REVIEW   **Open Access**

The effectiveness and complexity of interventions targeting sedentary behaviour across the lifespan: a systematic review and meta-analysis

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Abstract

Background: Evidence suggests that sedentary behaviour (SB) is associated with poor health outcomes. SB at any age may have significant consequences for health and well-being and interventions targeting SB are accumulating. Therefore, the need to review the effects of multicomponent, complex interventions that incorporate effective strategies to reduce SB are essential.

Methods: A systematic review and meta-analysis were conducted investigating the impact of interventions targeting SB across the lifespan. Six databases were searched and two review authors independently screened studies for eligibility, completed data extraction and assessed the risk of bias and complexity of each of the included studies.

Results: A total of 77 adult studies (*n*=62, RCTs) and 84 studies (*n*=62, RCTs) in children were included. The findings demonstrated that interventions in adults when compared to active controls resulted in non-significant reductions in SB, although when compared to inactive controls significant reductions were found in both the short (MD -56.86; 95%CI -74.10, -39.63; n=4632; I^2 83%) and medium-to-long term (MD -20.14; 95%CI -34.13, -6.16; n=4537; I^2 65%). The findings demonstrated that interventions in children when compared to active controls may lead to relevant reductions in daily sedentary time in the short-term (MD -59.90; 95%CI -102.16, -17.65; n=267; I^2 86%), while interventions in children when compared to inactive controls may lead to relevant reductions in the short-term (MD -25.86; 95%CI -40.77, -10.96; n=9480; I^2 98%) and medium-to-long term (MD -14.02; 95%CI -19.49, -8.55; n=41, 138; I^2 98%). The assessment of complexity suggested that interventions may need to be suitably complex to address the challenges of a complex behaviour such as SB, but demonstrated that a higher complexity score is not necessarily associated with better outcomes in terms of sustained long-term changes.

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Conclusions: Interventions targeting reductions in SB have been shown to be successful, especially environmental interventions in both children and adults. More needs to be known about how best to optimise intervention effects. Future intervention studies should apply more rigorous methods to improve research quality, considering larger sample sizes, randomised controlled designs and valid and reliable measures of SB.

Keywords: Sedentary behaviour, Systematic review, Meta-analysis, Complex interventions, Children, Adults

Introduction

Sedentary behaviour (SB) is defined as any waking behaviour where the energy expenditure is low and the predominant posture is sitting, reclining or lying [1]. SB is a multi-faceted and complex behaviour which is accumulated in multiple domains such as work, school or home, during transport and leisure time [2]. Accumulating evidence suggests that SB is associated with poor health outcomes [3, 4]. These relationships appear to remain after statistical adjustment for physical activity (PA) levels. However, recent research in adults has indicated that MVPA can attenuate the risk of all-cause mortality of high levels of SB [5, 6]. There remains therefore some debate as to the independence or interdependence of these two behaviours [7]. SB is an established risk factor for cardiovascular disease, type 2 diabetes and all-cause mortality [8, 9], as well as an emerging risk factor for several cancers [10, 11]. In the UK, it has been estimated that chronic disease associated with SB costs the NHS £0.7bn per annum in direct healthcare costs [12].

Accordingly, many European countries have now incorporated recommendations to reduce SB and break up sitting time as part of their PA guidelines [13, 14]. The SB activities and contexts of primary concern include TV viewing and other screen-focused behaviours as well as prolonged sitting within domestic, school, workplace and transportation environments [15, 16]. Additionally, throughout the various stages of life, people spend time in different social (i.e. friends, students, colleagues, family) and organisational environments (i.e. school and work) [17], and so SB is age and life stage dependent. SB at any age may have significant consequences for health and well-being [18–20]. It is also influenced by multiple factors that operate at an individual, social and institutional level. Consequently, interventions should be context-specific and relevant to the population segments being targeted [17, 21], and the need to develop and evaluate behaviour-specific, multicomponent, complex interventions that incorporate effective strategies to reduce SB are essential.

A variety of strategies and frameworks have been applied to SB interventions including, individualised and community-based tailoring, incorporating environmental, behavioural or mixed approaches to reducing sitting time. Environmental interventions may aim to modify home, school and/or workplace layouts as well as restructuring outdoor spaces and/or facilities to reduce sedentary time [22, 23]. Behavioural interventions focus on theory driven approaches that have the potential to influence behavioural determinants to promote healthier behaviours [24, 25]. Mixed approach interventions can include a combination of both environmental and behavioural components [26].

While there is limited information about the minimal amount of SB change required to produce meaningful health benefits, a recent systematic review by Peachey *et al.* [27] suggested that a 30-minute per day reduction in SB could be an effective threshold for observing long-term health benefits, such as improving cardiometabolic risk biomarkers. One of the main challenges when assessing the effectiveness of interventions, is addressing the issues that arise when a range of approaches have been applied and a variety of components are included in the intervention design to improve the same outcome. The Medical Research Council (MRC) published an updated framework for the development and evaluation of complex interventions in 2019 [28]. Within this framework, one of the key considerations is understanding the range of effects and how they vary dependent on the context (i.e. among recipients, between sites and over time) and the causes of that variation (i.e. variability in individual level outcomes). In addition, the guidelines consider the active components (i.e. variants of a package of care) and complexity of the intervention and how they influence or impact the effect [28]. One of the novel aspects of this review is that, in addition to establishing effectiveness, this review aims to understand the causal mechanisms (i.e. something that can explain the observed effect) that produce effective outcomes (i.e. reduce SB) that can be applied to intervention development. Although a number of previous reviews have been conducted on the effectiveness of SB interventions, most focus on specific settings [23] or population groups [27, 29, 30]. Interventions in these reviews vary in their complexity, but this has not previously been investigated. There is therefore a need to comprehensively review the full range of interventions by both setting and target, taking into account both effectiveness and complexity, as these factors contribute to the scaling up of public

health programmes to address SB in the population. Therefore, the aim of this systematic review was to synthesise and evaluate the effectiveness of SB interventional approaches to reduce sedentary time across the lifespan and establish the relationship between complexity and effectiveness.

