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Effectiveness of interventions for reducing non-occupational sedentary behaviour in adults and older adults: A systematic review and meta-analysis

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Abstract

Background: No systematic reviews of effectiveness of interventions for reducing non-occupational sedentary behavior is available. Therefore, the aim of this systematic review was to assess the effectiveness of interventions for reducing non-occupational sedentary behavior in adults and older adults.

Methods: An electronic search through nine databases was performed. Randomized controlled trial (RCT) and cluster RCT among adults testing effectiveness of interventions aimed to reduce non-occupational sedentary behaviour were considered for inclusion. Two review authors independently screened studies for eligibility and completed data extraction and risk of bias assessment.

Results: We included 19 studies that evaluated multicomponent lifestyle intervention, counselling or education, TV control devices and workplace interventions, which included sedentary behavior measures during leisure time. Evidence from the meta-analyses suggests that interventions can reduce leisure sitting time in adults in the medium-term (-29 min/day; 95% confidence interval [CI]: -55, -2.3) and TV viewing in the short (-25 min/day; 95% CI: -37, -13) and medium term (-11 min/day; 95% CI: -20, -2). No significant pooled effects were found for transport sitting time, leisure-time computer use and long-term outcomes. We found no evidence for effectiveness of interventions for reducing non-occupational sedentary time in older adults.

Conclusions: The findings of this systematic review suggest the interventions may be effective in reducing non-occupational sedentary behavior in the short-to-medium term in adults. However, no significant effect was found on long-term outcomes. The quality of evidence was however, very low to low. No evidence was available on the effectiveness of non-occupational interventions on reducing sedentary time in older adults. Further high-quality research with larger sample is warranted.

Keywords: TV viewing, leisure sitting, sitting, computer use, transport sitting

1. Introduction

Data based on self-reports from 28 European Union countries show that during a typical day, 18.5% of adults spend more than 7.5 hours sitting.[1] Moreover, time-use surveys show a significant decline in physical activity and increase in sedentary behavior globally. [2] As noted in a recent systematic review, older adults are even more sedentary than adults, as on average, they spend 9.4 hours per day in sedentary behaviour.[3] Studies have shown that sedentary behavior may be associated with increased risk of all-cause mortality, cardiovascular disease, type 2 diabetes, and site-specific cancer.[4] Furthermore, global estimates suggest that high levels of sedentary behavior and insufficient physical activity cause 3.8% and 9% of all deaths, respectively. [5] [6]

When outside of the workplace, people are exposed to many opportunities to engage in sedentary activities. The time spent in front of the computer or television screen and using devices like tablets, smartphones and gaming consoles has great potential to increase leisure-time sedentary behavior.[7] The self-reported data from USA Labor[8] shows that TV viewing was the most prevalent leisure activity (i.e., 2.8 hours per day) among US adults in 2015, accounting for more than half of all leisure-time activities.[8] Older adults also seem to spend a large proportion of their waking hours watching TV (i.e., 3.3 hours per day).[3] Additionally, at the population level, a significant amount of time is spent sitting in transport.[9] In a study among desk-based employees in Australia, self-reported transport related sitting time equated to 60 minutes per day which was approximately 11% of the total daily sitting time.[10] The use of sedentary forms of commuting has largely increased due to increased car ownership over the last several decades in high-income countries[11]

[12] and recent research indicates a significant association between greater use of cars and obesity.[13]

Interventions for reducing non-occupational sedentary behavior can be implemented at the individual, environmental, and wider community level. At the individual level, people can be made aware of the need to reduce their time spent in sedentary pursuits by: (i) counseling or interviewing,[14] (ii) self-monitoring, alongside goal setting to review their own behavior[15], and personalized feedback[16] and (iii) by using prompts, which remind them of the need to break prolonged sedentary periods. Interventions such as restricting access to the television by using an electronic lock-out systems[17] or, the installation of sit-stand desks[18] are employed to modify the environment of the individual, and as a result, to reduce sedentary time. At the community level, interventions can be policies for active transport or, policies for increasing the availability of open spaces in neighborhoods for recreational walking and cycling.[19]

Several systematic reviews have been published that focus on interventions for reducing sitting time at work.[20] [21] Although non-occupational sitting time comprises a large amount of total sedentary behaviour, somewhat surprisingly, no reviews have focused on the effects of interventions on reducing non-occupational sedentary behavior. Tharen-Borowski and colleagues[22] recently published a systematic review of non-worksite interventions for reducing sedentary behavior. However, they only reported their effects on reducing total sedentary time, not making the distinction between occupational and non-occupational domains. Therefore, the aim of this systematic review coupled with a meta-analysis was to provide an in-depth scrutiny of the current body of literature on the effects of interventions on reducing sedentary behavior in leisure-time, transport and household domains in adults and older adults, herein, referred collectively as non-occupational sedentary behavior.

2. Methods

2.1 Search Strategy

This review was performed adhering to the PRISMA guidelines.[23] The review protocol has been registered in PROSPERO (registration id: CRD42016051059). A comprehensive search of the following databases was performed: Academic Search Premier, Nursing/Academic Edition of Health Source, MasterFILE Premier, SPORTDiscus, MEDLINE/PubMed, Scopus, PsycINFO, CINAHL and Web of Science. Full search syntaxes can be found in Appendix 1. Secondary searches were performed by (a) scanning the reference list of each full text that was assessed and (b) performing forward citation tracking of the included studies (using Scopus, Web of Science, and Google Scholar databases). The search concluded on 19th October 2016.

2.2 Inclusion criteria

Studies were deemed suitable for inclusion if they met the following criteria:

(a) a randomized controlled trial (RCT), crossover RCT, or a cluster RCT conducted with participants aged 18 years or older. We planned to conduct a separate meta-analysis for studies with participants older than 60 years, as people in this age group are more likely to have comorbid conditions, and, therefore, types, context, and outcomes of the interventions in this age group might differ from those among adults of a younger age.

