BJSM Online First, published on January 13, 2018 as 10.1136/bjsports-2017-098270

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

Nipun Shrestha,[1] Jozo Grgic,[1] Glen Wiesner,[1] Alexandra Parker,[1] Hrvoje Podnar,[2] Jason A Bennie,[3] Stuart J H Biddle,[3] Zeljko Pedisic[1]

► Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/bjsports-2017-098270).

[1]Institute of Sport, Exercise and Active Living, Victoria University, Melbourne, Victoria, Australia
[2]Faculty of Kinesiology, University of Zagreb, Zagreb, Croatia
[3]Physically Active Lifestyles (USQ PALs) Research Group, Institute for Resilient Regions, University of Southern Queensland, Springfield Central, Queensland, Australia

Correspondence to
Dr. Zeljko Pedisic, Institute of Sport, Exercise and Active Living, Victoria University, Melbourne 3001, Australia; Zeljko.Pedisic@vu.edu.au

Accepted 19 December 2017

ABSTRACT

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

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

Results Nineteen studies that evaluated multicomponent lifestyle interventions, counselling or education, television (TV) control devices and workplace interventions were included. Evidence from the meta-analyses suggested that interventions can reduce leisure sitting time in adults in the medium term (−30 min/day; 95% CI −58 to −2), and TV viewing in the short term (−61 min/day; 95% CI −79 to −43) and medium term (−11 min/day; 95% CI −20 to −2). No significant pooled effects were found for transport sitting time, leisure-time computer use and longer term outcomes. No evidence was available on the 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 behaviour in the short to medium term in adults. However, no significant effect was found on longer term outcomes. The quality of evidence was, however, low to very 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 samples is warranted.

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 behaviour 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 behaviour may be associated with increased risk of all-cause mortality, cardiovascular disease, type 2 diabetes and site-specific cancers.[4] Furthermore, global estimates suggest that high levels of sedentary behaviour and insufficient physical activity are responsible for 3.8% (assuming independence of physical activity) 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 (TV) screen and using devices like tablets, smartphones and gaming consoles contributes significantly to increasing leisure-time sedentary behaviour.[7] The self-reported data from the US Labor survey[8] show that TV viewing was the most prevalent leisure activity (ie, 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 larger proportion of their waking hours watching TV (ie, 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 min 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 behaviour 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 (1) counselling or interviewing[14]; (2) self-monitoring, alongside goal setting to review their own behaviour,[15] and personalised feedback[16]; and (3) using prompts that remind them of the need to break prolonged sedentary periods. Interventions such as restricting access to TV using an electronic lockout systems[17] or 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, policy or public health interventions can promote active transport or increase the availability of open spaces in neighbourhoods 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

To cite: Shrestha N, Grgic J, Wiesner G, *et al*. *Br J Sports Med* Epub ahead of print: [*please include* Day Month Year]. doi:10.1136/bjsports-2017-098270

time comprises a large amount of total sedentary behaviour, no reviews have focused on the effects of interventions on reducing non-occupational sedentary behaviour. Thraen-Borowski and colleagues[22] recently published a systematic review of non-worksite interventions for reducing sedentary behaviour. However, this review reported the effects on reducing total sedentary time and did not make the distinction between occupational and non-occupational domains. Therefore, the aim of this systematic review and meta-analysis was to provide an indepth scrutiny of the current body of literature on the effects of interventions on reducing sedentary behaviour in leisure-time, transport and household domains in adults and older adults, herein referred collectively as non-occupational sedentary behaviour.

METHODS

Search strategy

This review was performed adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.[23] The review protocol was 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, Cumulative Index to Nursing and Allied Health Literature (CINAHL) and Web of Science. Full search syntaxes can be found in online supplementary file 1. Secondary searches were performed by (1) scanning the reference list of each full text that was assessed and (2) performing forward citation tracking of the included studies (using Scopus, Web of Science and Google Scholar databases). The search concluded on 19 October 2016.

Inclusion criteria

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

- A randomised controlled trial (RCT), cross-over 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.
- The interventions were aimed to reduce sedentary behaviour and/or increase physical activity and reported at least one domain of non-occupational sedentary behaviour, 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 (eg, accelerometer/inclinometer).
- The effectiveness of the interventions was compared with either no intervention or with another intervention.

Workplace interventions can, in addition to work-related sedentary behaviour, also influence non-occupational behaviour. Therefore, all studies implementing sedentary behaviour interventions at the workplace were included, if they reported effects on non-occupational sedentary behaviour. We included studies in which the intervention aimed at reducing non-occupational sedentary behaviour was provided at any frequency and for any duration. We also included 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).

Data extraction

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

- study design
- participant characteristics (including the number of participants randomised into groups and the mean age or age range)
- study location
- description of intervention and follow-up length
- description of the control group
- methods for the assessment of outcomes
- description of outcomes.

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

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 and study personnel trying to modify activity behaviour, so we did not consider this domain in classifying trials into high versus low risk of bias in overall judgement.

Statistical analysis

A meta-analysis was performed to calculate pooled effect sizes for different domains/types of non-occupational sedentary behaviour: total leisure-time sedentary behaviour, total transport sitting time, TV viewing time and leisure computer use. The meta-analysis was performed using the Comprehensive Meta-Analysis software (Biostat, Englewood, New Jersey, USA). The difference between the intervention group and the control group in the mean change from preintervention to postintervention 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 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 intracluster 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 behaviour 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 behaviour and their variances as recommended by Rongwei Fu and colleagues.[30]

Follow-up times of 4 months or less were deemed as short term, 4 months to 1 year as medium term, and more than 1 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%–40% as likely not important; 30%–60% as moderate heterogeneity; 50%–90% as substantial heterogeneity; and 75%–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 (online supplementary figure S2). In the latter sensitivity analysis, 3 months or less were considered a short term, 3–6 months a medium term, and more than 6 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 (online supplementary figure S2). Relatively low numbers of included studies prevented exclusion of studies with a high risk of bias to assess the robustness of findings. 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 (NS and JG) following the Grading of Recommendations Assessment, Development and Evaluation criteria (online supplementary table S3).[31 32]

RESULTS

Search results

Out of the 7518 documents identified in the initial search, 89 full-text studies were deemed as potentially relevant and were scrutinised. 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), and the interventions were not targeted to adults, that is, they were conducted in children but measured parents' sedentary behaviour (n=2) or were not RCTs (n=5). Twenty papers from 19 studies[14–18 25–27 33–44] are included in this review.