Methods

Study Inclusion Criteria

The process of review was reported according to the PRISMA Statement guidelines [31]. Studies were eligible for inclusion if they met the following criteria: [1] any intervention of any length, frequency, and intensity targeting SB; [2] study designs with a control or comparison group (e.g. usual care, alternative intervention) where the primary aim was to change the SB of individuals assessed by self-report (e.g., questionnaires) or device-based measures (e.g., accelerometer data); [3] community-dwelling (i.e. not institutional care); [4] SB was a reported outcome and [5] published in a peer-reviewed English language journal.

According to our aim of assessing effectiveness of the interventions, all outcomes relating to SB (self-reported or device-based measures) such as sedentary time, leisure or occupational sitting time, transport time, screen, media or television time were included. For the assessment of the effectiveness of SB interventions, studies had to include a control group. As per Martin *et al.* [29], we included studies with any type of comparator, considering inactive controls such as; no intervention, waiting list, attention control (e.g. general health information), and usual care (e.g. general lifestyle counselling), as well as active comparisons against alternative treatment conditions (e.g. a structured exercise programme).

Search Strategy

Relevant databases were searched using a search strategy adapted from previous reviews [29, 30]. A comprehensive search was performed up to 1 May 2019 using MEDLINE, PsycINFO, Web of Science, EMBASE, Physical Education Index, and SPORTDiscus. Keywords and title/abstract words related to exposure (sedentary lifestyle, sitting or lying, screen time, media time, driving) and intervention (intervention studies, health promotion, health education, behaviour change) were used. The search strategy was developed by authors (ATK, MAT and NEB) and is provided in Supplement A. Reference lists of the included studies and related systematic reviews were examined to identify any additional studies. Authors (ATK, NEB, MAT and JJW) independently reviewed titles and abstracts for inclusion. Two authors (NEB and MAT) then reviewed the full text of the remaining articles to determine final inclusion. All cases of disagreement were resolved by a third-party adjudicator, with included studies agreed by consensus.

Data Extraction

Characteristics of the included studies were independently extracted by two authors (NEB, JJW, IIM, PC, MGG, LCP, KW, SBA and MAT) including: sample size, age of participants, study design, intervention type, setting, SB outcome, assessment tool, outcome measure, length of intervention, underlying behavioural theory, and details of the control or comparison group. SB data (mean, standard deviation (SD)) were extracted and entered into Review Manager (RevMan) (*Version 5.3. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014*).

Risk of Bias

Authors independently assessed the risk of bias of each of the included studies using an adaptation of the Cochrane risk of bias tool [32]. Studies were appraised based on selection bias (i.e. random sequence generation, allocation concealment), detection bias (i.e. blinding of study personnel), attrition bias (high is less than 70% at follow-up) and the validity of the outcome measure included in the study (i.e. device-based versus self-reported measures). A judgement of 'low risk', 'high risk', or 'unclear risk' of bias was selected for each of the domains. We considered that studies had a high risk of bias when at least one of the criteria were judged as having a high risk of bias in any one of the criteria. Overall risk of bias was assessed as unclear if one or more of the criteria was assessed as unclear, but none were assessed as having a high risk of bias.

GRADE Assessment

The GRADE (Grading of Recommendations, Assessment, Development and Evaluations) is a systematic framework developed by Cochrane for rating the certainty of evidence in systematic reviews and other evidence syntheses [33]. Two authors (NEB and IIM) independently assessed the quality of evidence using the Cochrane GRADE assessment tool. An overall GRADE quality rating was applied to a body of evidence across outcomes, usually by taking the lowest quality of evidence from all the outcomes that were critical to decision making. For each of risk of bias, imprecision, inconsistency, indirectness, and publication bias, authors had the option of decreasing their level of certainty one or two levels based on the evidence available for that outcome. All cases of disagreement were resolved by a third-party (MR), with the overall certainty of evidence agreed by consensus.

Complexity Assessment

The Cochrane Collaboration's intervention Complexity Assessment Tool for Systematic Reviews was used to assess the complexity of the included intervention studies [34]. The tool comprises ten dimensions and facilitates an in-depth, systematic assessment of the complexity of interventions. The level of complexity for each of the included studies was determined based on the assessment levels of the core and optional dimensions. Each dimension was graded as 'simple', 'moderately complex' or 'complex' based on the criteria for each of the ten components. Studies were grouped based on intervention type (i.e. behavioural, environmental or mixed) for interventions targeting adults (18 years and over) and children (aged under 18 years). The global score for each included study was calculated by the sum of the individual rating scores (simple = 1, moderately complex = 2, complex = 3). Two authors independently appraised intervention complexity of all included studies, with discrepancies resolved through discussion.

Statistical Analysis

The included studies were grouped depending on intervention type (behavioural, environmental and mixed), length of follow-up (≤6 months, >6 months), age group of participants (children and adults), and control (active and inactive). A separate meta-analysis was performed based on the groupings listed above to calculate the pooled effect sizes for SB. The difference between the intervention groups and control/comparison group in the mean change from baseline to post-intervention and the comparison at follow-up were used as a measure of effect size. Separate meta-analyses were conducted for children and adults as we expected the type, context and outcomes of the interventions to differ based on their life stage. Where study authors reported multiple trial arms in a single trial, only the relevant arms were included. It was assumed that there could be much variation arising from the different populations and study designs. Therefore, prior to data synthesis, the clinical homogeneity with respect of the type of intervention, type of participants and the similarity of outcomes was assessed. Statistical heterogeneity of these groups of interventions was assessed using the I-squared statistic [32]. The meta-analyses were conducted in RevMan (Version *5.3. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014*).

The association between complexity and effectiveness was assessed through the examination of scatter plots where each studies global score for complexity was plotted against effect size (Cohen's D). The strength of association between complexity and effectiveness was assessed using a Spearman's rank order correlation test (IBM SPSS Statistics software, v23. Armonk, NY: IBM Corp) where *r*-value and significance (*p*-value) statistics were considered.