(b) the interventions were aimed to reduce sedentary behavior and/or increase physical activity and reported at least one domain of non-occupational sedentary behavior, such as total leisure sitting time, household sitting time, and transport sitting time, or total non-occupational sedentary behaviour measured by questionnaires or wearable devices (e.g., accelerometer/inclinometer).

(c) the effectiveness of the interventions was compared with either no intervention or with another intervention.

Workplace interventions can, in addition to work-related sedentary behavior, also influence non-occupational behavior. Therefore, all studies implementing sedentary behavior interventions at the workplace were included, if they reported effects on non-occupational sedentary behavior. We included studies in which the intervention aimed at reducing non–occupational sedentary behavior was provided at any frequency, and for any duration. We did not exclude full texts published in languages other than English.

To reduce selection bias, two authors (NS and HP) independently performed the search process. Studies were excluded based on the title, abstract or full text. Disagreements were resolved by discussion and consensus with a third author (ZP).

2.3 Data extraction

Studies were individually coded by two of the authors (NS and GW) for the following variables:

(a) study design;

(b) participant characteristics (including the number of participants randomized into groups and the mean age or age range)

(c) study location;

(d) description of intervention and follow-up length;

(e) description of the control group

(f) methods for the assessment of outcomes;

(g) description of outcomes.

Study authors were contacted to obtain missing information and verification of key study characteristics.

2.4 Appraisal of study quality

Two authors (NS and JG) independently assessed the risk of bias for each of the included studies using the Cochrane risk of bias tool.[24] We assigned a judgement of "low risk", "high risk" or "unclear risk" of bias relating to the following domains: random sequence generation; allocation concealment; blinding of participants and personnel; blinding of outcome assessment; incomplete outcome data; selective outcome reporting; validity of outcome measure; and baseline comparability/imbalance for age and gender.[20] The studies were judged as having a low risk of bias overall if they had a low risk of bias for random allocation, allocation concealment, blinding of outcome assessment, incomplete outcome data and valid outcome measure. It is difficult to blind participants, personnel in the studies trying to modify activity behavior, so we did not consider this domain in classifying trials into high versus low risk of bias in overall judgement.

2.5 Statistical analysis

A meta-analysis was performed to calculate pooled effect sizes for different domains/types of non-occupational sedentary behavior: total leisure-time sedentary behavior; total transport sitting time; TV viewing time; and leisure computer use. The meta-analysis was performed using the Comprehensive Meta-Analysis software (Biostat Inc., Englewood, NJ, USA). The difference between the intervention group and the control group in the mean change from pre- to post-intervention was used as a measure of effect size.

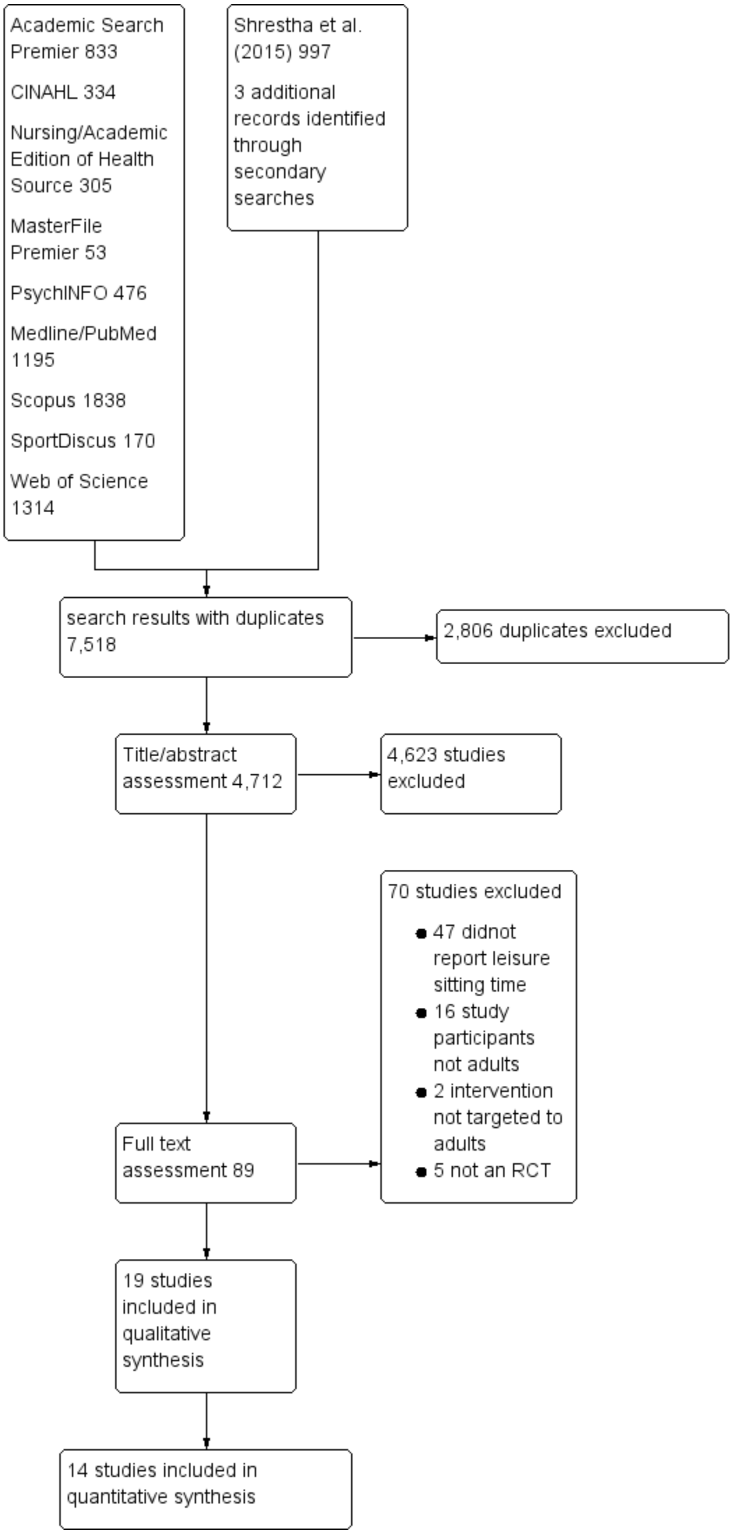
Three out of the four included cluster RCTs[25-27] accounted for the clustering. For these three studies we, therefore, did not need to adjust for the design effect. For the remaining study,[16] the design effect was calculated based on a relatively large assumed intra-cluster correlation coefficient of 0.10. This assumption was based on a realistic estimate by analogy from implementation research studies.[28] Where study authors reported multiple trial arms in a single trial, only the relevant arms were included. In studies where two comparisons needed to be combined in the same meta-analysis, to avoid double-counting, we reduced the number of participants in the control group by half. Verweij *et al*,[14] and Chau *et al*,[18] reported weekday and weekend leisure-time sedentary behavior separately. Since none of the included studies reported the correlation between weekday and weekend sitting time; we assumed the correlation of 0.44 previously reported by Drenowatz *et al*,[29] We then calculated combined effect size estimates for weekday and weekend sedentary behavior and their variances as recommended by Fu and colleagues.[30] Follow-up times of four months or less were deemed as short-term, four months to one year as medium-term, and more than one year as long-term. The I^2 statistic was used to assess heterogeneity among the trials in each analysis. We considered the observed value of I^2: 0% to 40% as likely not important; 30% to 60% as moderate heterogeneity; 50% to 90% as substantial heterogeneity; and 75% to 100% as considerable heterogeneity, as recommended by Higgins and Green.[24] The random effects model was used in all analyses. We performed a subgroup analysis according to different types of interventions to investigate heterogeneity among the trials. The sensitivity analysis was also carried out by excluding interventions that markedly increased the overall heterogeneity and by modifying the cut-offs for categorising the follow-up duration. In the latter sensitivity analysis, three months or less were considered a short-term, three to six months a medium-term, and more than six months a long-term follow-up. The only cross-over study,[18] included in the analyses was reported as a step-wedged cluster RCT and had no distinct first and second period. In the main analysis, we therefore included the original effect estimate reported in the study, and also performed a sensitivity analysis excluding this study. Relatively low number of included studies prevented us to assess the robustness of findings by excluding studies with high risk of bias from the meta-analyses. We could not assess for publication bias as none of the meta-analyses we conducted had 10 or more trials.[24] The statistical significance threshold was set a priori at $p < 0.05$. The quality of evidence was assessed independently by two authors following the Grading of Recommendations Assessment, Development and Evaluation (GRADE) criteria.[31 32]

