometer and leaflets. Control: received usual care	24	Not stated	Yes	IPAQ
De Greef et al,[18] 2011	Overweight/obese adults with type 2 diabetes	Intervention: received a pedometer-based behavioral intervention including a face-to-face session, pedometer, and 7 phone calls. Control: received usual care	24	10,000 steps/d	Yes	Accelerometer and IPAQ

Author, y	Population	Intervention and Control Description	Duration, wk[*]	Step Goal	Elements on SB	ST Measurement
Carr et al,[19] 2013	Inactive adults	Intervention: received a portable pedal machine, a motivational website, and a pedometer with feedbacks, aiming to reduce ST
Control: were asked to maintain current lives	12	Other goal	Yes	StepWatch
Andrews et al,[20] 2011[§]	Overweight/obese adults with type 2 diabetes	Intervention: received intensive diet intervention and were instructed to do brisk walking and walk more with pedometer use
Control: received intensive diet intervention or usual care	48	Not stated	No	Accelerometer
De Greef et al,[21] 2010	Adults with type 2 diabetes	Intervention: received a cognitive-behavioral program including a pedometer, instructions for increasing self-efficacy and setting goals
Control: received usual care	12	Self-set goal	Yes	Accelerometer
Baker et al,[22] 2008	Adults with insufficient activity	Intervention: received a physical activity consultation and a pedometer-based walking program
Control: were asked to maintain current lives	12	Other goal	No	IPAQ
Mutrie et al,[23] 2012	Adults with insufficient activity	Intervention: two 30-min physical activity consultations and a pedometer-based walking program
Control: were asked to maintain normal lives	12	Self-set goal	No	ActivPAL
Gilson et al,[24] 2009[‖]	Employees with different activity levels	Intervention: received pedometers and were asked to increase step counts through brisk, route-based walking, or to take incidental walking and accumulate step counts
Control: were asked to maintain normal lives	10	10,000 steps/d	Yes	Questionnaire

IPAQ = International Physical Activity Questionnaire, RCT = randomized controlled trial, SB = sedentary behavior, ST = sedentary time.
[*] Duration means the length of step counter intervention.
[†] It had 2 intervention groups: ST reduction and exercise training plus ST reduction groups.[11]
[‡] It had 2 intervention groups: pedometer only and pedometer plus website groups.[15]
[§] It had 2 control groups: usual care and intensive diet intervention groups.[20]
[‖] It had 2 intervention groups: route and incidental walking groups.[24]

Meta-Analysis of Step Counter Use and Sedentary Time

Fifteen studies involving a total of 3262 adults were pooled in this meta-analysis. Step counter use was associated with a small but significant overall reduction in sedentary time ($d = -0.20$, 95% CI -0.33 to -0.07; Figure 2), where the effect size was equaled to a reduction in sedentary time of $\sim$23 min/d compared with the controls. The Cochrane Q test indicated substantial heterogeneity among study results ($P = 0.001$), with an I^2 value estimating that 62% of the variance is caused by between study differences.

Subgroup analyses showed that step counter use together with a step goal led to a significant reduction in sedentary time ($d = -0.32$, 95% CI -0.53 to -0.11), even though heterogeneity between studies remained high ($I^2 = 68\%$, $P = 0.001$); whereas without, there was only a trend toward reduced sedentary time ($d = -0.09$, 95% CI -0.21 to 0.04; $I^2 = 38.7\%$, P for heterogeneity 0.18) (Table 2). The overall effect sizes did not differ significantly ($P = 0.42$) between step counter use with ($d = -0.29$, 95% CI -0.54 to -0.04) or without ($d = -0.17$, 95% CI -0.33 to -0.01) interventions aiming to promote sedentary behavior changes (Table 2). Notably, studies using objective methods for sedentary time measurement showed a greater reduction in sedentary time compared with those using subjective methods ($d = -0.52$, 95% CI -0.88 to -0.15 vs $d = -0.09$, 95% CI -0.19 to 0.11, $P = 0.03$ for between-group comparison), whereas heterogeneity of the latter subgroup was low ($I^2 = 24.5\%$, $P = 0.23$).

The random-effects meta-regression analyses showed that none of the following covariates was the potential predictor of changes in sedentary time: baseline age (β coefficient, -0.055, $P = 0.93$), baseline BMI (-0.039, $P = 0.33$), sex (-0.15, $P = 0.66$), length of intervention (0.009, $P = 0.26$), baseline

sedentary time (-0.00003, $P = 0.91$), baseline walking steps (0.00004, $P = 0.79$), and changes in walking steps (-0.0001, $P = 0.69$). Besides, neither the baseline values nor change scores of light, moderate, vigorous, moderate to vigorous, or total physical activity were found to be associated with changes in sedentary time (Table 3). When studies were individually removed, the overall effect sizes remained largely unchanged. Statistical evidence of publication bias was found among these studies (Begg test, $P = 0.001$; Egger test, $P = 0.01$). However, the application of the trim and fill method did not identify any missing study (Figure, Supplemental Digital Content 5, http://links.lww.com/MD/A390, which shows the graph of the filled funnel plot) or change the overall effect size ($d = -0.20$, 95% CI -0.33 to -0.07).