Included studies

Twelve of the 19 included studies were RCTs,[15 17 34–43] 2 were cross-over RCTs[18 33] and 5 were cluster RCTs.[14 16 25–27] The included studies assessed the effectiveness of (1) multicomponent lifestyle interventions that included a sedentary behaviour and/or physical activity element[15 26 34–38 40–42]; (2) counselling or education to reduce and self-monitor leisure-time sedentary behaviour[16 25 43]; (3) TV control devices to restrict access to TV[17 39]; and (4) interventions implemented at the workplace that included sedentary behaviour measures during leisure time.[14 18 27 33]

Various domains of leisure-time sedentary behaviour 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 36 37 37] and transport sitting time in 3 studies.[16 18 34] In five studies, the follow-up was 4 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]

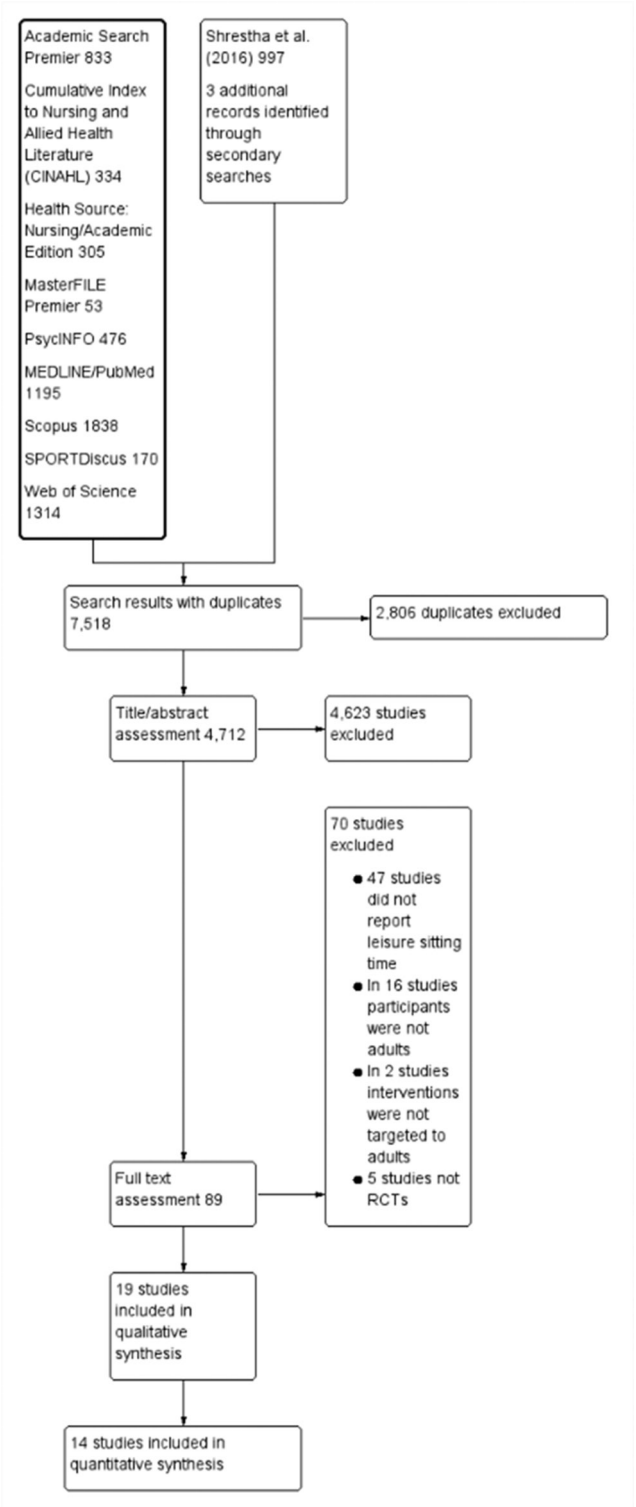

Figure 1 PRISMA flow diagram. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RCT, randomised controlled trial.

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 the 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 behaviour and one activity behaviour (high sedentary

leisure time or low physical activity) was assessed. In Tomayko *et al*[42] the delivery format of a curriculum for obesity prevention among families with young children (the 'Healthy lifestyle toolkit') compared inhome mentoring with delivery by mail.[42] Raynor *et al*[39] conducted two pilot studies where a sedentary behaviour intervention (counselling and restricting access to TV) was compared with a physical activity counselling intervention. The study by Steeves *et al*[41] compared participants who were instructed to 'briskly step or walk for the duration of each commercial break on TV' with participants who were 'walking briskly for at least 30 min'. The included studies were conducted in Australia, USA, China and high-income nations in Europe, namely Denmark, Belgium, Finland and the Netherlands. A description of characteristics of each included study is presented in online supplementary table S4.

Risk of bias in included studies

Nine studies did not report how the random sequence was generated and were rated 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 rated as either high risk or unclear risk for the performance bias domain. Leisure sedentary behaviour 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 goals and purpose of the intervention, which may have influenced their reporting of sedentary time. This was, therefore, rated as a high risk for detection bias. Sedentary behaviour was assessed using TV control devices in two studies[17 39] and combined self-report and accelerometers in three studies.[18 25 33] These studies did not report the blinding of outcome assessor and were rated as unclear risk for detection bias. Studies with an attrition rate of less than 10% and studies that performed intention-to-treat analysis were rated as 'low risk' for the domain of attrition bias. Six studies[14 16 27 34 38 43] were rated as high risk for attrition bias. Five papers did not present results for all the outcomes mentioned in their study protocols; missing results may be presented in future papers from the same study. Such studies were, therefore, rated as unclear risk for selective reporting.[16 27 36 40 43] The remaining studies reported results for all outcomes mentioned in the protocol or in the methods section and were rated at low risk for selective reporting.[14 15 17 18 25 26 34 35 37–39 41 42] Overall, we rated all 19 studies to be at a high risk of bias. A summary of the ratings for each risk of bias item for the included studies is presented in figure 2 and online supplementary figure S5.