3. Results

3.1 Search results

Out of the 7518 documents identified in the initial search, 89 full-text studies were deemed as potentially relevant and were scrutinized in detail. As shown in Figure 1, 70 studies were excluded based on the following reasons: studies did not report leisure sitting time (*n* = 47), they were not conducted among adults (*n* = 16), the interventions were not targeted to adults, that is, they were conducted in children but measured parents' sedentary behavior (*n* = 2) or were not RCTs (*n* = 5). Twenty papers from nineteen studies[14-18 25-27 33-44] are included in this review.

Figure 1 PRISMA flow diagram. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RCT, randomised controlled trial.



3.2 Included studies

Twelve of the 19 included studies were RCTs,[15 17 34-43] two were cross-over RCTs[18 33] and five were cluster RCTs.[14 16 25-27] The included studies assessed the effectiveness of: [i] multi-component lifestyle interventions that included a sedentary behavior and/or physical activity element;[15 26 34-38 40-42] [ii] counselling or education to reduce and self-monitor leisure time sedentary behavior;[16 25 43] [iii] television control devices to restrict access to TV;[17 39] and [iv] interventions implemented at the workplace which included sedentary behavior measures during leisure time.[14 18 27 33]

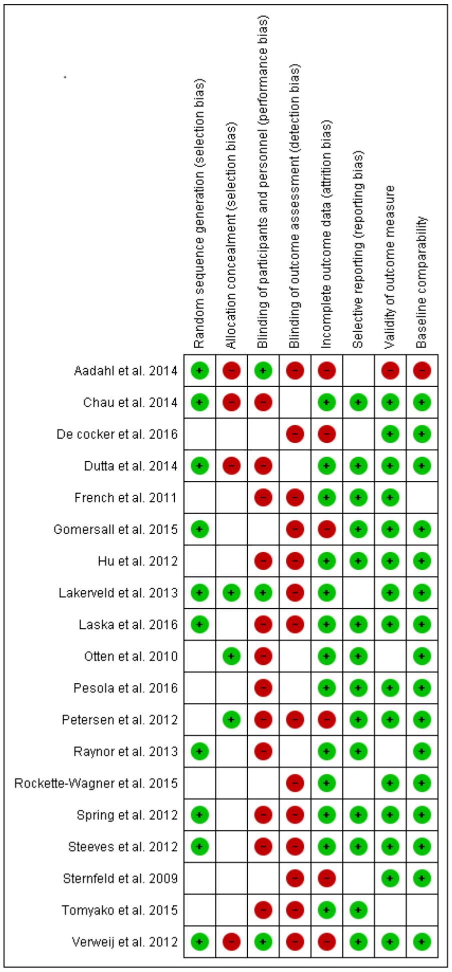
Various domains of leisure-time sedentary behavior were reported in these studies. TV viewing was reported in 10 studies,[16 17 26 34 36 37 39-42] total leisure sitting time in 9 studies[14 15 18 25 27 33 35 36 38 43], leisure computer use in 4 studies, [34 37 36 37] and transport sitting time in 3 studies.[16 18 34] In five studies the follow-up was four months or less,[16-18 33 38] while in nine studies it was 12 months or less.[14 15 25-27 34 39 41 43] The remaining five studies followed participants for more than 12 months.[35-37 40 42]

