Interventions with potential to reduce sedentary time in adults

Title: Interventions with potential to reduce sedentary time in adults – systematic review and meta-analysis

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ABSTRACT

Context: Time spent in sedentary behaviours (SB) is associated with poor health, irrespective of the level of physical activity. The aim of this study was to evaluate the effect of interventions which included SB as an outcome measure in adults.

Methods: Thirteen databases, including The Cochrane Library, MEDLINE, and SPORTDiscus, trial registers and reference lists, were searched for randomised controlled trials until January 2014. Study selection, data extraction and quality assessment were performed independently. Primary outcomes included SB, proxy measures of SB and patterns of accumulation of SB. Secondary outcomes were cardio-metabolic, mental health and body composition. Intervention types were categorised as SB only, physical activity (PA) only, PA and SB or lifestyle (PA/SB and diet).

Results: Of 8087 records, 51 studies met the inclusion criteria. Meta-analysis of 34/51 studies showed a reduction of 22 min/day in sedentary time in favour of the intervention group (95%CI -35 to -9 min/day, n=5,868). Lifestyle interventions reduced SB by 24 min/day (95%CI -41 to -8 min/day, n=3,981, moderate quality) and interventions focusing on SB only by 42 min/day (95%CI -79 to -5 min/day, n=62, low quality). There was no evidence of an effect of PA and combined PA/SB interventions for reducing sedentary time.

Conclusions: There was evidence that it is possible to intervene to reduce SB in adults. Lifestyle and SB only interventions may be promising approaches. More high quality research is needed to determine if SB interventions are sufficient to produce clinically meaningful and sustainable reductions in sedentary time.

What are the new findings?

- Interventions targeting sedentary behaviour and lifestyle interventions can reduce sedentary time in adults.

- Interventions targeting an increase in physical activity and interventions combining an increase of physical activity with reducing sedentary behaviour did not reduce sedentary time in adults.

- We do not yet know if effective interventions for reducing sedentary behaviour result in clinically meaningful and sustained improvements in health outcomes.

How might it impact on clinical practice in the near future?

- Awareness will be raised on the topic of sedentary behaviour and its impact on health

- Further research will be conducted that will help determine the clinical significance of changing patterns of sedentary behaviour

- Interventions that target sedentary behaviour will be developed and tested

INTRODUCTION

There is growing public health concern about the amount of time spent in sedentary behaviours (SB). SB are defined as behaviours where sitting or lying is the dominant posture and energy expenditure is very low[1]. Sedentary time accumulates daily while commuting, at work, at home and during leisure time[2]. Too much time spent in SB is associated with poor health, including elevated cardio-metabolic risk markers, type 2 diabetes and premature mortality[3-9], independent of time spent in moderate-to-vigorous physical activity (PA)[4]. Independent of total sedentary and moderate-to-vigorous activity time, increased breaks in sedentary time have been shown to be beneficially associated with waist circumference, BMI, triglycerides and 2-hour plasma glucose[10]. Interventions interrupting extended sitting with frequent short activity breaks have enhanced markers of cardio-metabolic health[11-13].

Recent systematic reviews have summarised the literature in respect to health implications [14 15-18], measurement [19], prevalence [20], correlates [21] and interventions in young people[22]. To date only one review of the evidence on interventions to influence total SB in adults has been conducted[23]. The review concluded that interventions with a specific goal of increasing PA levels and those which combined an increase in PA levels with a decrease in sedentary time resulted in modest reductions in SB, while interventions focusing on SB only resulted in greater reduction of sedentary time. The present systematic review expands this existing evidence[23] in five ways; i) evaluating lifestyle interventions (i.e. inclusion of more than one lifestyle behaviour such as physical activity and diet); ii) conducting subgroup analyses; iii) assessing effects on pattern of SB accumulation; iv) including only randomised controlled trials (RCTs); and v) assessing effects on health outcomes.

The primary aim of this review was to evaluate the effect of interventions which included a SB outcome measure in adults. The secondary aim was to determine the effects of interventions, which included a SB outcome, on measures of health.