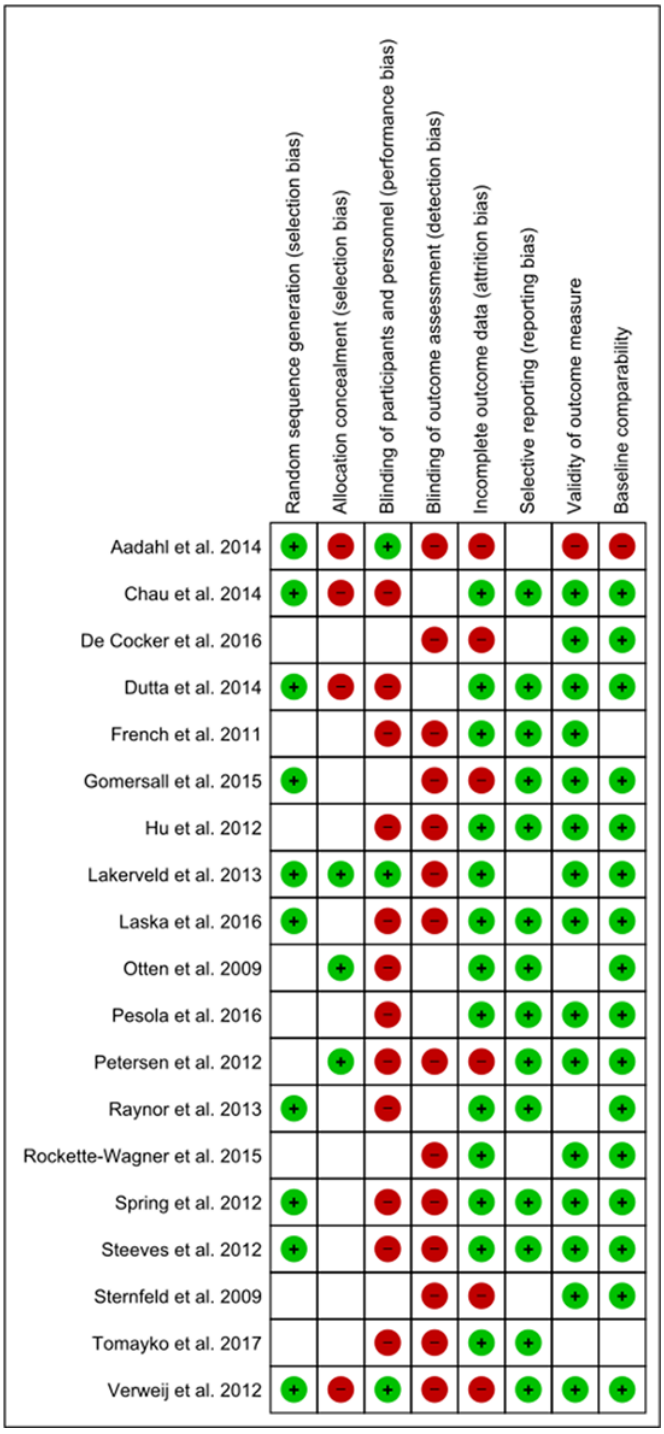

Figure 2 Risk of bias summary: review authors' judgements about each risk of bias item for each included study.

Effects of interventions

Studies were pooled according to outcome measure. 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.

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 min per day (95% 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 min per day (95% CI −62 to 2 min/day; I^2=94%), again with considerable heterogeneity (online supplementary figure S2). 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 an average reduction in total leisure sitting time of 90 min 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

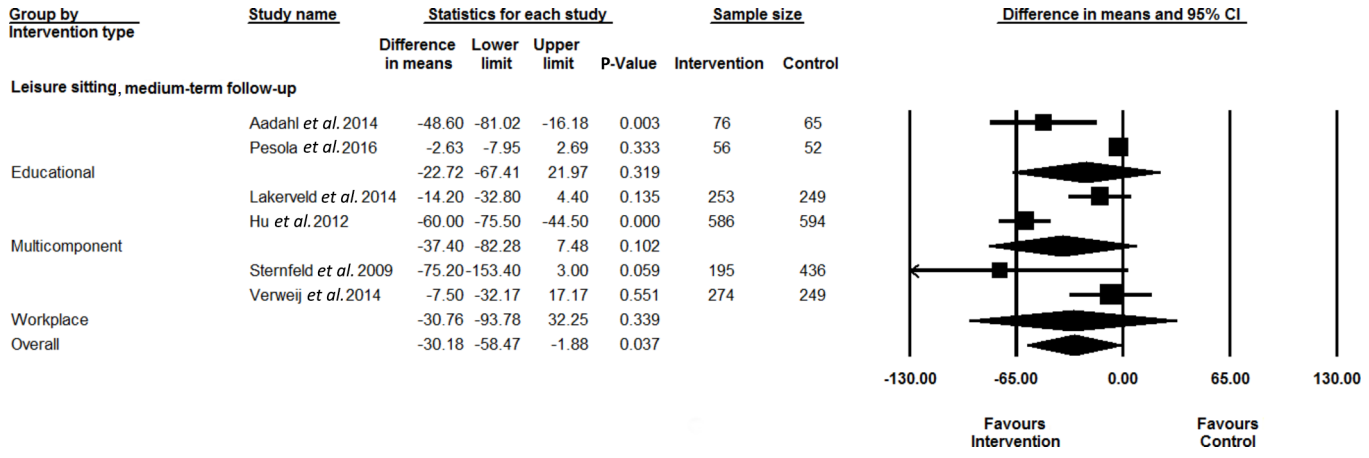

Figure 3 Forest plot showing effects of interventions on total leisure sitting time.

behaviour, and the study was therefore not included in the meta-analysis. None of the included studies reported total leisure sitting time at short-term and long-term follow-up (figure 3).