In 11 studies the control group participants were instructed to maintain their usual lifestyle or received usual care,[14 16-18 25-27 33 34 40 43] whereas, in four studies, control group participants received general information on healthy lifestyles.[35-38] Spring *et al*,[15] conducted a four-arm trial where the effectiveness of a different combination of advice to change one dietary behavior and one activity behavior (high sedentary leisure time or low physical activity) were assessed. In the Tomyako *et al*,[42] the delivery format of a curriculum for obesity prevention among families with young children (the ‘Healthy lifestyle toolkit’) compared in-home mentoring to delivery by mail.[42] Raynor *et al*,[39] conducted two pilot studies where sedentary behavior intervention (counseling and restricting access to television) was compared with physical activity counseling intervention. In the study by Steeves *et al*,[41] participants who were instructed to ‘briskly step or walk for the duration of each commercial break on TV’ were compared to participants who were ‘walking briskly for at least 30 minutes’. The included studies were conducted in Australia, USA, China and high-income nations in Europe, namely Denmark, Belgium, Finland and Netherlands. A description of characteristics of each included study is presented in Supplementary table 1.

3.3 Risk of bias in included studies

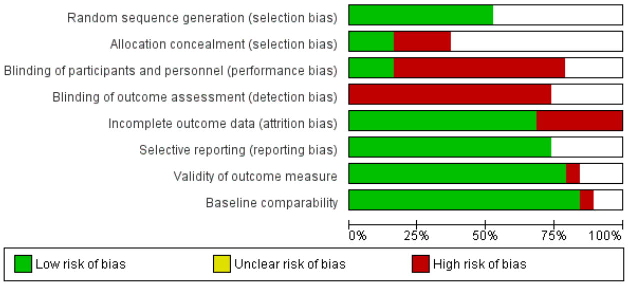
Nine studies did not report how the random sequence was generated and were thus judged to be at unclear risk for the selection bias domain.[16 17 25-27 35 38 40 42] Only three studies reported allocation concealment.[17 36 38] Except for three studies,[14 36 43] blinding of participants and personnel was not possible, and thus the studies were judged as either high risk or unclear risk for the performance bias domain. Leisure sedentary behavior was assessed with self-administered questionnaires in 13 studies.[14-16 26 27 34-38 40-43] In these studies, participants receiving the intervention would have been aware of the set goals and the purpose of the intervention and may have misreported sedentary time. This was, therefore, judged as a high risk for detection bias. Sedentary behavior was assessed using television control devices in two studies[17 39] and with both self-reports and accelerometers in three studies.[18 25 33] These studies did not report the blinding of outcome assessor and were thus, judged unclear risk for detection bias. We judged the studies with the attrition rate of less than 10% and studies that performed intention to treat analysis as “low risk” for the domain of attrition bias. Six studies[14 16 27 34 38 43] were judged as high risk for attrition bias. Five papers did not present results for all the outcomes mentioned in their study protocols. It might be that the missing results will be presented in future papers from the same study. Such studies were, therefore, judged unclear risk for selective reporting.[16 27 36 40 43] Remaining studies reported results for all outcomes mentioned in the protocol or in the methods section and were thus judges at low risk for selective reporting.[14 15 17 18 25 26 34 35 37-39 41 42] Overall, we judged all 19 studies to be at a high risk of bias. A summary of the judgments about each risk of bias item for each of the included studies is presented in Figure 2.

Figure 2 Risk of bias summary: review authors' judgements about each risk of bias item for each included study.



	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Validity of outcome measure	Baseline comparability
Aadahl et al. 2014	+	−	+	−	−		−	−
Chau et al. 2014	+	−	−		+	+	+	+
De cocker et al. 2016				−	−		+	+
Dutta et al. 2014	+	−	−		+	+	+	+
French et al. 2011			−	−	+	+	+	
Gomersall et al. 2015	+			−	−	+	+	+
Hu et al. 2012			−	−	+	+	+	+
Lakerveld et al. 2013	+	+	+	−	+		+	+
Laska et al. 2016	+		−	−	+	+	+	+
Otten et al. 2010		+	−		+	+		+
Pesola et al. 2016			−		+	+	+	+
Petersen et al. 2012		+	−	−	−	+	+	+
Raynor et al. 2013	+		−		+	+		+
Rockette-Wagner et al. 2015				−	+		+	+
Spring et al. 2012	+		−	−	+	+	+	+
Steeves et al. 2012	+		−	−	+	+	+	+
Sternfeld et al. 2009				−	−		+	+
Tomyako et al. 2015			−	−	+	+		
Verweij et al. 2012	+	−	+	−	−	+	+	+

Risk of bias summary: review authors' judgements about each risk of bias item for each included study.



Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.

3.4 Effects of interventions

Studies were pooled according to outcome measure (see Figure 3). We could not pool studies according to the type of intervention as interventions were heterogeneous and there were only a few studies for each intervention. However, a subgroup analysis was performed according to type of intervention to investigate heterogeneity.

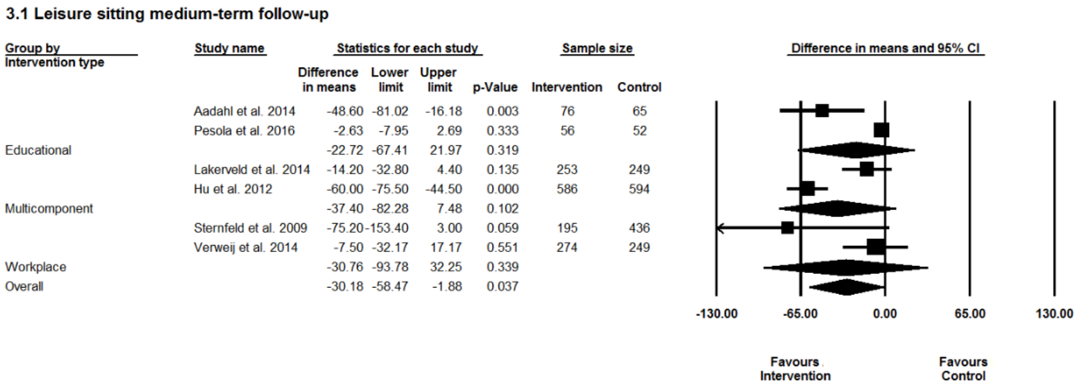
3.4.1 Outcome: Total leisure sitting time