METHODS

The protocol for this review is available online at the *International Prospective Register for Systematic Reviews*[24].

Study Selection Criteria

Studies were eligible for inclusion if they met the following criteria:

Study design: RCTs

Population: Adults aged 18 years or more who have left school.

Intervention: Any intervention which included a SB outcome measure in free-living adults was included; those in clinical settings such as hospitals were excluded. Eligible comparison conditions were no intervention, waiting list, attention control (e.g., general health information), usual care (e.g., diabetes treatment involving lifestyle counselling) and alternative treatment conditions (e.g., a structured exercise programme).

Outcomes: Studies reporting any of the following outcomes were included:

- Objectively measured SB obtained from accelerometers
- Objectively measured sitting time obtained from inclinometers
- Objectively or self-reported patterns of accumulation of SB
- Self-reported total sitting time
- Self-reported proxy-measures of SB (eg. screen time, occupational sitting time and transport time)

Other inclusion criteria: Only full text articles published in English language were included in this review.

Data sources and Searches

In January 2014, the Cochrane Central Register of Controlled Trials (Issue 12 of 12 December 2013), MEDLINE (1946-November week 3 2013), EMBASE (1980-week 1 2014), PsycINFO (1806-November week 5 2013), SPORTDiscus (1975-7 January 2014), CINAHL (1937-7 January 2013), Cochrane Database of Systematic Reviews (Issue 1 of 12 January 2014), Database of Health Promotion Research (Biblomap, Issue 4 of 4, October 2013), Database on Obesity and SB Studies (16 January 2014), Conference Proceedings Citation Indexes (Web of Science, 1900 to current), controlled-trials.com (16 January 2014), WHO International Clinical Trial Registry (16 January 2014), and the Networked Digital Library of Theses and Dissertations (1900-current) were searched. The search strategy for MEDLINE is listed in Supplement 1. Reference lists and citations of relevant studies were examined and experts in the field contacted for details of ongoing and unpublished studies.

Study Selection

At least two reviewers independently screened the titles/abstracts (AM, RJ) and full text articles (AM and RJ, CF, or DHS). Eligibility disagreements were resolved by a third reviewer (NM).

Data extraction and Quality assessment

Duplicate data extraction was performed independently for 10% of the included studies (AM and RJ, CF, or DHS) and discrepancies resolved through discussion. The following secondary outcomes for this review were recorded from included studies:

- Biomarkers of cardio-metabolic risk (e.g. blood glucose levels, blood lipid levels)
- Mental health (e.g. depression, anxiety, stress)
- Objectively obtained body composition (e.g. body mass index).

The full list of extracted data items can be obtained from the study protocol[24].

Quality of all studies was assessed by two reviewers (AM, DHS) using the Tool for Assessing Risk of Bias from the Cochrane Collaboration[25]. Risk of bias was scored as 'high', 'unclear' or 'low' for the following domains: a) participant selection bias, b) intervention performance bias, c) effect detection bias, d) outcome reporting bias, e) attrition bias, and f) bias due to comparability of baseline groups.

Publication bias was examined using a funnel plot whenever meta-analyses included 10 or more studies[25].

Quality of evidence for primary outcomes was assessed using the GRADEpro software developed by the Grading of Recommendations Assessment Development and Evaluation (GRADE) Working Group[26]. An overall quality score is based on the assessment of risk of bias, indirectness, imprecision, inconsistency, and publication bias of primary outcomes. The GRADE Working Group grades of evidence are high, moderate, low, and very low quality.

Data synthesis and analysis

Studies reporting similar outcome measures were combined in meta-analyses using random effects models to account for intervention heterogeneity. Where suitable data were not reported efforts were made to obtain the data from study authors. To account for variability between studies inverse variance was used giving more weight for studies with less variability. Effect sizes were estimated as mean differences (minutes/day) between intervention and control group. Review Manager 5.2 was used for quantitative analysis[27].

For cluster RCTs where control of clustering was missing, intervention effects were approximately corrected by reducing the sample size of each trial to its 'effective sample size'. The sample size was divided by the design effect which is [1+(M-1)*ICC], where M is the average of cluster size and ICC is the intracluster correlation coefficient[25]. An ICC of 0.01 was used.