Outcome: TV viewing

We pooled six studies reporting TV viewing time at short-term follow-up.[16–18 34 37 39] The pooled analysis showed that the interventions reduced TV viewing by on average 61 min per day (95% CI −79 to −43; I^2=79%), with considerable heterogeneity. The sensitivity analysis performed by excluding the studies that assessed restricting access to the TV using TV control devices[17 39] resulted in an average reduction of 34 min per day (95% CI −60 to −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 min per day on average (95% CI −86 to −15; I^2=78%) as in the main analysis, with considerable heterogeneity. In the subgroup analysis, the interventions aimed at restricting access to TV using TV control devices reduced TV viewing by on average 128 min per day (95% CI −170 to −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 time at medium-term follow-up.[26 34 36 37 40] The pooled effect size estimate showed a mean reduction of 11 min per day (95% CI −20 to −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 time 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 to 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-term, medium-term 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 min at 6-month follow-up. Similarly, Tomayko *et al*[42] reported a half an hour reduction in TV viewing for a healthy lifestyle toolkit delivered either by mail or inhome mentoring (figure 4).

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=4 min/day; 95% CI −10 to 19; I^2=0%). Lakerveld *et al*[36] reported a non-significant reduction of −2 min/day (95% CI −9.4 to 5.4) in leisure computer use at medium-term follow-up. Two studies reported leisure computer use at longer term follow-up.[36 37] The pooled effect size was not significant (d=5 min/day; 95% CI −2 to 12; I^2=0%) (figure 5).

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 −20 to 10; I^2=0%). Gomersall *et al*[34] reported a non-significant reduction of 5 min/day (95% CI −12 to 22) in transport sitting time at medium-term follow-up. No studies reported total transport sitting time at long-term follow-up (figure 6).

Interventions in older adults

We did not find any RCTs with the mean age of participants older than 60 years.

DISCUSSION

The findings of this review demonstrated that interventions may reduce sedentary leisure time in the medium term and TV viewing time in the 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 from performing a robust meta-analysis and drawing firm conclusions. The quality of evidence was low to very low for all outcomes.

Currently, most adults spend a significant amount of sitting time in front of the TV.[8] Therefore, even a small reduction in TV viewing might result in significant public health benefits.[45] One of the strategies for reducing TV viewing time was restricting access by using a TV 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 remain unclear and questionable.

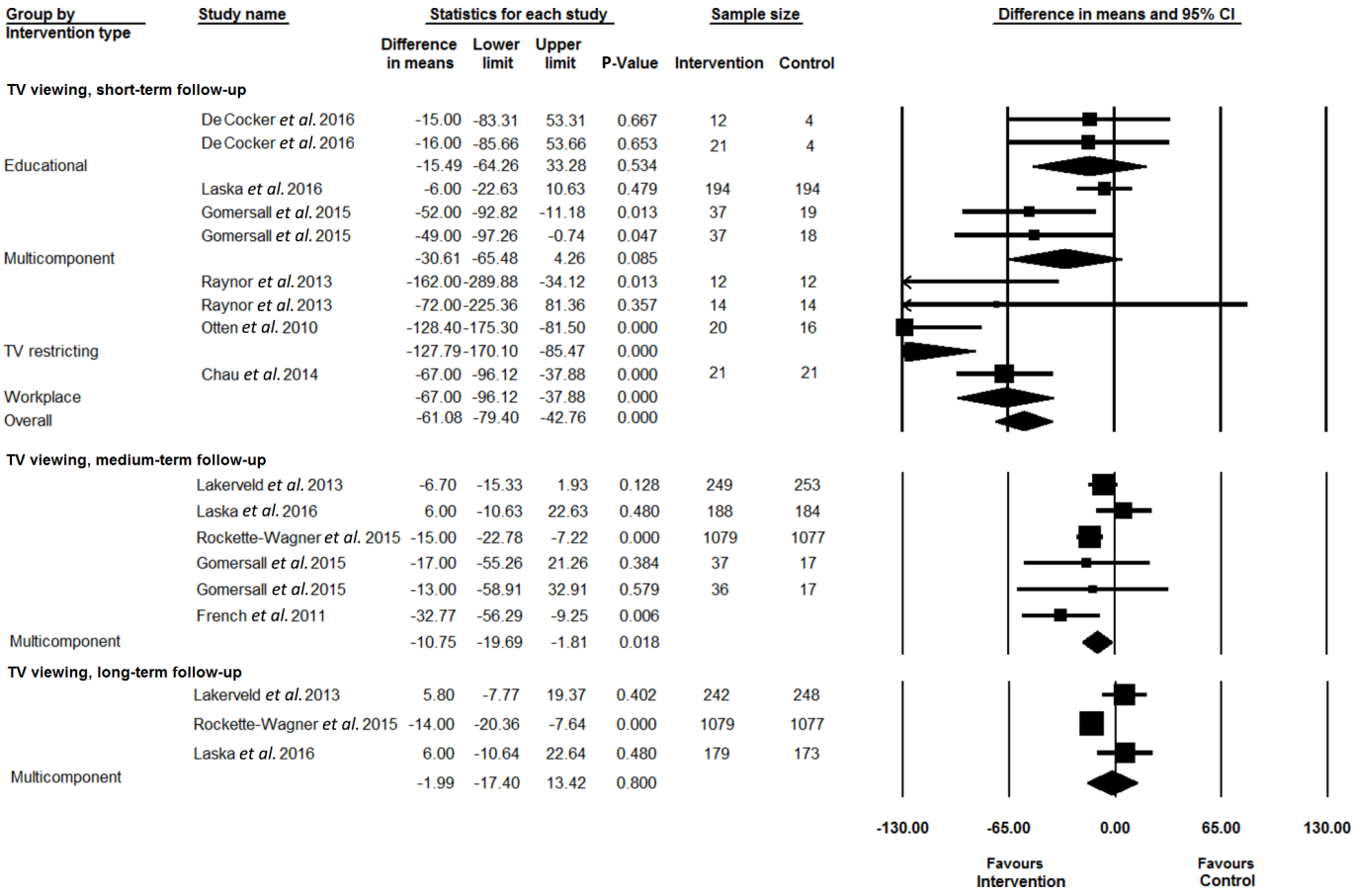

Figure 4 Forest plot showing effects of interventions on television (TV) viewing sitting time.