Results

Search Results

The search of the selected databases returned 24,130 potentially relevant studies, with 9,206 duplicates removed using Endnote (vX7.7.1. Toronto Canada: Thomson Reuters Cord, 2016). A total of 14,924 potentially relevant studies remained for title, abstract and key word screening. Following full-text screening and eligibility assessment of 426 studies, 161 studies were deemed as relevant and were included in the narrative synthesis, with 126 included in the meta-analysis. Figure 1 presents the identification, screening, eligibility and inclusion of studies within this systematic review [31].

Included Studies

Within the 161 studies included in the narrative synthesis, 77 interventions [35–110] related to adults (mean age range: 26-76 years) while 84 interventions [64, 74, 108, 111–191] targeted children (mean age range: 2-19 years). The adult studies consisted of 62 randomised controlled trials (RCTs) of which nine were cluster RCTs and five were randomised cross-over trials. In addition, 15 studies employed a quasi-experimental design, of which thirteen controlled before and after trials, one was a natural experiment, and one an interrupted time series. The studies in children included 62 RCTs of which 23 were cluster RCTs and two were randomised cross-over trials. A further 22 employed a quasi-experimental design, of which 16 were controlled trials, five cluster controlled before and after trails, and one natural experiment. The control group participants received one of the following conditions: inactive (i.e. no intervention, waitlist control) or active (i.e. alternative intervention, generic health-related advice). Characteristics of the included studies are presented in Supplement B.

Most included studies measured SB using self-reported tools. Within the adult studies, over 10 different self-reported measures were used, including validated, and non-validated questionnaires. Within the studies in children, over 20 different self-reported measures were used, including validated questionnaires, non-validated parent-reported tools, and self-reported tools. The device-based measures used in adult and children studies included: ActivPAL, ActiGraph, and Hookie AM20. Additionally, adult studies included GENEactiv, MyWellness Key, and Sensewear armbands.

Within the meta-analysis, the follow-up length for 37 of the inactive control studies in adults was less than six months of which 20 were behavioural, 10 environmental, and seven were mixed interventions. The remaining 10 inactive control studies in adults included in the meta-

Fig. 1 PRISMA flow diagram [31].
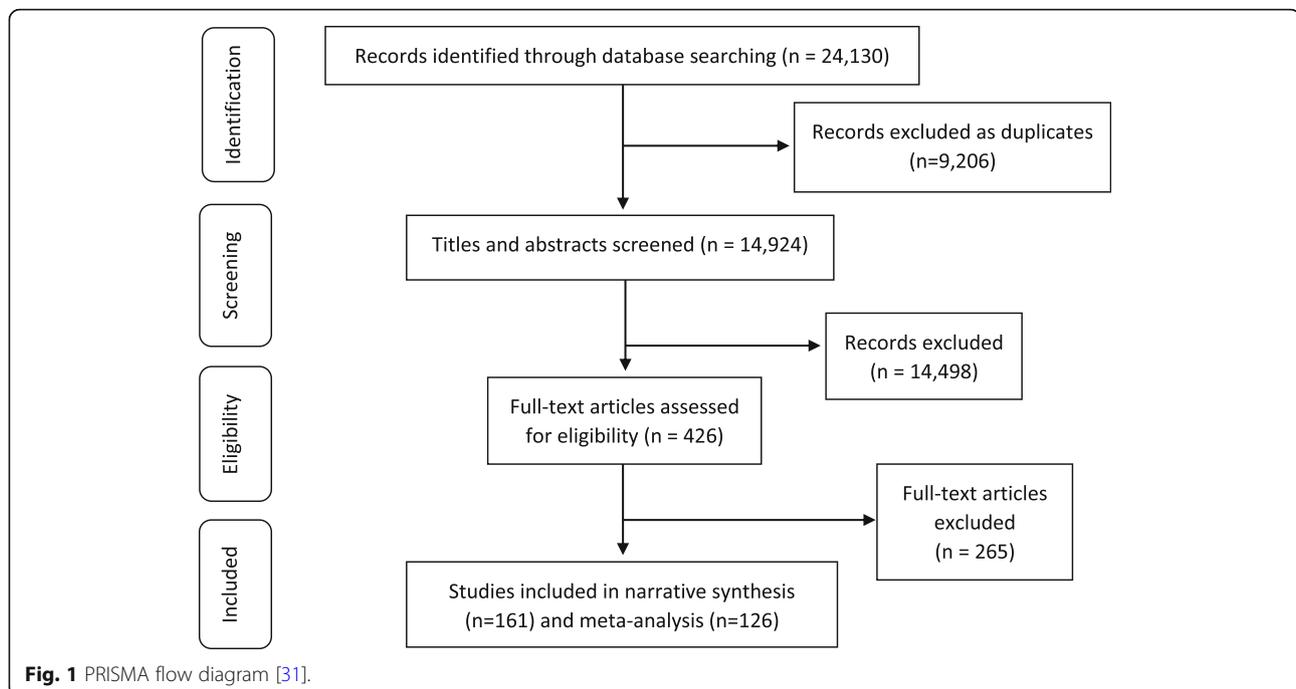
analysis had a follow-up of more than six months of which included five mixed, four behavioural, and one environmental intervention. In 15 of the active control studies in adults, the follow-up was less than six months of which nine were behavioural, five mixed, and one environmental intervention. The remaining four active control studies in adults included in the meta-analysis had a follow-up of more than six months and were mixed interventions.

In 35 of the inactive control studies in children the follow-up was less than six months of which 18 were behavioural, nine were mixed, and eight environmental interventions. The remaining 24 inactive control studies in children included in the meta-analysis had a follow-up of more than six months of which included 16 mixed, six behavioural, and two environmental interventions. In 11 of the active control studies in children the follow-up was less than six months of which four were behavioural and seven were mixed interventions. The remaining three active control studies in children included in the meta-analysis had a follow-up of more than six months of which included two mixed and one behavioural intervention.