Where suitable data were available studies were combined in a meta-analysis regardless of whether missing data were imputed by authors. Variation in the degree of missing data was considered as a potential source of heterogeneity of results. A sensitivity analysis to examine the effect of inclusion of complete cases on robustness of intervention effects was performed.
Further heterogeneity of findings was assessed by comparing similarity of included studies in terms of study design, participants, interventions, outcomes, and study quality. The cause of heterogeneity was evaluated by conducting subgroup and sensitivity analyses. Statistical heterogeneity was assessed by calculating the I^2 statistic indicating the variability of the intervention effect due to heterogeneity. Variability of more than 50% may indicate moderate to substantial heterogeneity of intervention effects according to the Cochrane Handbook[25].

Subgroup analyses within this review focused on:

- Intervention type (SB, PA, or lifestyle which, in addition to physical activity/sedentary behavior, also included a dietary/nutrition component)
- Gender (men, women, men/women)
- Intervention duration (≤ 3 months, 3-6 months, > 6 months)
- Follow-up duration (<3 months, 3-6 months, 7-12 months, >12 months)
- Intervention setting (work place versus home/community)
- Outcome measurement tool (objective measurement tool, sitting time self-report, proxy measurement tool)
- Study aim (SB as primary versus secondary study aim)

Sensitivity analyses were used to test the effect of including studies which were cluster designs, used usual care or alternative treatment comparison groups, or were at 'high risk' of performance and attrition bias.

Included studies lacking data suitable for meta-analysis are described narratively.

RESULTS

Results of the literature search

Figure 1 displays the PRISMA diagram of the literature search. Inclusion criteria were met by 57 records which comprised 51 studies. Thirty six studies provided adequate data to be included in meta-analyses.

FIGURE 1 ABOUT HERE

Characteristics of included studies

Study and participant characteristics are summarised in Table 1 of the supplemental material. Of the 51 included studies (18,480 participants), 44 studies were RCTs[28-70] and seven studies were cluster RCTs[71-77] conducted in Europe (n=25), USA (n=18), Australia (n=7), and China (n=1). The majority of studies were carried out in a mixed gender population (n = 35); 13 studies targeted women only[29 42 50 51 56 57 60 61 67 69 71 76] and three studies targeted men only[29 31 44]. Most studies included participants aged between 18-60 years (n=44), while seven studies included participants older than 60 years of age[33 35 37 38 48 62 72]. Twenty three studies were conducted in overweight or obese adults, five studies in participants with type 2 diabetes mellitus, and three studies in participants with high levels of cardiovascular risk factors. Two studies were conducted in pregnant women.

Types of intervention and comparison conditions varied substantially between included studies (Supplement Table 1). Three studies employed an intervention specifically to reduce SB[40 44 63], 16 studies aimed at increasing PA levels[30 35 36 39 41 46 48 49 55 58-60 64 66 72 78], nine studies combined both approaches of reducing SB and increasing PA[32 43 53 62 65 68 70 76 77], one study assessed the effect of a dietary intervention on SB[61], and 22 studies (20 reports) applied a multi-component lifestyle intervention and observed effects on sedentary behavior (among other outcomes)[29 33 34 37 38 42 45 47 50-52 54 56 57 67 69 71 73-75]. Twenty studies offered an alternative intervention[30 36 39-41 45 46 49 52-55 59 61-63 68 72 77], 10 studies usual/routine care[29 37 38 42 50 51 67 71 74 75], seven studies used a waiting list control[29 34 48 64 69 76 78], five studies an attention control[35 44 56 57 60], and control participants of seven studies received no intervention at all[32 33 43 47 58 66 70 73].

Risk of bias of included studies

Figure 2 shows each risk of bias item presented as percentages across all included studies.