We pooled six studies reporting total leisure sitting time at medium-term follow-up.[14 25 27 35 36 43] The pooled analysis showed that the interventions reduced sitting time on average by 30 minutes per day (95% confidence interval [CI] -58 to -2 min/day). However, there was substantial heterogeneity between pooled studies (I^2 = 91%). When the sensitivity analysis was performed by excluding the studies conducted in the workplace setting,[14 27] the pooled effect showed a similar reduction in sitting time of 30 minutes per day (95% CI: -62, -2 min/day; I^2 = 94%), again with considerable heterogeneity. In the subgroup analysis, none of the interventions showed a significant reduction in total leisure sitting time at medium-term follow up.

Three studies could not be included in the meta-analysis.[15 33 38] Spring *et al*,[15] only reported a reduction in total leisure sitting time by on average 90 minutes per day at 20 weeks follow-up. Dutta *et al*,[33] reported no difference in total leisure sitting time between intervention and control periods. Data presented by Petersen *et al*,[38] did not allow for calculation of time spent in sedentary behaviour, and the study was, therefore, not included in the meta-analysis.

None of the included studies reported total leisure sitting time at short and long-term follow up.

Figure 3 Forest plot showing effects of interventions on total leisure sitting time.



3.1 Leisure sitting medium-term follow-up

Group by Intervention type	Study name	Difference in means	Lower limit	Upper limit	p-Value	Intervention	Control
	Aadahl et al. 2014	-48.60	-81.02	-16.18	0.003	76	65
	Pesola et al. 2016	-2.63	-7.95	2.69	0.333	56	52
Educational		-22.72	-67.41	21.97	0.319		
	Lakerveld et al. 2014	-14.20	-32.80	4.40	0.135	253	249
	Hu et al. 2012	-60.00	-75.50	-44.50	0.000	586	594
Multicomponent		-37.40	-82.28	7.48	0.102		
	Sternfeld et al. 2009	-75.20	-153.40	3.00	0.059	195	436
	Verweij et al. 2014	-7.50	-32.17	17.17	0.551	274	249
Workplace		-30.76	-93.78	32.25	0.339		
Overall		-30.18	-58.47	-1.88	0.037		

3.4.2 Outcome: TV viewing

We pooled six studies reporting TV viewing at short-term follow-up.[16-18 34 37 39] The pooled analysis showed that the interventions reduced TV viewing by on average 56 minutes per day (95% CI: -73, -38; I^2 = 79%), with considerable heterogeneity. The sensitivity analysis performed by excluding the studies that assessed restricting access to the TV using television control devices [17 39] resulted in an average reduction of 34 minutes per day (95% CI: -60, -8; I^2 = 69%), with substantial heterogeneity. In the sensitivity analysis, excluding the cross-over study,[18] the pooled effect showed a similar reduction of 51 minutes per day on average (95% CI: -86, -15; I^2 = 78%) as in the main analysis, with considerable heterogeneity. In the subgroup analysis, the interventions aimed at restricting access to the TV using television control devices reduced TV viewing by on average 128 minutes per day (95% CI: -170, -85; I^2 = 0%). The subgroup analysis did not show a significant reduction for multicomponent interventions[34 37] and educational interventions.[16]

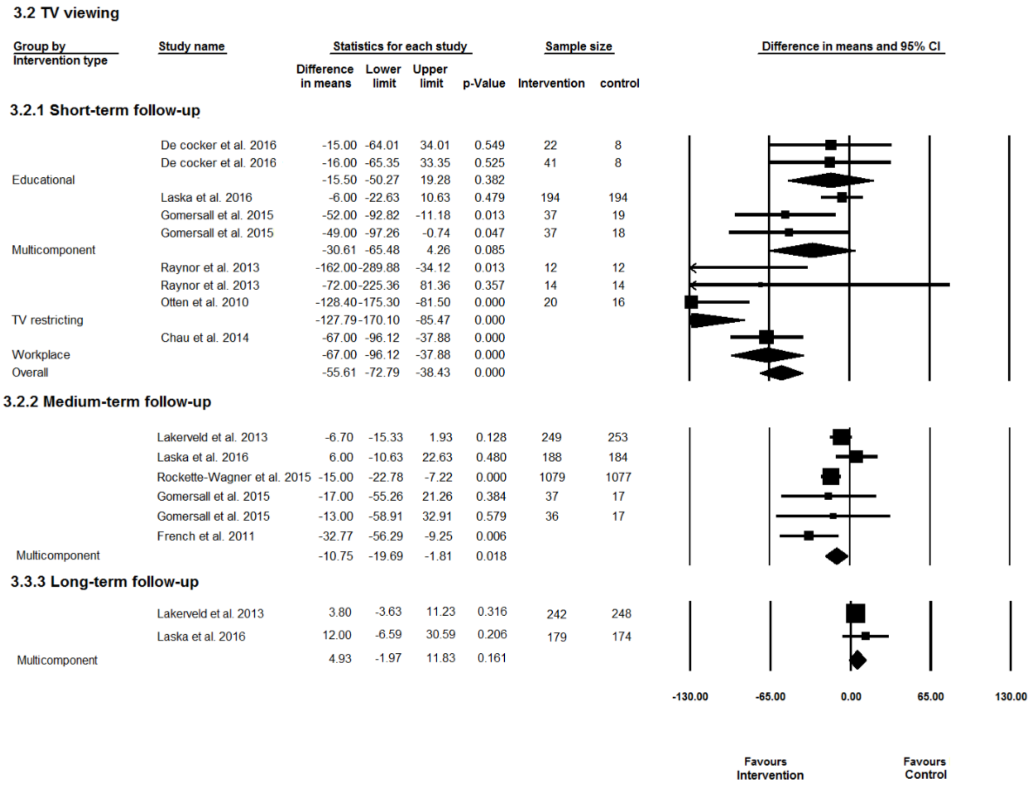
Five studies reported TV viewing at medium-term follow-up [26 34 36 37 40]. The pooled effect size estimate showed a mean reduction of 11 minutes per day (95% CI: -20, -2; I^2 = 49%), with moderate heterogeneity. All five studies included in this analysis evaluated the effectiveness of multicomponent interventions.