Our findings are consistent with those of two prior systematic reviews[46 47] that primarily included studies that assessed restricting access by using TV control devices. We found that other interventions, such as educational intervention,[16] may have impact on TV viewing time, but it is potentially somewhat smaller than for 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 hypothesised that reducing occupational sedentary time will result in compensatory effects (ie, increases 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 behaviour interventions at work made people aware of the potential

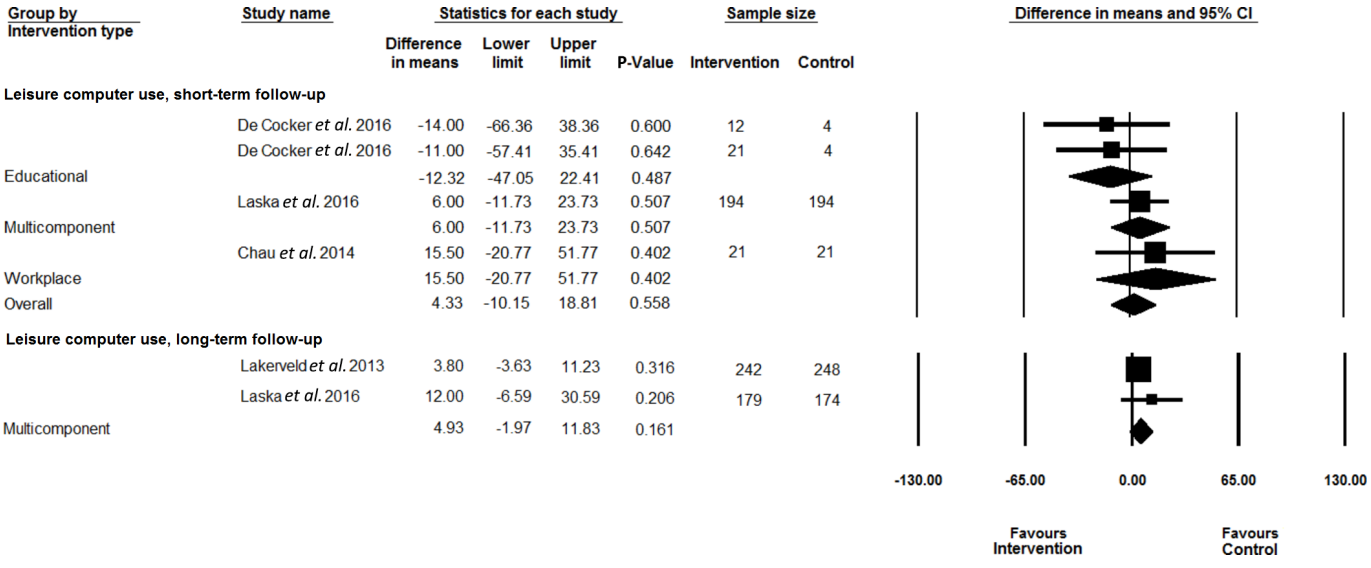

Figure 5 Forest plot showing effects of interventions on leisure computer use sitting time.

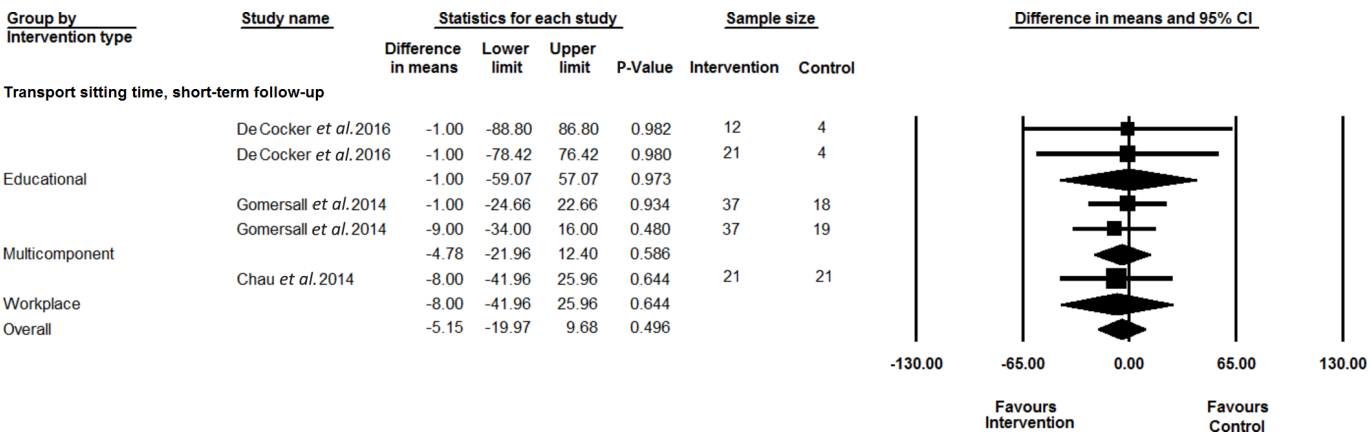

Figure 6 Forest plot showing effects of interventions on total transport sitting time.

hazards of sitting, not only reducing sitting time at work but potential generalising to behaviours 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 behaviour, and their effects on transport sitting time should, therefore, 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 behaviour 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 behaviour in this age group.[51 52] Hence, interventions targeting reductions 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.

No significant reduction in sedentary behaviour was found for educational interventions. Multicomponent interventions were found only to be effective in reducing TV viewing time in the medium term. However, this finding needs to be interpreted with caution 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 behaviour. It is unknown if reducing their use may have an impact on population sedentary behaviour. Various other strategies to reduce leisure sitting time like standing during commercial breaks,[53] using active gaming platforms[47] and use of new technologies (eg, apps delivered on smartphones and tablets)[15 54–56] may also need to be examined in future trials.

Evidence on the health effects of interventions targeting sedentary behaviour reductions is limited and equivocal. For example, a recent large intervention trial by Healy *et al*[57] did not find significant effects of reducing sitting time on most cardiometabolic risk biomarkers considered in the study,[57] while several observational studies reported a favourable association of reallocating sedentary behaviour to light or moderate-to-vigorous intensity physical activity with cardiometabolic biomarkers,[58–60] depressive symptoms[61] and mortality risk.[45 62 63] The findings from observational studies suggest that reallocating 30 min of sedentary behaviour to light physical activity leads to 1.9% lower triglycerides,[59] 2.4% lower insulin[59] and a 20% reduction in the mortality risk at 5-year follow-up.[63] Although in the 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.