Selection bias. Correct randomisation was used in 65% of the studies (33/51) and therefore there was low risk of bias in these studies. However, for the remaining studies insufficient details were reported and thus assessed as 'unclear'. In nearly 70% (35/51) of the studies there was lack of reporting on whether or not participants knew in advance their group allocation and thus there was an unclear risk of bias. For studies that provided information, studies were judged to be at low risk of allocation concealment bias.

Performance bias. It is recognised that in lifestyle interventions it is not possible to blind participants and researchers delivering the intervention to group allocation and this creates high risk of bias. However, 67% (34/51) of included studies were considered at low risk of performance bias because SB was not the primary outcome. A further 31% (16/51) of included studies were judged to be at high risk of performance bias because the participants and researchers delivering the intervention were not blinded to the purpose of the intervention which was reducing SB. Risk of bias was unclear for one study[33] due to insufficient information provided.

Detection bias. Sixty-one percent of the studies (31/51) assessed SB through self-reports and thus were of high risk for detection bias. The risk of cross-contamination was 'low' in half of the studies and 'unclear' in the other half.

Attrition bias. The issue of incomplete outcome data was sufficiently addressed in 47% (24/51) of the studies and thus these studies were of low risk of attrition bias. However, 43% (22/51) of the studies did not account for missing data and thus were of high risk of attrition bias. Five studies were of 'unclear' risk of attrition bias.

Comparability of baseline groups. Over 50% (29/51) of the studies were of low risk of bias. Apparent flaws in the randomisation process were found in three studies[53 76 78] and therefore assessed at high risk of bias related to the comparability of baseline groups.

Reporting bias. For half of the studies (26/51) access to a published study protocol or trial register was missing so that the risk of selective reporting was 'unclear'. However, nearly 50% (24/51) of the studies where of low risk of selective outcome reporting. One study did not report all outcomes as stated in the study protocol and thus of high risk of selective reporting[70].

Publication bias. Lifestyle interventions were the only category of interventions where at least 10 studies were available and thus suitable for assessment of publication bias using the funnel plot (Supplement figure 1). The asymmetric distribution of effect sizes might indicate a publication bias towards studies with beneficial effects for reducing SB. However, an asymmetric funnel plot might be a study size effect.

FIGURE 2 ABOUT HERE

Effect of interventions

Primary outcomes

Primary outcomes reported were overall time spent in SB as minutes per day (n=49) or percentage of assessed time period (n=3), number of sitting breaks (n=3), and number of prolonged sitting events (n=3).

Supplement table 1 summarises the original trial authors' conclusions of study outcomes. Twenty studies indicated a beneficial effect of interventions for reducing SB in favour of the intervention group. Of these, 10 studies employed a lifestyle intervention[29 33 34 37 38 42 51 52 54 74], six studies targeted increase in PA[30 41 46 48 64 78], two studies were combined PA/SB interventions[32 68], and two studies were SB interventions[40 63]. Two studies reported a beneficial intervention effect in favour of the control group[39 60]; both studies were PA interventions. Comparison conditions were attention control[60] and an alternative exercise treatment[39]. Twenty-four studies suggested no evidence of a group difference in SB: ten lifestyle interventions [29 45 50 52 56 57 67 71 73 75], seven PA interventions[35 36 49 55 58 66 72], six PA/SB interventions[53 62 65 70 76 77], and one SB intervention[44]. Four studies - two lifestyle[47 69], one PA/SBs[43], one dietary intervention[61] - did not conclude on SB outcomes despite assessing SB.

Meta-analysis of 34 studies (5,868 participants) suggested an overall reduction in sedentary time by a mean differences (MD) of -22.34 minutes/day (95% CI -35.81 to -8.88, p=0.001, I^2=71%) in favour of the intervention group. Figure 3 shows effect sizes of individual studies and pooled results by intervention type. Findings indicated a beneficial effect of interventions specifically targeting the reduction in SB as well as interventions employing a lifestyle intervention approach on reduced SB. Specific SB interventions (n=2, 62 participants) yielded a MD of -41.76 minutes/day (95% CI -78.92 to -4.60, p=0.003, I^2=65%) and lifestyle interventions (n=20, 3,881 participants) a MD of -24.18 minutes/day (95% CI -40.66 to -7.70, p=0.004, I^2=75%). There was no evidence of a statistically significant effect of PA interventions or combined SB/PA interventions for reducing SB. Pooled intervention effects on SB patterns indicated no statistically significant effect for both number of sitting breaks per hour or number of prolonged sitting events of more than 30 minutes.