Complexity Assessment
Each of the included studies were assessed for the level of complexity of the intervention components using the Cochrane Complexity Assessment Tool [34]. There was significant variety in the level of complexity of the included studies where global scores for complexity ranged from 10/30 (least complex) to 30/30 (most complex),

with the mean score being 17.64 (SD 4.14). Results from the complexity assessment demonstrated that environmental interventions were less complex in both adult and children studies. In both adult and children studies, mixed and behavioural interventions scored as complex in relation to two dimensions including, the active components of the intervention and the behaviours or actions to which the intervention was directed. Mixed interventions carried out in children were scored as complex in relation to the degree to which the effects of the intervention were changed by recipient or provider factors. The complexity star chart for intervention studies in adults is presented in Figure 2 and the complexity star chart for intervention studies in children is presented in Figure 3.

The relationship between complexity and effectiveness by Cohen's D effect size are presented in Figures 4 and 5. A Spearman's rank-order correlation assessed the relationship, resulting in a non-significant relationship (r=-0.23; p=0.799), suggesting that for these interventions, there was no increased effectiveness with more complex interventions.

Risk of Bias Assessment
The individual risk of bias assessment is included in Supplement C.

Adult Interventions (n=77 studies)
Seventeen studies were rated as high risk for selection bias due to lack of detail regarding the randomisation process or because they were non-randomised. Three
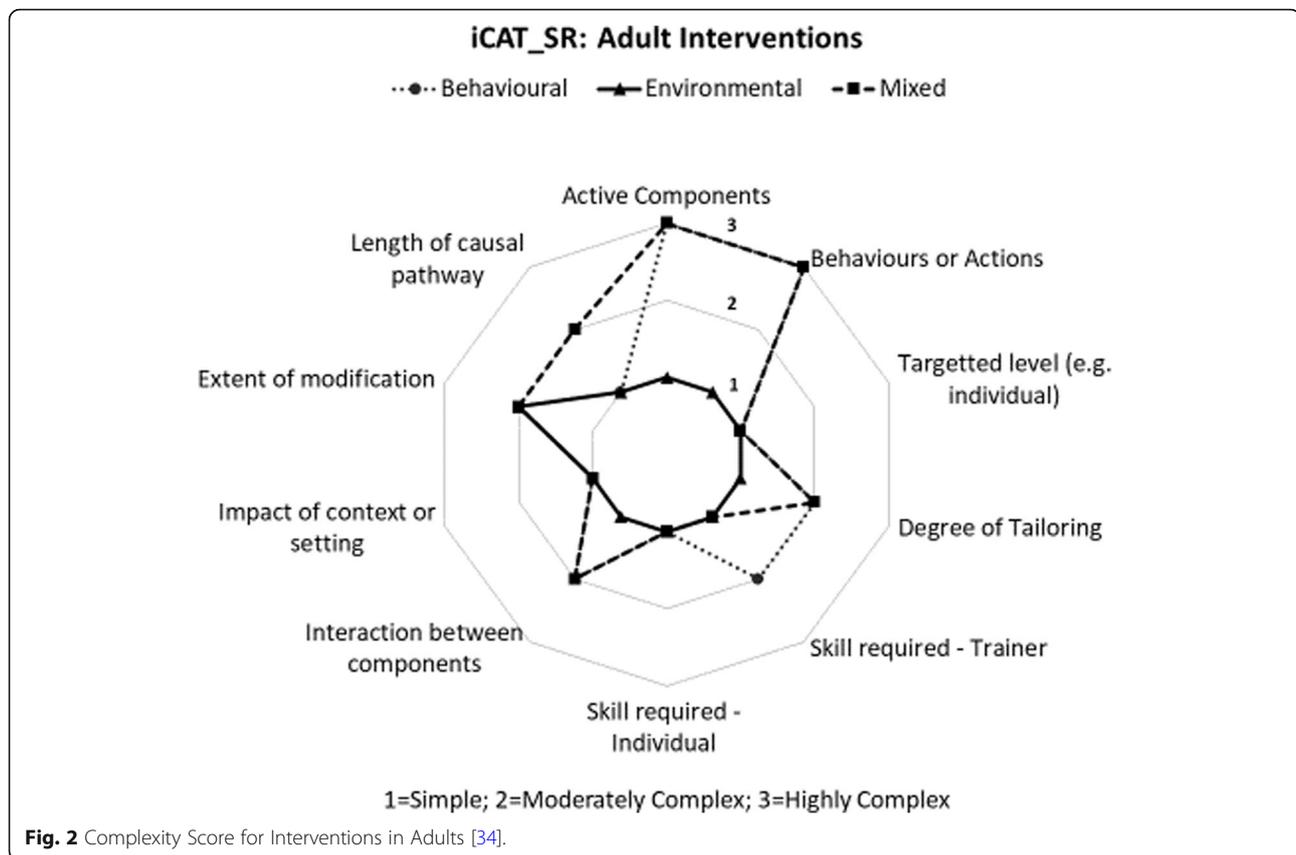
Fig. 2 Complexity Score for Interventions in Adults [34].