Three studies reported TV viewing at long-term follow-up.[36 37 40] The pooled analysis of these studies did not show a significant reduction in TV viewing time (*d* = -2 min/day; 95% CI: -17, 13; I^2 = 80%). All three studies included in this analysis evaluated the effectiveness of multicomponent interventions.

We also performed sensitivity analysis by modifying the cut-offs for short, medium and long term follow-up. The effect sizes were similar for all the follow-up categories; however, the reduction in TV viewing time for medium-term follow-up was no longer significant.

In the studies that were not included in the pooled analysis, Steeves *et al*,[41] found that participants in both stepping and walking groups during TV commercial breaks reduced TV viewing by 60 minutes at 6 months follow-up. Similarly, Tomayako *et al*,[42] reported a half an hour reduction in TV viewing for a healthy lifestyle toolkit delivered either by mail or in-home mentoring (Figure 4).

Figure 4 Forest plot showing effects of interventions on television (TV) viewing sitting time.



3.2 TV viewing

Group by Intervention type	Study name	Statistics for each study				Sample size	
		Difference in means	Lower limit	Upper limit	p-Value	Intervention	control
3.2.1 Short-term follow-up							
	De cocker et al. 2016	-15.00	-64.01	34.01	0.549	22	8
	De cocker et al. 2016	-16.00	-65.35	33.35	0.525	41	8
Educational		-15.50	-50.27	19.28	0.382		
	Laska et al. 2016	-6.00	-22.63	10.63	0.479	194	194
	Gomersall et al. 2015	-52.00	-92.82	-11.18	0.013	37	19
	Gomersall et al. 2015	-49.00	-97.26	-0.74	0.047	37	18
Multicomponent		-30.61	-65.48	4.26	0.085		
	Raynor et al. 2013	-162.00	-289.88	-34.12	0.013	12	12
	Raynor et al. 2013	-72.00	-225.36	81.36	0.357	14	14
	Otten et al. 2010	-128.40	-175.30	-81.50	0.000	20	16
TV restricting		-127.79	-170.10	-85.47	0.000		
	Chau et al. 2014	-67.00	-96.12	-37.88	0.000		
Workplace		-67.00	-96.12	-37.88	0.000		
Overall		-55.61	-72.79	-38.43	0.000		
3.2.2 Medium-term follow-up							
	Lakerveld et al. 2013	-6.70	-15.33	1.93	0.128	249	253
	Laska et al. 2016	6.00	-10.63	22.63	0.480	188	184
	Rockette-Wagner et al. 2015	-15.00	-22.78	-7.22	0.000	1079	1077
	Gomersall et al. 2015	-17.00	-55.26	21.26	0.384	37	17
	Gomersall et al. 2015	-13.00	-58.91	32.91	0.579	36	17
	French et al. 2011	-32.77	-56.29	-9.25	0.006		
Multicomponent		-10.75	-19.69	-1.81	0.018		
3.3.3 Long-term follow-up							
	Lakerveld et al. 2013	3.80	-3.63	11.23	0.316	242	248
	Laska et al. 2016	12.00	-6.59	30.59	0.206	179	174
Multicomponent		4.93	-1.97	11.83	0.161		

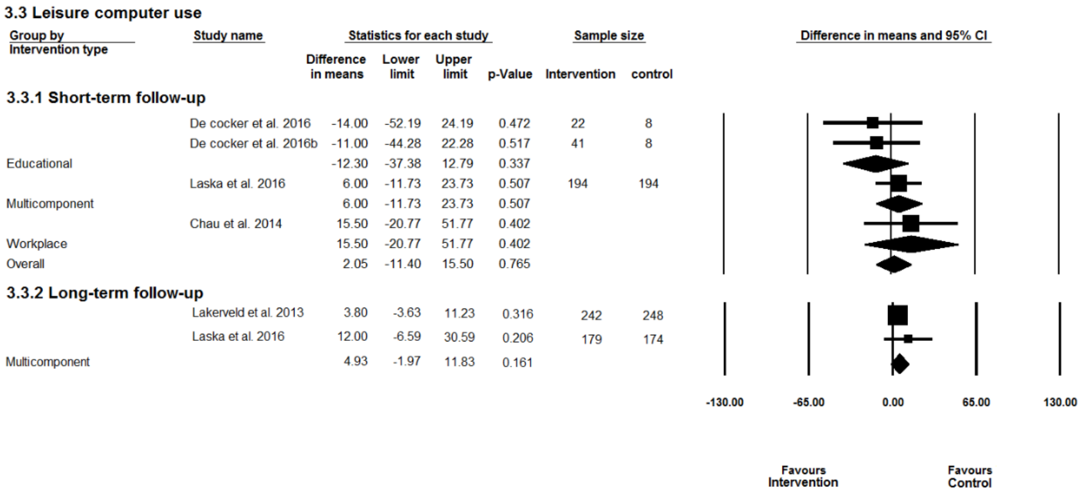
3.4.3 Outcome: Leisure computer use

We pooled three studies reporting leisure computer use at short-term follow-up.[16 18 37] The meta-analysis did not find a significant pooled effect size (*d* = 2 min/day; 95% CI: -11, 16; I^2 = 0%).