Most interventions aimed at reducing one or two domains of sedentary behaviour. However, any reduction in one domain of sedentary behaviour 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 behaviours (eg, TV viewing may be replaced by listening to music while sitting or seated computer use).[64] Therefore, future non-occupational sedentary behaviour interventions should consider including components that target each domain separately and consider ways to replace one sedentary behaviour with a more active alternative.

A review by Gardner *et al*[65] indicated that interventions for adults that are primarily aimed at reducing sedentary behaviour rather than increasing physical activity seem to be most promising in reducing sedentary behaviour. 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 min/day was suggested to have the potential to produce clinically meaningful positive effects on health,[45 58–63] in most intervention studies, it was not clear to which component of time-use non-occupational sedentary time was reallocated, because all the remaining activity-related and inactivity-related components of the 24-hour day, that is, sleeping, quiet standing, light physical activity and moderate-to-vigorous physical activity, were not assessed. The distribution of time spent in sedentary behaviour, sleep, light physical activity and moderate-to-vigorous physical activity seems to be significantly associated with a variety of health outcomes.[66] 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.[67] Furthermore, it has been shown that the clustering of unhealthy lifestyle behaviours, such as low physical activity, high sedentary behaviour and poor sleep duration, may be associated with obesity.[68] Future intervention trials might, therefore, need to consider tracking the reduction/increase in a specific behaviour and the distribution of time over all the above-mentioned time-use components. It is important to note that some sedentary behaviours (eg, socialising/reading) may provide health benefits, such as improved mental well-being, despite being conducted in a seated position.[69 70] Sedentary behaviour, therefore, cannot be characterised as ultimately 'unhealthy'.

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 accessors. Most studies included in the meta-analyses assessed sedentary behaviour using self-reports. While self-reports may have lower reliability than some device-based measures of sedentary behaviour, they have significant comparative advantages for assessing domain-specific 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-report, their data do not allow for discerning between domains of sitting time.[72] Additionally, motion sensors that 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 consider using both device-based measurements 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 determined whether the screen time was spent sitting or 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.

CONCLUSIONS

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

What is already known?

- Sedentary behaviour is associated with increased risk of all-cause mortality, cardiovascular disease, type 2 diabetes and site-specific cancer.
- Television (TV) viewing is the most prevalent leisure activity, often accounting for more than a half of total leisure time.
- The use of sedentary forms of commuting has largely increased over the last several decades due to increased car ownership in high-income countries.

What are the findings?

- Public health interventions are likely to reduce total leisure sedentary time among adults on average by 30 min/day.
- TV viewing interventions among adults are likely to result to an average reduction of 34 min/day in the short term and around 11 min/day in the medium term.
- These intervention effects may be considered relatively small and their clinical and public health significance is unknown.
- There is a lack of high-quality randomised controlled trials assessing the effectiveness of interventions for reducing sedentary behaviour in non-occupational domains, particularly among older adults.

Contributors NS and ZP conceived the idea for the review. NS, ZP, SJHB and JAB conceptualised the review. NS took the lead in writing the protocol. NS and ZP designed the systematic search strategies. NS and HP conducted the study selection. NS and GW did the data extraction. NS and JG did risk of bias assessment and GRADE assessment. NS and ZP conducted the data analysis. NS drafted the initial manuscript. ZP, GW, JG, AP, SJHB, JAB and HP contributed to writing the manuscript.

Competing interests SJHB received a sit-to-stand desk from Ergotron from 2012 to 2014, received consultancy fees from Halpern PR paid to the Victoria University, and gave professional advice to Active Working and Get Britain Standing and Bluearth. JAB had a research fellowship partially funded by Fitness Australia, a not-for-profit association.

Provenance and peer review Not commissioned; externally peer reviewed.

Author note This article is a part of a PhD project of the first author, NS, supervised by AP, SJHB and ZP (principal supervisor).

REFERENCES

1 Loyen A, van der Ploeg HP, Bauman A, *et al*. European sitting championship: prevalence and correlates of self-reported sitting time in the 28 European Union Member States. *PLoS One* 2016;11:e0149320.
2 Ng SW, Popkin BM. Time use and physical activity: a shift away from movement across the globe. *Obes Rev* 2012;13:659–80.
3 Harvey JA, Chastin SF, Skelton DA. How sedentary are older people? a systematic review of the amount of sedentary behavior. *J Aging Phys Act* 2015;23:471–87.
4 Thorp AA, Owen N, Neuhaus M, *et al*. Sedentary behaviors and subsequent health outcomes in adults a systematic review of longitudinal studies, 1996-2011. *Am J Prev Med* 2011;41:207–15.
5 Rezende LFM, Sá TH, Mielke GI, *et al*. All-cause mortality attributable to sitting time: analysis of 54 countries worldwide. *Am J Prev Med* 2016;51:253–63.
6 Lee IM, Shiroma EJ, Lobelo F, *et al*. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet* 2012;380:219–29.
7 Shuval K, Gabriel KP, Leonard T. TV viewing and BMI by race/ethnicity and socio-economic status. *PLoS One* 2013;8:e63579.
8 Labor USDo. *American time use survey summary*, 2016.
9 Sugiyama T, Ding D, Owen N. Commuting by car: weight gain among physically active adults. *Am J Prev Med* 2013;44:169–73.
10 Bennie JA, Pedisic Z, Timperio A, *et al*. Total and domain-specific sitting time among employees in desk-based work settings in Australia. *Aust N Z J Public Health* 2015;39:237–42.
11 Rapino MBaM. *Commuting in the United States: 2009. ACS-15*. Washington, DC: U.S. Census Bureau, 2011.
12 Statistics ABo. *Environmental issues: waste management and transport use*, 2009.
13 McCormack GR, Virk JS. Driving towards obesity: a systematized literature review on the association between motor vehicle travel time and distance and weight status in adults. *Prev Med* 2014;66:49–55.
14 Verweij LM, Proper KI, Weel AN, *et al*. The application of an occupational health guideline reduces sedentary behaviour and increases fruit intake at work: results from an RCT. *Occup Environ Med* 2012;69:500–7.
15 Spring B, Schneider K, McFadden HG, *et al*. Multiple behavior changes in diet and activity: a randomized controlled trial using mobile technology. *Arch Intern Med* 2012;172:789–96.
16 De Cocker K, De Bourdeaudhuij I, Cardon G, *et al*. The effectiveness of a web-based computer-tailored intervention on workplace sitting: a randomized controlled trial. *J Med Internet Res* 2016;18:e96.
17 Otten JJ, Jones KE, Littenberg B, *et al*. Effects of television viewing reduction on energy intake and expenditure in overweight and obese adults: a randomized controlled trial. *Arch Intern Med* 2009;169:2109–15.
18 Chau JY, Daley M, Dunn S, *et al*. The effectiveness of sit-stand workstations for changing office workers' sitting time: results from the Stand@Work randomized controlled trial pilot. *Int J Behav Nutr Phys Act* 2014;11:127.
19 Sallis JF, Cervero RB, Ascher W, *et al*. An ecological approach to creating active living communities. *Annu Rev Public Health* 2006;27:297–322.
20 Shrestha N, Kukkonen-Harjula KT, Verbeek JH, *et al*. Workplace interventions for reducing sitting at work. *Cochrane Database Syst Rev* 2016;3:CD010912.
21 Chu AH, Ng SH, Tan CS, *et al*. A systematic review and meta-analysis of workplace intervention strategies to reduce sedentary time in white-collar workers. *Obes Rev* 2016;17:467–81.