studies were rated as unclear due to a lack of information regarding how the random sequence was generated. Regarding detection bias, 26 studies did not report whether the study personnel were blinded to the intervention and were rated to be unclear risk for detection bias. Twenty-six studies were blinded and rated as low risk, with the remaining 25 studies rated as high risk as there was no allocation concealment. Eight studies were rated as a high risk of attrition bias, two studies were rated as unclear as they gave no indication of the number of participants returning for post-intervention follow-up. The validity of the outcome measure included in the study was also assessed for risk of bias. Thirty studies included self-reported measures of SB and were rated as high risk, with the remaining 47 studies rated as low risk due to the inclusion of device-based measures. The largest risk of bias for the adult interventions came from the validity of the outcome measure, with almost 40% of studies including self-reported measures of SB. A summary of the risk of bias assessment in adults is shown in Figure 6.
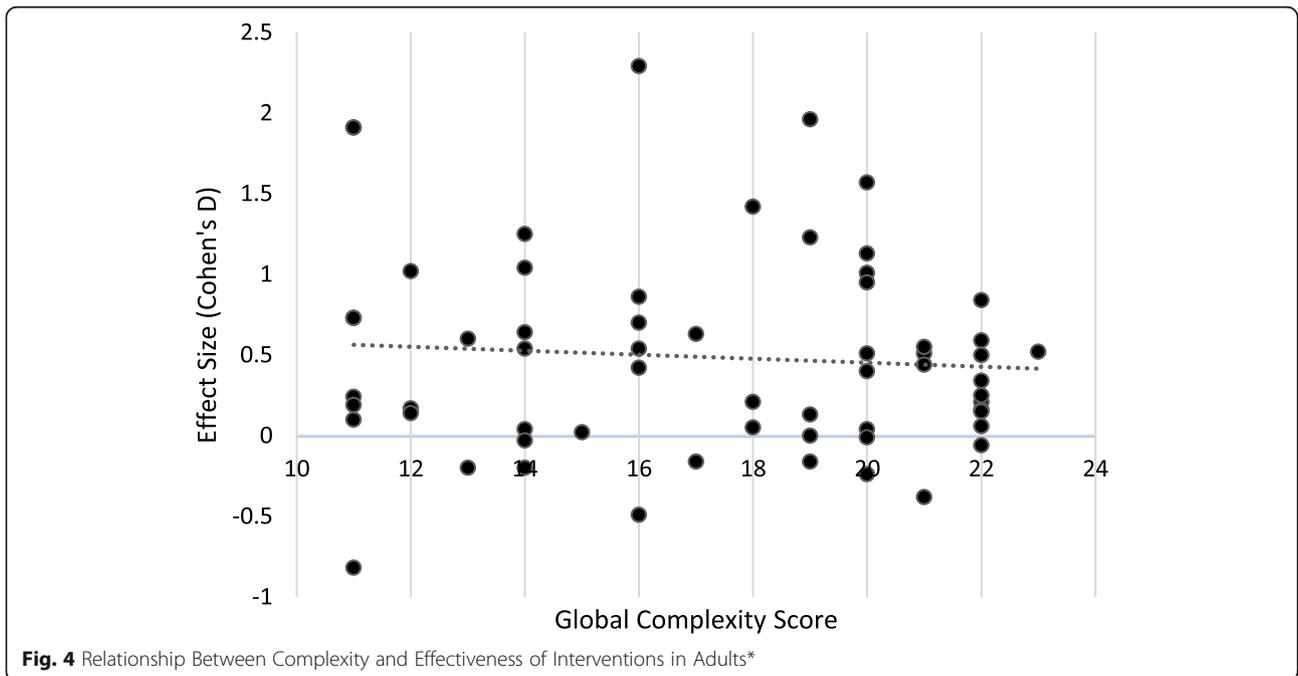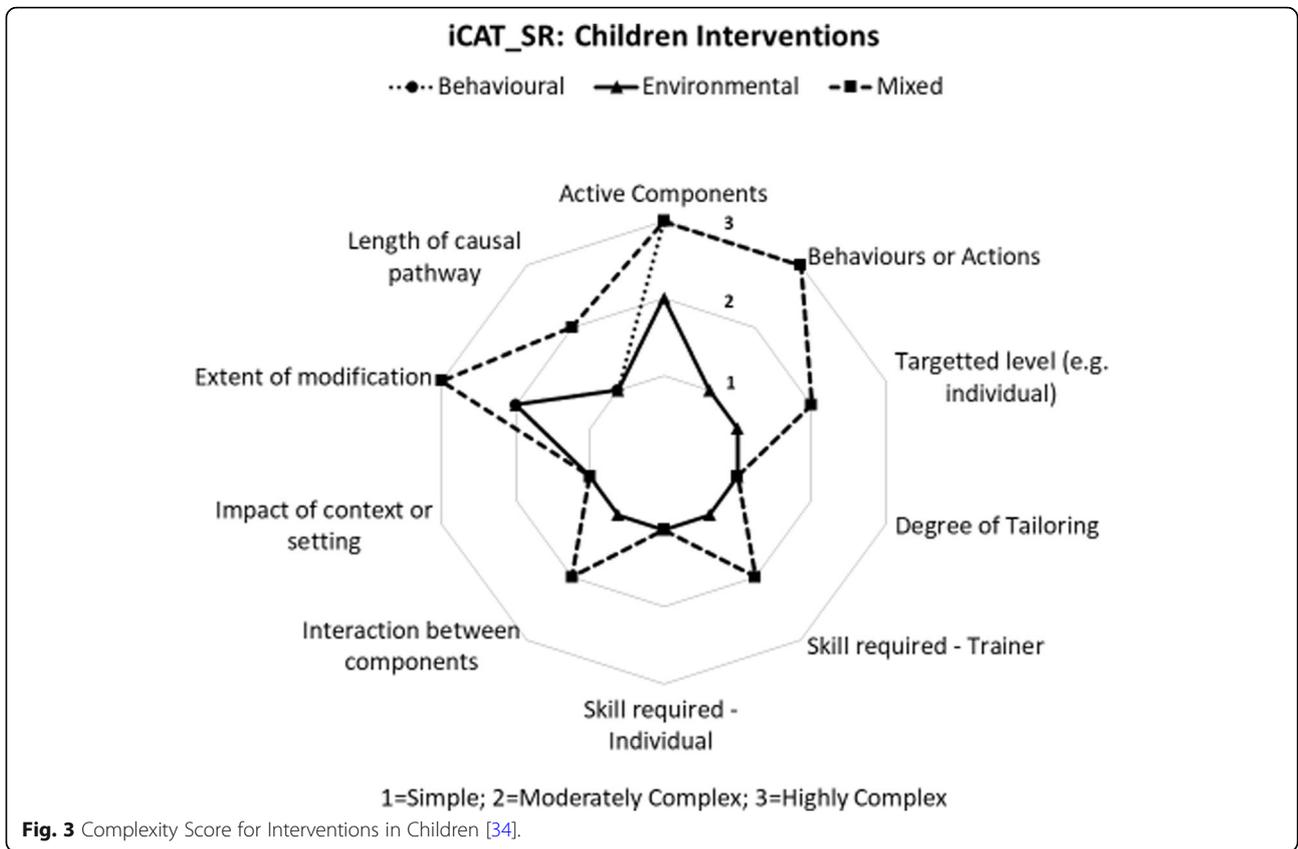
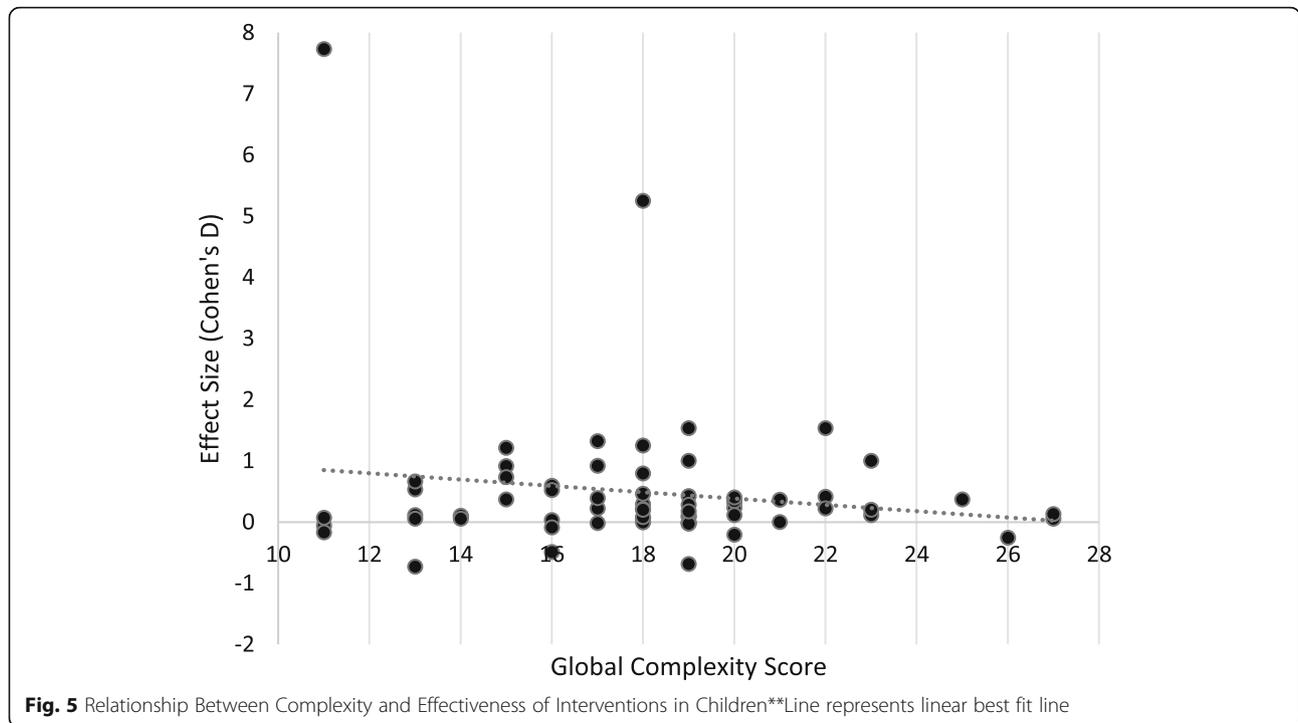### Children Interventions (n=84 studies)