FIGURE 3 ABOUT HERE

As indicated by the large I^2 statistic, the level of statistical heterogeneity between studies was high. Subgroup analyses were conducted (defined a priori) to assess potential reasons for heterogeneity (Table 1). A significant subgroup difference between assessed groups was detected for gender and intervention duration. Studies in men-only (n=2; 434 men), but not women-only (n=10; 1,541 women), resulted in significant intervention effects for reduced SB of intervention group participants (MD -57.94 minutes/day, 95% CI -86.14 to -29.74 minutes/day, p<0.001). Combined effects of mixed gender studies (n=22; 3,393 participants) also showed benefit in favour of the intervention group (MD -25.32 minutes/day, 95% CI -42.94 to -7.69 minutes/day, p=0.005). Interventions of up to three months resulted in a significant reduction in sedentary time by a MD of -47.51 minutes/day (95% CI -76.57 to -18.46 minutes/day, p=0.001, 14 studies, 1,474 participants) in favour of the intervention group whereas longer intervention durations of more than 3 months did not show beneficial intervention effects (Table 1). Heterogeneity between studies could not be explained by follow-up duration, intervention setting, type of assessment tool and whether reducing SB was a primary or secondary aim of the study. However, subgroup analysis revealed that long-term effects of interventions were evident up to 12 months.

The beneficial intervention effects attenuated at follow-up duration of more than 12 months. All intervention settings except workplaces resulted in significant reduction in SB in favour of the intervention group. Objective assessment of SB using an inclinometer and subjective assessment using proxy measure questionnaires resulted in a detection of a beneficial intervention effect. The overall intervention effect was not influenced by whether SB was a primary or secondary outcome (Table 1).

Table 1: Intervention effects for change of sedentary behaviour by subgroups

Subgroup	Studies	Participants	Intervention effect [min/day], MD (95% CI, I^2)
Sex[a]			
Men	2	434	-57.94 (-86.14, -29.74; 0%)
Women	10	1541	-5.97 (-23.51, 11.57; 33%)
Men/Women	22	3893	-25.32 (-42.94, -7.69; 83%)
Intervention duration[b]			
≤ 3 months	14	1474	-47.51 (-76.57, -18.46; 81%)
3 - 6 months	11	2119	-15.20 (-33.08, 2.68; 67%)
> 6 months	9	2275	0.30 (-17.83, 18.44; 61%)
Follow-up duration[c]			
<3 months	17	1954	-42.17 (-67.31, -17.02; 84%)
3-6 months	13	2489	-22.29 (-41.61, -2.96; 77%)
7-12 months	11	2327	-26.60 (-45.95, -7.24; 73%)
>12 months	5	1264	-3.06 (-34.05, 27.94; 83%)
Intervention setting[c]			
Workplace	8	1790	-8.93 (-26.64, 8.78; 66%)

Other	26	4078	-28.21 (-46.34, -10.09; 80%
Assessment tool[c]			
ActivPAL	2	67	-45.37 (-87.99, -2.74; 76%)
Actigraph	4	334	-27.93 (-70.71, 14.85; 75%)
Sitting time questionnaire	12	2576	-10.92 (-30.59, 8.74; 57%)
Proxy measure questionnaire	17	2983	-29.39 (-50.56, -8.21; 84%)
Intervention aim[c]			
SB Primary outcome	14	2258	-24.05 (-45.43, -2.67; 73%)
SB Secondary outcome	22	3764	-23.17 (-40.02, -6.32; 80%)

[a] – statistically significant subgroup difference at $p<0.01$, [b] – statistically significant subgroup difference at $p<0.05$, [c] – non-significant subgroup difference

Sensitivity analyses (Supplement Tables 2-5) show that results on SB for different types of interventions were not affected by inclusion of cluster RCTs, studies of high risk of attrition and performance bias, and studies with usual care or alternative treatment as comparison group.