Lakerveld et al.[36] reported a non-significant reduction of -2 minutes/day (95% CI: -9.4, 5.4) in leisure computer use at medium-term follow-up.

Two studies reported leisure computer use at long-term.[36 37] The pooled effect size was not significant (*d* = 5 min/day; 95% CI: -2, 12; I^2 = 0%) (Figure 5).

Figure 5 Forest plot showing effects of interventions on leisure computer use sitting time.



3.3 Leisure computer use

Group by Intervention type	Study name	Statistics for each study				Sample size	
		Difference in means	Lower limit	Upper limit	p-Value	Intervention	control
3.3.1 Short-term follow-up							
	De cocker et al. 2016	-14.00	-52.19	24.19	0.472	22	8
	De cocker et al. 2016b	-11.00	-44.28	22.28	0.517	41	8
Educational		-12.30	-37.38	12.79	0.337		
	Laska et al. 2016	6.00	-11.73	23.73	0.507	194	194
Multicomponent		6.00	-11.73	23.73	0.507		
	Chau et al. 2014	15.50	-20.77	51.77	0.402		
Workplace		15.50	-20.77	51.77	0.402		
Overall		2.05	-11.40	15.50	0.765		
3.3.2 Long-term follow-up							
	Lakerveld et al. 2013	3.80	-3.63	11.23	0.316	242	248
	Laska et al. 2016	12.00	-6.59	30.59	0.206	179	174
Multicomponent		4.93	-1.97	11.83	0.161		

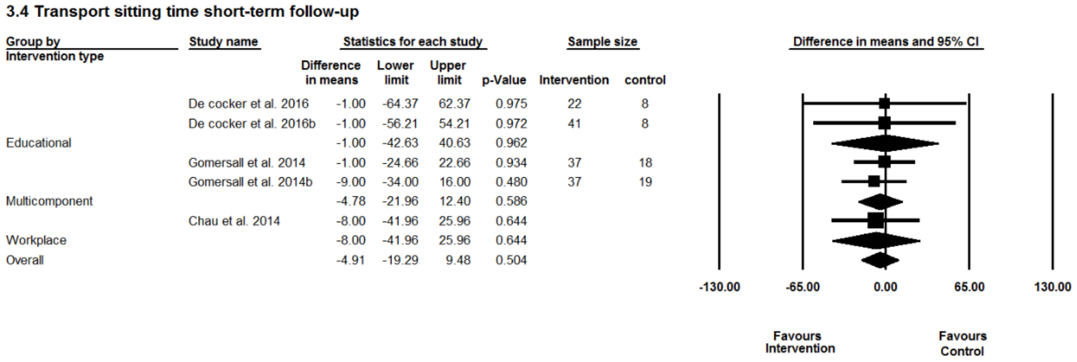
3.4.4 Outcome: Total transport sitting time

We pooled three studies reporting transport sitting time at short-term follow-up.[16 18 34] The pooled effect size was not significant (*d* = -5 min/day; 95% CI: -19, 9; I^2 = 0%).

Gomersall et al.[34] reported a non-significant reduction of 5 minutes/day (95% CI: -12, 22) in transport sitting time at medium-term follow up.

No study reported total transport sitting time at long-term follow-up (Figure 6).

Figure 6 Forest plot showing effects of interventions on total transport sitting time.



3.4 Transport sitting time short-term follow-up

Group by Intervention type	Study name	Statistics for each study				Sample size	
		Difference in means	Lower limit	Upper limit	p-Value	Intervention	control
	De cocker et al. 2016	-1.00	-64.37	62.37	0.975	22	8
	De cocker et al. 2016b	-1.00	-56.21	54.21	0.972	41	8
Educational		-1.00	-42.63	40.63	0.962		
	Gomersall et al. 2014	-1.00	-24.66	22.66	0.934	37	18
	Gomersall et al. 2014b	-9.00	-34.00	16.00	0.480	37	19
Multicomponent		-4.78	-21.96	12.40	0.586		
	Chau et al. 2014	-8.00	-41.96	25.96	0.644		
Workplace		-8.00	-41.96	25.96	0.644		
Overall		-4.91	-19.29	9.48	0.504		

3.4.5 Interventions in older adults

We did not find any RCTs with participants older than 60 years.

4. Discussion

The findings of this review show that interventions may reduce sedentary leisure time in the medium-term and TV viewing in short- to medium-term. However, we found no evidence of long-term efficacy for any intervention. Furthermore, the heterogeneity in reported outcomes, interventions and control arms (usual care/another active intervention) prevented us to perfom a robust meta-analysis and draw firm conclusions. The quality of evidence was very low to low for all outcomes.

Currently, most adults spend a significant amount of time in front of the TV.[8] Therefore, even a small reduction in TV viewing might result in significant public health benefits.[45] One type of the interventions for reducing TV viewing time was restricting access to the

TV using a television control device. It seems that such an intervention for reducing TV viewing time is likely to be effective in the short to medium term. However, the practical usability and acceptability of such devices remains unclear and questionable. Our findings are consistent with those of two systematic reviews[46 47] that primarily included studies that assessed restricting access to TV using television control devices. We found that other interventions may have an impact on TV viewing, but that it is potentially somewhat smaller than for the interventions using the TV control device.

Interestingly, Chau *et al*,[18] reported a decrease in TV viewing time by implementing a sit-stand workstation. Similar findings were reported by De Cocker *et al*,[16] by implementing a web-based, interactive, computer-tailored intervention in a workplace setting. It was previously hypothesized that reducing occupational sedentary time will result in compensatory effects (i.e., increase in non-occupational sedentary time).[48] However, findings of Chau *et al*,[18] and De Cocker *et al*,[16] studies do not support this hypothesis. It might be that sedentary behavior interventions at work made people aware of the potential hazards of sitting and they not only reduced sitting at work but also outside of work. Further research on the topic is warranted.