Seventeen studies were rated as high risk for selection bias as they were non-randomised. Seven studies were rated as unclear due to a lack of information regarding how the random sequence was generated. Regarding detection bias, 48 studies did not report whether the study personnel were blinded to the intervention and were rated to be unclear risk for detection bias. Seventeen studies were blinded and rated as low risk, with the remaining 19 studies rated as high risk as there was no allocation concealment. Fifteen studies were rated as high risk of attrition bias. The validity of the outcome measure included in the study was assessed for risk of bias. Forty-nine studies included self-reported measures and were rated as high risk, with the remaining 35 studies rated as low risk due to the inclusion of device-based measures. The largest risk of bias for the children interventions came from the validity of the outcome measure, with almost 60% of studies including self-reported measures of SB. A summary of the risk of bias assessment in children is shown in Figure 7.

Effectiveness

Of the 161 studies included in the review, 126 studies provided data for inclusion in the meta-analysis. Studies were excluded from the meta-analysis due to insufficient data provided (i.e. did not provide a measure of variance) or the study's SB outcome measures were inappropriate data types for meta-analyses.

Fig. 3 Complexity Score for Interventions in Children [34].

Fig. 4 Relationship Between Complexity and Effectiveness of Interventions in Adults*

Fig. 5 Relationship Between Complexity and Effectiveness of Interventions in Children**Line represents linear best fit line

Effects of Adult Interventions

Studies in adults were pooled according to the type of intervention (i.e. behavioural, environmental or mixed), the length of follow up (≤6 months or >6 months) and type of control (active or inactive). The results from the meta-analysis of the adult studies is presented in Tables 1 and 2.

The findings from the adult interventions that included an inactive control demonstrated a clinically meaningful effect in the short-term i.e. ≤6 months [24]. The findings from the environmental and mixed interventions in the medium-term demonstrated a moderate but relevant reduction in daily SB. The results from the adult studies demonstrated moderate to high heterogeneity at both short and medium-term across both active and inactive control comparators. Results for the reductions in percentage of daily time in SB were not robust due to the scarcity of data.

Effects of Children Interventions

Studies in children were pooled according to the type of intervention (i.e. behavioural, environmental or mixed), the length of follow up (≤6 months or >6 months) and type of control (active or inactive). The results from the meta-analysis of the children studies is presented in Tables 3 and 4.