22 Thraen-Borowski KM, Ellingson LD, Meyer JD, *et al*. Nonworksite interventions to reduce sedentary behavior among adults: a systematic review. *Transl J Am Coll Sports Med* 2017;2:68–78.
23 Moher D, Liberati A, Tetzlaff J, *et al*. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *J Clin Epidemiol* 2009;62:1006–12.
24 Higgins JPT, Green S. *Cochrane handbook for systematic reviews of interventions version 5.1.0*: The Cochrane Collaboration, 2011. http://handbook.cochrane.org
25 Pesola A. *Reduced muscle inactivity, sedentary: effectiveness of a one-year family-based cluster randomized controlled trial*. Jyväskylä, Finland: PhD, University of Jyväskylä, 2016.
26 French SA, Gerlach AF, Mitchell NR, *et al*. Household obesity prevention: Take action-a group-randomized trial. *Obesity* 2011;19:2082–8.
27 Sternfeld B, Block C, Quesenberry CP, *et al*. Improving diet and physical activity with ALIVE: a worksite randomized trial. *Am J Prev Med* 2009;36:475–83.
28 Campbell MK, Mollison J, Grimshaw JM. Cluster trials in implementation research: estimation of intracluster correlation coefficients and sample size. *Stat Med* 2001;20:391–9.
29 Drenowatz C, Gribben N, Wirth MD, *et al*. The association of physical activity during weekdays and weekend with body composition in young adults. *J Obes* 2016;2016:1–8.
30 Rongwei Fu BWV, Shamliyan TA, O'Neil ME, *et al*. Handling continuous outcomes in quantitative synthesis. *Methods guide for comparative effectiveness reviews*. Rockville, MD: Agency for Healthcare Research and Quality, 2013.
31 Guyatt G, Oxman AD, Akl EA, *et al*. GRADE guidelines: 1. Introduction-GRADE evidence profiles and summary of findings tables. *J Clin Epidemiol* 2011;64:383–94.
32 Guyatt GH, Oxman AD, Kunz R, *et al*. GRADE guidelines 6. Rating the quality of evidence--imprecision. *J Clin Epidemiol* 2011;64:1283–93.
33 Dutta N, Koepp GA, Stovitz SD, *et al*. Using sit-stand workstations to decrease sedentary time in office workers: a randomized crossover trial. *Int J Environ Res Public Health* 2014;11:6653–65.
34 Gomersall S, Maher C, English C, *et al*. Time regained: when people stop a physical activity program, how does their time use change? A randomised controlled trial. *PLoS One* 2015;10:e0126665.
35 Hu G, Tian H, Zhang F, *et al*. Tianjin gestational diabetes mellitus prevention program: study design, methods, and 1-year interim report on the feasibility of lifestyle intervention program. *Diabetes Res Clin Pract* 2012;98:508–17.
36 Lakerveld J, Bot SD, van der Ploeg HP, *et al*. The effects of a lifestyle intervention on leisure-time sedentary behaviors in adults at risk: the Hoorn Prevention Study, a randomized controlled trial. *Prev Med* 2013;57:351–6.
37 Laska MN, Lytle LA, Nanney MS, *et al*. Results of a 2-year randomized, controlled obesity prevention trial: Effects on diet, activity and sleep behaviors in an at-risk young adult population. *Prev Med* 2016;89:230–6.
38 Petersen CB, Severin M, Hansen AW, *et al*. A population-based randomized controlled trial of the effect of combining a pedometer with an intervention toolkit on physical activity among individuals with low levels of physical activity or fitness. *Prev Med* 2012;54:125–30.
39 Raynor HA, Steeves EA, Bassett DR, *et al*. Reducing TV watching during adult obesity treatment: two pilot randomized controlled trials. *Behav Ther* 2013;44:674–85.
40 Rockette-Wagner B, Edelstein S, Venditti EM, *et al*. The impact of lifestyle intervention on sedentary time in individuals at high risk of diabetes. *Diabetologia* 2015;58:1198–202.
41 Steeves JA, Bassett DR, Fitzhugh EC, *et al*. Can sedentary behavior be made more active? A randomized pilot study of TV commercial stepping versus walking. *Int J Behav Nutr Phys Act* 2012;9:95.
42 Tomayko EJ, Prince RJ, Cronin KA, *et al*. The healthy children, strong families intervention promotes improvements in nutrition, activity, and body weight in American Indian families with young children - ERRATUM. *Public Health Nutr* 2017;20:380.
43 Aadahl M, Linneberg A, Møller TC, *et al*. Motivational counseling to reduce sitting time: a community-based randomized controlled trial in adults. *Am J Prev Med* 2014;47:576–86.
44 Gomersall SR, Norton K, Maher C, *et al*. In search of lost time: when people undertake a new exercise program, where does the time come from? A randomized controlled trial. *J Sci Med Sport* 2015;18:43–8.
45 Wijndaele K, Sharp SJ, Wareham NJ, *et al*. Mortality risk reductions from substituting screen time by discretionary activities. *Med Sci Sports Exerc* 2017;49:1111–9.
46 Wu L, Sun S, He Y, *et al*. The effect of interventions targeting screen time reduction: a systematic review and meta-analysis. *Medicine* 2016;95:e4029.
47 Ramsey Buchanan L, Rooks-Peck CR, Finnie RKC, *et al*. Reducing recreational sedentary screen time: a community guide systematic review. *Am J Prev Med* 2016;50:402–15.