DISCUSSION

This meta-analysis shows that among adults, step counter use was associated with a small but significant overall effect in reducing sedentary time compared with controls. It further shows that step goal setting was a key predictor of reduced sedentary time, whereas having interventions aiming to promote sedentary behavior changes seemed to be not. Furthermore, this study also shows that using objective methods (eg, accelerometers) for sedentary time measurement obtained a greater reduction in sedentary time compared with using subjective methods (eg, questionnaires), indicating that objective methods might have a higher sensitivity or accuracy than subjective methods in determining sedentary time.

Step counters are commonly used in walking programmes, and our results are partly in agreement with the findings from Prince et al,[35] who showed that physical activity interventions

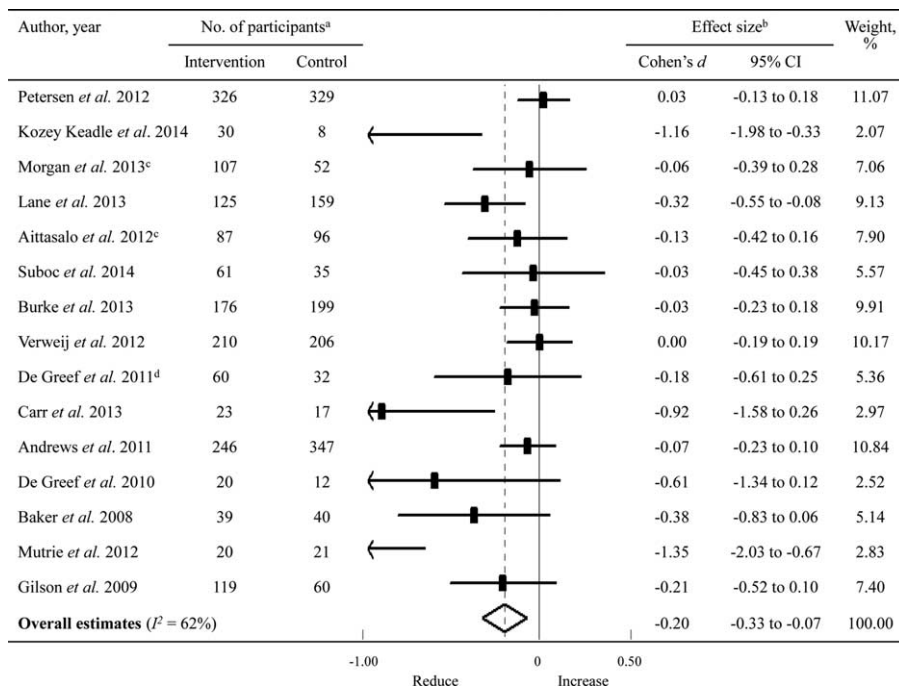| Author, year	No. of participants[a]			Effect size[b]		Weight, %
	Intervention	Control		Cohen's d	95% CI	
Petersen et al. 2012	326	329		0.03	-0.13 to 0.18	11.07
Kozey Keadle et al. 2014	30	8		-1.16	-1.98 to -0.33	2.07
Morgan et al. 2013[c]	107	52		-0.06	-0.39 to 0.28	7.06
Lane et al. 2013	125	159		-0.32	-0.55 to -0.08	9.13
Aittasalo et al. 2012[c]	87	96		-0.13	-0.42 to 0.16	7.90
Suboc et al. 2014	61	35		-0.03	-0.45 to 0.38	5.57
Burke et al. 2013	176	199		-0.03	-0.23 to 0.18	9.91
Verweij et al. 2012	210	206		0.00	-0.19 to 0.19	10.17
De Greef et al. 2011[d]	60	32		-0.18	-0.61 to 0.25	5.36
Carr et al. 2013	23	17		-0.92	-1.58 to 0.26	2.97
Andrews et al. 2011	246	347		-0.07	-0.23 to 0.10	10.84
De Greef et al. 2010	20	12		-0.61	-1.34 to 0.12	2.52
Baker et al. 2008	39	40		-0.38	-0.83 to 0.06	5.14
Mutrie et al. 2012	20	21		-1.35	-2.03 to -0.67	2.83
Gilson et al. 2009	119	60		-0.21	-0.52 to 0.10	7.40
Overall estimates ($I^2 = 62\%$)				-0.20	-0.33 to -0.07	100.00

FIGURE 2. Forest plot examining the association between step counter use and sedentary time among adults. (A) The sample size represented the number of participants included in the per-protocol or intention-to-treat analyses. (B) Effect size was calculated using a random-effects model. (C) Data of sedentary time were imputed using the combined mean values of sedentary time on work and nonwork days. (D) Accelerometer-measured sedentary time was used in this meta-analysis. CI = confidence interval.