Fig. 6 Risk of Bias - Interventions in Adults

Fig. 7 Risk of Bias - Interventions in Children
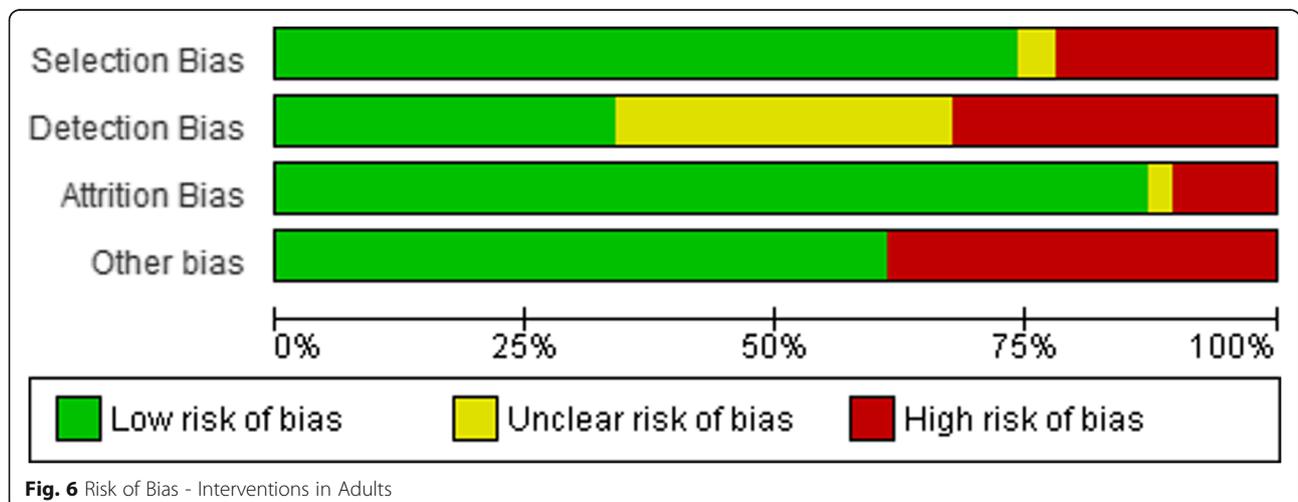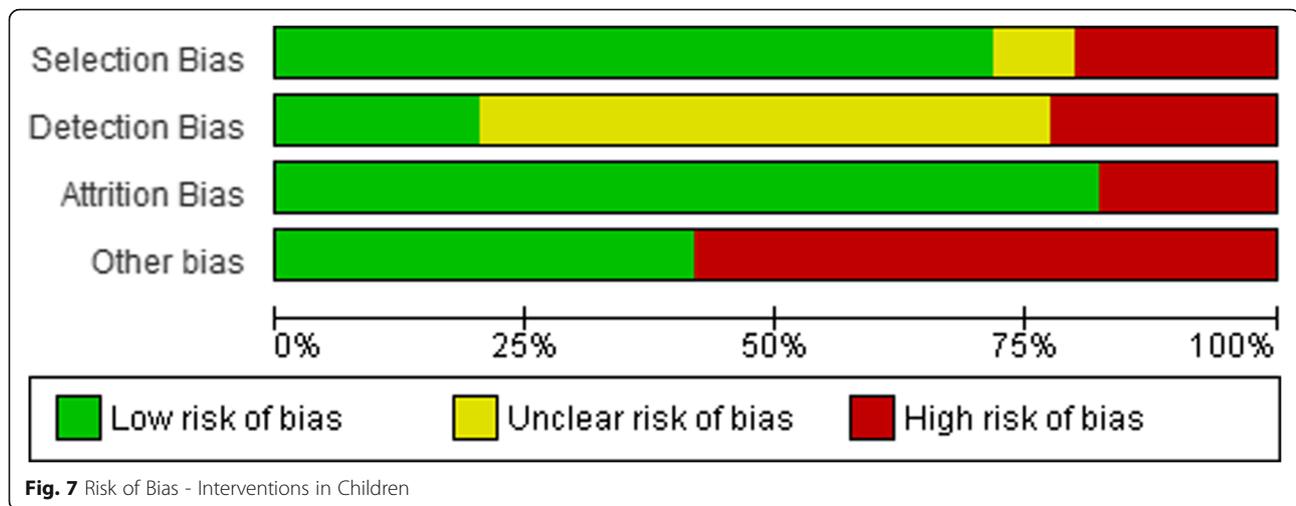
The findings from the analyses of the children's studies demonstrated moderate reductions in daily SB with behavioural, environmental and mixed interventions that included an inactive control, in the short-term. Results for the reductions in percentage SB time were not very robust due to the scarcity of data. Furthermore, findings for behavioural and mixed in the medium-term were inconclusive due to the lack of studies included in this outcome. The results from the children studies demonstrated extreme heterogeneity in behavioural interventions at short-term and mixed interventions at medium-term across the inactive control comparator outcomes. Within the active control outcomes, extreme heterogeneity was demonstrated in mixed interventions at short-term. In a sensitivity analysis, studies including children aged less than five were removed as potentially their environments may differ. Mixed interventions in children

when compared to inactive controls became non-significant in the short term (-23.13; 95%CI -66.47, 20.21; n=3678; I^2 37%).

GRADE Assessment

The GRADE approach was used to assess the certainty in evidence across all outcomes. The overall GRADE quality rating and scoring for risk of bias, imprecision, inconsistency, indirectness, and publication bias are presented in Supplement D. Due to the high heterogeneity across the outcomes, the majority were ranked as having a very low to low certainty of evidence.