Secondary outcomes

Studies reported intervention effects on plasma glucose concentration[31 42 56], glycosylated haemoglobin levels[37 42 69], triglyceride levels[31 42 56 69], low density lipoprotein levels[31 42 56 69], total cholesterol[37 42 56 69], high density lipoprotein levels[31 39 42 56 64 69], blood pressure[32 38 43 57 59 65 70], body mass index (BMI), [29 33 36 37 42 55-59 62 64 69 74], waist circumference[31 42 55 56 58 59 62 64 69 74 76], percentage body fat [42 55 56 58 62 64], and mental health outcomes[29 41 48 49 64 72]. All studies applied a PA-only or lifestyle intervention and less than half of the studies showed a reduction in SB. Therefore it is not possible to determine the intervention effect of reduced sedentary behaviour on cardio-metabolic risk, body composition and metal health outcome. Meta-analysis results for each outcome are not reported here but results are available from the authors.

Quality of evidence

Table 2 summarises the quality of evidence for reducing sedentary time by intervention type and duration. Due to the intention of comparing different types of intervention with various comparison conditions, which was considered in the sensitivity analyses, the quality of evidence

was not downgraded for indirectness or heterogeneity. Many plausible reasons for heterogeneity exist (e.g., variation in population age, ethnicity, socio-economic status).

Lifestyle interventions. The overall quality of evidence for lifestyle interventions was moderate with downgrading the evidence by one level due to limitations in the design and implementation of included studies.

PA/SB interventions. The overall quality of evidence of combined PA and SB interventions for reducing SB was moderate. The quality was downgraded by one level for high risk of bias in the majority of included studies.

PA interventions. Overall, the quality of PA intervention was moderate with the majority of studies having a high risk of detection and attrition bias.

SB interventions. The quality of evidence for reducing SB in adults was low based on the two studies available. The quality was downgraded twice for imprecision of results and high risk of performance bias. Participants and personnel were not blinded to the intervention intention.

385 **Table 2: GRADE assessment of quality of evidence**

Interventions for reducing sedentary behaviour

Outcomes	Illustrative comparative risks* (95% CI) Corresponding risk **Interventions for reducing sedentary behaviour**	No of Participants (studies)	Quality of the evidence (GRADE)
Effect of lifestyle interventions	The mean effect of lifestyle interventions in the intervention groups was **24.18 minutes/day lower** (40.66 to 7.70 lower)	3981 (20 studies)	⊕⊕⊕⊖ **moderate**[1]
Intervention duration ≤3 months	The mean effect of lifestyle interventions - intervention duration ≤ 3 months in the intervention groups was **97.75 minutes/day lower** (121.88 to 73.61 lower)	297 (5 studies)	⊕⊕⊕⊕ **high**
Intervention duration 3-6 months	The mean effect of lifestyle interventions - intervention duration 3-6 months in the intervention groups was **8.42 minutes/day lower** (19.05 lower to 2.21 higher)	1664 (7 studies)	⊕⊕⊕⊖ **moderate**[2]
Intervention duration > 6 months	The mean effect of lifestyle interventions - intervention duration > 6 months in the intervention groups was **3.99 minutes/day lower** (21.93 lower to 13.96 higher)	2040 (8 studies)	⊕⊕⊕⊖ **moderate**[1]
Effect of physical activity/sedentary behaviour interventions	The mean effect of physical activity/sedentary behaviour interventions in the intervention groups was **32.51 minutes/day lower** (106.52 lower to 41.50 higher)	471 (4 studies)	⊕⊕⊕⊖ **moderate**[1]
Intervention duration ≤3 months	The mean effect of physical activity/sedentary behaviour interventions - intervention duration ≤ 3 months in the intervention groups was **54.69 minutes/day lower** (166.60 lower to 57.22 higher)	214 (3 studies)	⊕⊖⊖⊖ **very low**[3,4]
Intervention duration 3-6 months	The mean effect of physical activity/sedentary behaviour interventions - intervention duration 3-6 months in the intervention groups was **23.60 minutes/day higher** (0.78 higher to 46.42 higher)	257 (1 study)	⊕⊕⊕⊖ **moderate**[5]
Intervention duration > 6 months	**No evidence available**	0 (0)	No evidence available
Effect of physical activity interventions	The mean effect of physical activity interventions in the intervention groups was **6.08 minutes/day lower** (38.00 lower to 25.84 higher)	1354 (8 studies)	⊕⊕⊕⊖ **moderate**[6]
Intervention duration ≤3 months	The mean effect of physical activity interventions - intervention duration ≤ 3 months in the intervention groups was **10.43 minutes/day lower** (49.85 lower to 28.98 higher)	935 (5 studies)	⊕⊕⊕⊖ **moderate**[6]
Intervention duration 3-6 months	The mean effect of physical activity interventions - intervention duration 3-6 months in the intervention groups was **21.52 minutes/day lower** (103.55 lower to 60.51 higher)	184 (2 studies)	⊕⊕⊕⊖ **moderate**[6]
Intervention duration > 6 months	The mean effect of physical activity interventions - intervention duration > 6 months in the intervention groups was	235 (1 study)	⊕⊕⊕⊖ **moderate**[7]