TABLE 2. Subgroup Analyses

Subgroups	No. of Studies (No. of Subjects)	Effect Size[*]		Heterogeneity	
		Cohen d	95% CIs	I^2 (%)	P
Step goal use					
With	11 (1594)	−0.32	−0.53 to −0.11	68	0.001
10,000 steps/d	3 (367)	−0.16	−0.37 to 0.06	<1	0.15
Alternative goals	8 (1227)	−0.43	−0.73 to −0.13	76	<0.01
Without	4 (1668)	−0.09	−0.21 to 0.04	38.7	0.18
Components on SB					
With	7 (956)	−0.29	−0.54 to −0.04	61	0.02
Without	8 (2306)	−0.17	−0.33 to −0.01	66.8	0.004
ST measurement					
Questionnaires	8 (2330)	−0.09	−0.19 to 0.11	24.5	0.23
Instruments[†]	7 (932)	−0.52	−0.88 to −0.15	76	<0.01

CI = confidence interval, SB = sedentary behavior, ST = sedentary time.
[*] Effect size was calculated using a random-effects model.
[†] Accelerometer-measured sedentary time from the study by De Greef et al[18] (2011) was used in this meta-analysis.

were associated with a significant but small reduction in sedentary time among adults. However, the authors failed to specify the applied physical activity interventions. Among the characteristics of step counter interventions, having a step goal was found to be essential in reducing sedentary time, whereas the respective benefits of using different step goals in reducing sedentary time remain unclear. Interestingly, on the one hand, in studies where step counter users had a 10,000 steps/d goal, there was only an overall trend toward reduced sedentary time, which could also be seen in the individual studies. On the other hand, setting an alternative personalized step goal yielded significantly reduced sedentary time among step counter users, although the step goals varied substantially from each other.

Therefore, to specify the goal use among step counter users is required in future studies.

It has been well documented that interventions with focus on reducing sedentary behaviors are associated with clinically meaningful reductions in sedentary time.[35] This is reasonably in accordance with our findings that step counter use with interventions aiming to promote changes in sedentary behaviors was correlated with reduced sedentary time. However, it is worth noting that this recommendation might be unnecessary because a comparable reduction in sedentary time was observed in step counter users regardless of having such interventions or not. Yet it should be acknowledged that conclusions from indirect comparisons (subgroup analyses) are less reliable compared

TABLE 3. Univariate Weighted Random-Effects Meta-Regression Models

Covariates	No. of Studies	Coefficients	95% CIs	P
Baseline age[*]	14	−0.055	−1.42 to 1.31	0.93
Baseline BMI	10	−0.039	−0.13 to 0.049	0.33
Sex (proportion of females)	15	−0.15	−0.86 to 0.57	0.66
Length of intervention	15	0.009	−0.0073 to 0.025	0.26
Baseline sedentary time	14	−0.00003	−0.0006 to 0.0005	0.91
Baseline walking steps	8	0.00004	−0.0003 to 0.0004	0.79
Changes in walking steps	8	−0.0001	−0.0007 to 0.0005	0.69
Baseline light physical activity	4	0.003	−0.032 to 0.039	0.72
Changes in light physical activity	4	−0.008	−0.077 to 0.061	0.66
Baseline moderate physical activity	4	0.007	−0.042 to 0.055	0.61
Changes in moderate physical activity	4	0.007	−0.11 to 0.13	0.83
Baseline vigorous physical activity	4	0.03	−0.12 to 0.17	0.52
Changes in vigorous physical activity	4	0.03	−1.06 to 1.12	0.92
Baseline MVPA	7	0.003	−0.019 to 0.026	0.73
Changes in MVPA	7	−0.02	−0.079 to 0.029	0.29
Baseline total physical activity	6	−0.001	−0.0049 to 0.003	0.54
Changes in total physical activity	6	−0.01	−0.043 to 0.024	0.46

BMI = body mass index, CI = confidence interval, MVPA = moderate-to-vigorous physical activity.
[*] Age data were logarithmic transformed.

with those from head-to-head trials. Future studies using randomized controlled designs are worth being conducted to assess whether the supplementation of components on reducing sedentary behaviors to step counter use would give any additional benefits on sedentary time reduction.