We did not find significant pooled effects of interventions on transport sitting time. This might be because none of the interventions was specifically aimed at reducing transport sitting time. Various interventions for increasing active travel (such as walking and cycling) might serve as a possible avenue for reducing sedentary behavior, and their effects on transport sitting time should, therefore, should be investigated in future studies.[49] Furthermore, no evidence was available on the efficacy of interventions on sedentary time among older adults. A recently published review by Copeland *et al.*[50]

concluded that sedentary behavior interventions were feasible and effective in reducing sedentary time in older adults. However, there were only two pre-post studies that reported leisure time sedentary behavior.[51] [52] Hence, interventions targeting reduction in specific domains of leisure time sedentary behaviour in older adults need to be designed and tested using an RCT in a larger sample of participants.

Though educational interventions seem to be promising, there was no significant reduction in sedentary behaviour with such interventions. Multicomponent interventions were found to be only effective in reducing TV viewing time in the medium term. However, these finding needs to be interpreted with scrutiny as there were very few studies in each analysis.

Furthermore, there is very little evidence available about the contribution of newer technologies, such as smartphones and tablets, to sedentary behavior. It is unknown if reducing their use may have an impact on population sedentary behavior. Various other strategies to reduce leisure sitting time like standing during commercial breaks [53], using active gaming platforms[47] and use of new technologies (e.g., apps delivered on smartphones and tablets)[15] [54-56] may also need to be considered and examined in future trials.

Several studies reported a favorable association of reallocating sedentary behavior to light or moderate-to-vigorous intensity physical activity with cardio metabolic biomarkers,[57-59] depressive symptoms[60] and mortality risk.[45] [61] [62] For example, for reallocating 30 minutes of sedentary behavior to light physical activity one can expect 1.9% lower triglycerides,[58] 2.4% lower insulin[58] and a 20% reduction in the mortality risk at 5 years follow up.[62] Although in a short term such reallocations seem to be attainable, we did not find any evidence showing the potential of interventions to sustain such reallocations over a longer period.

It is important to note that some sedentary behaviours (e.g., socializing/reading) may provide health benefits, such as improved mental well-being, despite being conducted in a seated position.[63] [64] Sedentary behaviour, therefore, cannot be characterised as ultimately ‘unhealthy’. Recent theoretical frameworks suggest that a right balance between the amounts of time spent sleeping, in sedentary behaviour, and in physical activity may be needed for good health. [65] [66] Effectiveness of different strategies for achieving the optimal balance between these behaviours may be an interesting topic for future intervention trials.

Most sedentary behavior interventions aimed at reducing one or two domains of sedentary behavior. However, any reduction in one domain of sedentary behavior does not mean it will be replaced with only light or moderate physical activity. It is also possible that it will lead to an increase in other sedentary behaviors (e.g., TV viewing may be replaced by listening to music while sitting or seated computer use).[67] Therefore, future leisure sedentary behavior interventions should consider having components targeting each domain separately and consider ways to be replacing one sedentary behavior with a more active alternative.

A review by Gardner *et al*,[68] indicated that interventions for adults that are primarily aimed at reducing sedentary behavior rather than increasing physical activity seem to be most promising in reducing sedentary behavior. We could not test their hypothesis, because of the small number of studies included in each meta-analysis. Although reducing total sedentary time by 30 minutes/day was suggested to have a potential to produce clinically meaningful positive effects on health,[45 57-62] in most intervention studies, it was not clear to which component of time-use was non-occupational sedentary time reallocated, because they did not assess all the remaining activity- and inactivity-related components of the 24-hour day; that is, sleeping, quiet standing, light physical activity, and moderate-to-vigorous physical activity. The distribution of time spent in sedentary behavior, sleep, light physical activity and moderate-to-vigorous physical activity seems to be significantly associated with a variety of health outcomes.[69] It would seem that focusing solely on one of these components of time-use might be misguided; rather the focus should be on achieving a sustainable balance in all components.[66] Furthermore, it has been shown that clustering of unhealthy lifestyle behaviors, such as low physical activity, high sedentary behavior and poor sleep duration may be associated with obesity.[70] Future intervention trials might, therefore, need to consider tracking not only the reduction/increase in a specific behavior but also, the distribution of time over all the above-mentioned time-use components.

The major limitations of this review are the small number of included studies and significant heterogeneity between them. Most of the studies had methodological limitations including small sample size and failure to blind outcome accessor. Most studies included in the meta-analyses assessed sedentary behavior using self-reports. While self-reports may have lower reliability than some device-based measures of sedentary behavior, they have significant comparative advantages for assessing domain- and type-specific sitting time.[71] This is especially the case for the activities that are performed on a regular basis, such as TV viewing.[71] A limitation of accelerometers and similar device-based measures is that, without the support of self-reports, their data does not allow for discerning between domains of sitting time.[72] Additionally, motion sensors which do not have inbuilt inclinometers might have questionable validity as they often cannot distinguish between quiet standing and sitting and may, therefore, overestimate sitting time.[72] Future intervention trials should, therefore, consider using both device-based measurement and self-reports to gather more robust and complete data. Furthermore, from the studies on TV viewing and computer use, very often it could not be discerned whether the screen time was spent sitting and standing. The same methodological issue was also found in the studies on sedentary behaviour in the transport domain. Future studies evaluating the effectiveness of interventions to reduce screen time and transport-related sedentary behaviour should select measures that allow for better differentiation between sitting and standing.

5. Conclusions

Our findings suggest that it is possible to reduce non-occupational sedentary behavior in short to medium-term through targeted interventions in adults. However, it is still unclear whether such behavioral change is feasible and sustainable over long term to attain health benefits. Higher quality studies in larger sample of participants are required to determine the approaches that will be most effective at inducing a reduction in non-occupational sedentary behavior in long-term conditions. The future studies should also consider addressing the optimum balance between all activity- and inactivity-related behaviors; sleep, sedentary behavior, light intensity and moderate-to-vigorous intensity physical activity, to attain healthy lifestyle.

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