	48.60 minutes/day higher (1.66 to 95.54 higher)		
Effect of sedentary behaviour interventions	The mean effect of sedentary behaviour interventions in the intervention groups was **41.76 minutes/day lower** (78.92 to 4.60 lower)	62 (2 studies)	⊕⊕⊖⊖ **low**[3,8]
Intervention duration ≤3 months	The mean effect of sedentary behaviour interventions - intervention duration ≤ 3 months in the intervention groups was **41.76 minutes/day lower** (78.92 to 4.60 lower)	62 (2 studies)	⊕⊕⊖⊖ **low**[3,8]
Intervention duration 3-6 months	**No evidence available**	0 (0)	No evidence available
Intervention duration > 6 months	**No evidence available**	0 (0)	No evidence available

*The basis for the **assumed risk** (e.g. the median control group risk across studies) is provided in footnotes. The **corresponding risk** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI). **CI:** Confidence interval;

GRADE Working Group grades of evidence
High quality: Further research is very unlikely to change our confidence in the estimate of effect.
Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.
Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.
Very low quality: We are very uncertain about the estimate.

[1] The majority of studies were of high risk of selection, performance or detection bias.
[2] Half of the studies were of high risk for performance bias (no blinding of participants or personnel to the intervention intention).
[3] The wide confidence interval indicates imprecision of results.
[4] All studies were of high risk of performance bias and more than half showed high risk of attrition.
[5] The study was of high risk of selection bias.
[6] Studies were of high risk of detection or attrition bias.
[7] The study was of high risk of detection bias.
[8] The studies were of high risk of high risk of performance bias, i.e. participants and personnel were not blinded.

DISCUSSION

Summary of main findings

There was clear evidence that it is possible to intervene to reduce SB in adults by 22 minutes/day in favour of the intervention group. Moderate to high quality evidence on the efficacy of lifestyle interventions for reducing SB suggests this may be a promising approach. Interventions focusing on SB only resulted in greatest reduction in sedentary time (42 minutes/day); however the quality of evidence was low and restricted to two studies only. Findings suggested that intervention durations up to three months and interventions targeting men and mixed genders can produce significant reductions in SB. There was no evidence that PA and combined PA/SB interventions reduced SB. Evidence of intervention effects on changes in patterns of accumulation of SB was limited. Encouragingly, intervention effects were evident up to 12 months. Interventions in any setting except the workplace resulted in significant reduction in SB in favour of the intervention group.

This systematic review sought to evaluate the evidence of effects of interventions which included SB as outcome measure on cardio-metabolic risk factors, body composition and mental health outcomes. Studies reporting these outcomes were PA or lifestyle interventions and thus it was unclear whether any intervention effect was due to reduction in SB. Furthermore, the majority of studies that assessed health-related outcomes did not show a reduction in SB. However, improvement of health-outcomes due to reduction of SB have been demonstrated in laboratory based studies[79] and a recently published community-based RCT [80].