48 Mansoubi M, Pearson N, Biddle SJ, *et al*. Using sit-to-stand workstations in offices: is there a compensation effect? *Med Sci Sports Exerc* 2016;48:720–5.
49 Saunders LE, Green JM, Petticrew MP, *et al*. What are the health benefits of active travel? A systematic review of trials and cohort studies. *PLoS One* 2013;8:e69912.
50 Copeland JL, Ashe MC, Biddle SJ, *et al*. Sedentary time in older adults: a critical review of measurement, associations with health, and interventions. *Br J Sports Med* 2017;51:1539.
51 Asaoka S, Fukuda K, Tsutsui Y, *et al*. Does television viewing cause delayed and/or irregular sleep?wake patterns? *Sleep Biol Rhythms* 2007;5:23–7.
52 Lewis LK, Rowlands AV, Gardiner PA, *et al*. Small steps: preliminary effectiveness and feasibility of an incremental goal-setting intervention to reduce sitting time in older adults. *Maturitas* 2016;85:64–70.
53 Busschaert C, Ridgers ND, De Bourdeaudhuij I, *et al*. Socio-demographic, social-cognitive, health-related and physical environmental variables associated with context-specific sitting time in belgian adolescents: a one-year follow-up study. *PLoS One* 2016;11:e0167553.
54 Hadgraft N, Owen N, Behavior S. Sedentary behavior and health: broadening the knowledge base and strengthening the science. *Res Q Exerc Sport* 2017;88:123–9.
55 King AC, Hekler EB, Grieco LA, *et al*. Harnessing different motivational frames via mobile phones to promote daily physical activity and reduce sedentary behavior in aging adults. *PLoS One* 2013;8:e62613.
56 Stephenson A, McDonough SM, Murphy MH, *et al*. Using computer, mobile and wearable technology enhanced interventions to reduce sedentary behaviour: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act* 2017;14:105.
57 Healy GN, Winkler EAH, Eakin EG, *et al*. A cluster RCT to reduce workers' sitting time: impact on cardiometabolic biomarkers. *Med Sci Sports Exerc* 2017;49:2032–9.
58 Whitaker KM, Buman MP, Odegaard AO, *et al*. Sedentary behaviors and cardiometabolic risk, an isotemporal substitution analysis. *Am J Epidemiol* 2017.
59 Buman MP, Winkler EA, Kurka JM, *et al*. Reallocating time to sleep, sedentary behaviors, or active behaviors: associations with cardiovascular disease risk biomarkers, NHANES 2005–2006. *Am J Epidemiol* 2014;179:323–34.
60 Falconer CL, Page AS, Andrews RC, *et al*. The potential impact of displacing sedentary time in adults with type 2 diabetes. *Med Sci Sports Exerc* 2015;47:2070–5.
61 Mekary RA, Lucas M, Pan A, *et al*. Isotemporal substitution analysis for physical activity, television watching, and risk of depression. *Am J Epidemiol* 2013;178:474–83.
62 Loprinzi PD, Loenneke JP. Mortality risk and perceived quality of life as a function of waking time in discretionary movement-based behaviors: isotemporal substitution effects. *Qual Life Res* 2017;26:343–8.
63 Fishman EI, Steeves JA, Zipunnikov V, *et al*. Association between objectively measured physical activity and mortality in NHANES. *Med Sci Sports Exerc* 2016;48:1303–11.
64 Biddle SJ, Petrolini I, Pearson N. Interventions designed to reduce sedentary behaviours in young people: a review of reviews. *Br J Sports Med* 2014;48:182–6.
65 Gardner B, Smith L, Lorencatto F, *et al*. How to reduce sitting time? A review of behaviour change strategies used in sedentary behaviour reduction interventions among adults. *Health Psychol Rev* 2016;10:89–112.
66 Chastin SF, Palarea-Albaladejo J, Dontje ML, *et al*. Combined effects of time spent in physical activity, sedentary behaviors and sleep on obesity and cardio-metabolic health markers: a novel compositional data analysis approach. *PLoS One* 2015;10:e0139984.
67 Pedišić Ž, Dumuid D, Olds TS. Integrating sleep, sedentary behaviour, and physical activity research in the emerging field of time-use epidemiology: definitions, concepts, statistical methods, theoretical framework, and future directions. *Kinesiology* 2017;49:252–69.
68 Cassidy S, Chau JY, Catt M, *et al*. Low physical activity, high television viewing and poor sleep duration cluster in overweight and obese adults; a cross-sectional study of 398,984 participants from the UK Biobank. *Int J Behav Nutr Phys Act* 2017;14:57.
69 Alpass FM, Neville S, Loneliness NS. Loneliness, health and depression in older males. *Aging Ment Health* 2003;7:212–6.
70 Hertzog C, Kramer AF, Wilson RS, *et al*. Enrichment effects on adult cognitive development: can the functional capacity of older adults be preserved and enhanced? *Psychol Sci Public Interest* 2008;9:1–65.
71 Healy GN, Clark BK, Winkler EA, *et al*. Measurement of adults' sedentary time in population-based studies. *Am J Prev Med* 2011;41:216–27.
72 Pedišić Ž, Bauman A. Accelerometer-based measures in physical activity surveillance: current practices and issues. *Br J Sports Med* 2015;49:219–23.