The method of sedentary time measurement makes a substantial difference in the observed effect sizes in reducing sedentary time among step counter users, which may in part reflect a greater sensitivity or accuracy of objective methods in assessing sedentary time compared with subjective methods. However, it cannot be completely ruled out that this discrepancy might be also due to the potential differences of the step counter interventions (clinical heterogeneity). Subjective measurement using questionnaires such as IPAQ have been validated in epidemiological studies,[36] but uncertainty remains regarding their relation to the objective measurement using devices such as accelerometers.[37–39] Despite a moderate correlation observed between these 2 methods in measuring sedentary time, it is noted that the sedentary time is still largely underestimated using subjective versus objective methods.[38] Besides, it should be noted that any of the objective methods that were used in the included studies of this meta-analysis cannot detect specific domains of sedentary time, such as the time spent using computers, watching TV, or sitting at work. Therefore, as also suggested by Healy et al,[40] future studies would benefit from the incorporation of both methods, not only for measuring the total sedentary time, but also for capturing the domain-specific sedentary time and for exploring the patterns of sedentary time accumulation.

In recent years, there is an ongoing controversy with regard to the association between physical activity and sedentary time. The systematic review from Mansoubi et al suggested that the time from sedentary behaviors and light physical activity would be reallocated from one to another,[27] which is sometimes also referred to "displacement hypothesis." However, Pearson et al[41] pointed it out in a more conservative way that, although sedentary behaviors are inversely associated with physical activity, their relationship is so weak that the reallocation of time from sedentary behaviors to physical activity should not be considered in a simplified or direct manner. Besides, a cross-sectional survey has shown that the patterns in physical activity and sedentary behaviors may be mutually exclusive, indicating that there might be no real correlation between the time spent being physically active or sedentary.[8] Partly in line with these, our meta-regression analyses also do not show any clear or strong evidence regarding the association between changes in sedentary time and any forms of physical activity.

The current findings from our study provide evidence in support of the widespread recommendation and adoption of step counter use in health promotion programmes.[42] Moreover, our study gives a potential explanation for the observed health benefits resulting from step counter use including weight loss[26,43] because epidemiological evidence suggests that decreased sedentary time is associated with reduced BMI,[44] in which reduction is assumed to be independent of increased physical activity.[43] In addition, there is emerging evidence that frequent interruptions from sedentary time are associated with an improved metabolic profile including reduced waist circumference and BMI.[45] It seems likely that weight loss resulted from step counter use could be also related to the breaks in sedentary time, at least partly. However, to date, very few studies with very small sample sizes have focused on this topic and showed only some trends.[9,11] More RCTs with larger

sample sizes are therefore required to address this concern in future.

The main strengths of this meta-analysis include an extensive literature search, a reasonably large sample size, and comprehensive summaries of the effects of step counter use on sedentary time, along with the exploration of heterogeneity using a broad range of study and intervention characteristics as covariates. However, when interpreting these results, several limitations must be considered. First, the search strategy used in this meta-analysis was restricted to English-language studies, which might lead to a language or cultural bias. Moreover, a publication bias was detected using either Begg test or Egger test, increasing the risk of reporting bias resulting from possible small-study effects.[31] However, the trim and fill method suggested that, the overall effect size derived from the currently included studies was unlikely to be affected by publication bias. Second, as indicated in the previous studies[25,26] because step counter interventions generally included some other components (eg, step goals, promotions of sedentary behavior changes), it is difficult to establish their independent contributions to the observed effect sizes. Third, there existed some evidence of heterogeneity across studies, which were just partly explained by the use of step goals and the methods used for sedentary time measurement (subgroup analyses). This would somehow weaken the robustness of our main findings. Moreover, meta-regression analyses might have limited power to detect significant predictors that moderate the sedentary time changes related to pedometer intervention or explain the potential sources of heterogeneity.[31] Fourth, the high dropout rates and the attrition bias reported in this meta-analysis might downgrade the evidence level. Fifth, although this meta-analysis shows that step counter use was associated with an overall reduction in sedentary time of ~23 min/d, it remains unknown whether changes of this magnitude are sufficient to benefit healthy outcomes. Finally, this meta-analysis fails to show evidence regarding the effects of step counter use in workplace settings in reducing sedentary time among adults because several included studies did not clearly state whether the step counters were used for workplace interventions.[15,18,22]

In summary, this study provided evidence that step counter use leads to reduced sedentary time in adults, and the step goal setting is an important predictor of reduced sedentary time. Future studies are required to specify the goal use among step counter users to employ objective and subjective methods for measuring both total and domain-specific sedentary time, to address the magnitude of reductions in sedentary time sufficient to benefit healthy outcomes, and to investigate the effects of step counter use on breaking up the prolonged sedentary time to gain additional health benefits.

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