Comparison of the findings with the literature

Prince et al[23] published a systematic review on the effects of interventions for reducing SB in adults. Our findings are consistent with Prince et al in relation to the effect of PA/SB interventions and interventions focusing on SB only despite no overlap of included studies in the latter. The SB studies on which Prince et al based their main conclusion were excluded from this review because the studies either did not report a valid SB outcome measure[81] or the intervention was not independent of the outcome (measuring TV viewing time while blocking TV function)[82]. In contrast to Prince et al., we found no evidence of a beneficial effect on SB from interventions focused on increasing PA. This difference in findings may be explained by six studies in our

review being classed as lifestyle interventions while Prince et al. classed them as PA interventions and one study being classed as PA/SB intervention while Prince et al classed it as PA intervention.

Other systematic reviews have been conducted with a focus on the effect of workplace interventions for reducing sitting time[83-85]. Some findings are consistent[83] with the findings of this study on the effect of workplace interventions to reduce SB while others were not[84 85]. Inconsistency can be explained by differences in inclusion criteria, since the majority of studies included in these reviews did not qualify for our review.

Implications for research and practice

Findings from lifestyle interventions and studies focusing on reducing SB are promising. Whilst this is encouraging, SB is a health-related behaviour and part of a pathway to better health outcomes. More high quality research is needed that includes clinical health outcome measures.

The majority of studies included in the meta-analyses assessed intervention effects using self-report. While self-report measures are pragmatic and may provide contextual information, they have limitations in terms of accuracy. Subgroup analysis revealed that objective assessment of SB using the *activ*PAL™ (which objectively measures posture) and subjective assessment using proxy measure questionnaires (captures context specific sitting time) resulted in a detection of a beneficial intervention effect. Researchers and practitioners should use measurement tools with demonstrated reliability and validity.

Heterogeneity between studies was only partly explained by differences of studies in gender and intervention duration. Further work is warranted to identify the 'active ingredients' of the successful interventions and to explore the specific behaviour change techniques employed. Additionally, future studies should consider the influence of gender. Limited evidence was available on intervention effects on the pattern of accumulation of sedentary time in older adults.

Strengths and Limitations

The systematic and transparent methods reported here reduce identification and selection bias. The inclusion criteria used for study designs (only RCTs) meant that the risk of bias was reduced. Overall, the robust methods used in this review ensure that the results and conclusions are likely to be as truly valid and replicable as possible. Subgroup and sensitivity analyses enabled a more

nuanced understanding and interpretation of the results, as well as exploring the effect of potentially influential variables. Lastly, our exploration of the clinical outcomes was a strength, and led to the identification of research gaps which should be addressed in future RCTs .

One limitation was that no subgroup analysis for age was undertaken because there were too few studies in older adults.

Conclusion

There was evidence that it is possible to intervene to reduce SB in adults by around 22 minutes/day. Lifestyle interventions and those targeting SB only may be promising approaches, but more high quality research is needed. More research is also needed to determine if SB interventions are sufficient to produce clinically meaningful and sustainable reductions in sedentary time. Further work is needed to identify the 'active' intervention components.

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Competing interests

The authors declare no competing interests.

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Supplement material

Search strategy for Ovid Medline

Table 1: Characteristics and authors' conclusions of intervention effect of included studies

Figure 1: Funnel plot of studies included in meta-analyses by study type.

Table 2: Sensitivity analysis for studies of 'high' risk of performance bias

Table 3: Sensitivity analysis for studies of 'high' risk of attrition bias

Table 4: Sensitivity analysis for cluster RCTs

Table 5: Sensitivity analysis for studies with usual care and alternative treatment as control condition

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FIGURE TITLES

Figure 1: PRISMA diagram of the literature search results

Figure 2: Risk of bias item presented as percentages across all studies

Figure 3: Forest plot of the intervention effect for reducing sitting time in minutes/day in adults by type of intervention. PA: physical activity, SB: sedentary behaviour