Discussion

The findings of the review have shown that behavioural and environmental interventions in adults resulted in a significant short-term (≤6 months) reduction in SB and

Table 1 Effectiveness of SB Interventions in Adults Compared to an Inactive Control

Subgroup 1: Behavioural	Studies (**n**=)	I (**n**=)	C (**n**=)	I^2	MD (95%CI)
Outcome 1: SB min/day (≤6mo)	19	1179	1015	83%	-60.57 [-86.67, -34.46]
Outcome 2: SB min/day (>6mo)	4	701	501	63%	-7.30 [-28.98, 14.38]
Outcome 3: SB percentage (≤6mo)	1	56	63	N/A	-1.02 [-3.03, 0.99]
Subgroup 2: Environmental	**Studies (n=)**	**I (n=)**	**C (n=)**	I^2	**MD (95%CI)**
Outcome 1: SB min/day (≤6mo)	8	181	167	86%	-64.05 [-104.64, -23.46]
Outcome 2: SB min/day (>6mo)	1	222	264	N/A	-35.20 [-80.94, 10.54]
Outcome 3: SB % (≤6mo)	2	52	49	0%	-13.95 [-15.33, -12.56]
Subgroup 3: Mixed	**Studies (n=)**	**I (n=)**	**C (n=)**	I^2	**MD (95%CI)**
Outcome 1: SB min/day (≤6mo)	7	552	526	87%	-42.63 [-77.62, -7.63]
Outcome 2: SB min/day (>6mo)	5	1797	1052	72%	-30.25 [-52.92, -7.58]
Overall Results	**Studies (n=)**	**I (n=)**	**C (n=)**	I^2	**MD (95%CI)**
Outcome 1: SB min/day (≤6mo)	34	1912	1708	83%	-56.86 [-74.10, -39.63]
Outcome 2: SB min/day (>6mo)	10	2720	1817	65%	-20.14 [-34.13, -6.16]
Outcome 3: SB % (≤6mo)	3	108	112	98%	-9.80 [-10.94, -8.65]

Table 2 Effectiveness of SB Interventions in Adults Compared to an Active Control

Subgroup 1: Behavioural	Studies (n=)	I (n=)	C (n=)	I²	MD (95%CI)
Outcome 1: SB min/day (≤6mo)	9	404	384	87%	-36.69 [-76.23, 2.86]
Outcome 2: SB min/day (>6mo)	4	145	152	69%	-3.77 [-20.95, 13.41]
Subgroup 2: Environmental	**Studies (n=)**	**I (n=)**	**C (n=)**	**I²**	**MD (95%CI)**
Outcome 1: SB min/day (≤6mo)	1	15	16	N/A	2.58 [-57.81, 62.97]
Subgroup 3: Mixed	**Studies(n=)**	**I(n=)**	**C(n=)**	**I²**	**MD (95%CI)**
Outcome 1: SB min/day (≤6mo)	3	88	97	0%	-11.13 [-35.60, 13.33]
Outcome 2: SB min/day (>6mo)	1	24	12	N/A	-29.60 [-72.36, 13.16]
Outcome 3: SB percentage (≤6mo)	2	35	36	0%	-1.29 [-4.01, 1.43]
Overall Results	**Studies (n=)**	**I (n=)**	**C (n=)**	**I²**	**MD (95%CI)**
Outcome 1: SB min/day (≤6mo)	13	507	497	81%	-25.89 [-53.51, 1.73]
Outcome 2: SB min/day (>6mo)	5	169	164	62%	-6.49 [-22.34, 9.37]
Outcome 3: SB percentage (≤6mo)	2	35	36	0%	-1.29 [-4.01, 1.43]

interventions using a mix of strategies resulted in a statistically significant reduction in SB. In both the short and medium-term. The heterogeneity of the results was high in all cases, reducing the confidence in the consistency of the findings, in addition, the GRADE assessment demonstrated very low certainty of evidence against the relevant outcomes. In children, SB interventions with short-term follow-up (≤6 months) resulted in a statistically significant difference in favour of the intervention. Overall, there was high heterogeneity and the GRADE certainty of evidence assessment was rated low. For both adult and children studies, the complexity assessment revealed no association between effect size and complexity of the intervention, suggesting that complexity has no impact on the effectiveness of interventions. It is important to recognise that the complexity assessment is not without limitations. The tool is designed to be applied in reviews including a group of very similar interventions. However, interventions included within the current review varied in terms of the active components, the degree of tailoring and the nature of the causal pathways between the intervention and outcome. In order to avoid poor reporting, interventions were grouped based on their type (i.e. behavioural, environmental or mixed), whether the intervention included an active or inactive control and the length of follow-up. These steps were taken in order to avoid misinterpretation of data and promote comparison between similar studies as the tool intends. One of the main benefits of using this tool is that it facilitates an in-depth, systematic assessment of the complexity of interventions, leading to an increased understanding of how complex interventions work [34].

Table 3 Effectiveness of SB Interventions in Children Compared to an Inactive Control

Subgroup 1: Behavioural	Studies (*n*=)	I (*n*=)	C (*n*=)	I²	MD (95%CI)
Outcome 1: SB min/day (≤6mo)	18	2490	2632	99%	-27.20 [-46.99, -7.40]
Outcome 2: SB min/day (>6mo)	6	1629	1567	87%	-6.20 [-26.42, 14.02]
Subgroup 2: Environmental	**Studies (*n*=)**	**I (*n*=)**	**C (*n*=)**	**I²**	**MD (95%CI)**
Outcome 1: SB min/day (≤6mo)	8	255	237	77%	-18.57 [-40.12, 2.99]
Outcome 2: SB min/day (>6mo)	2	41	41	0%	-8.75 [-17.18, -0.32]
Subgroup 3: Mixed	**Studies (*n*=)**	**I (*n*=)**	**C (*n*=)**	**I²**	**MD (95%CI)**
Outcome 1: SB min/day (≤6mo)	6	1941	1925	37%	-27.41 [-51.18, -3.63]
Outcome 2: SB min/day (>6mo)	15	18710	19150	99%	-17.54 [-24.15, -10.92]
Outcome 3: SB % (≤6mo)	3	627	435	0%	-1.70 [-2.93, -0.48]
Overall Results	**Studies (*n*=)**	**I (*n*=)**	**C (*n*=)**	**I²**	**MD (95%CI)**
Outcome 1: SB min/day (≤6mo)	32	4686	4794	98%	-25.86 [-40.77, -10.96]
Outcome 2: SB min/day (>6mo)	23	20380	20758	98%	-14.02 [-19.49, -8.55]
Outcome 3: SB % (≤6mo)	3	627	435	0%	-1.70 [-2.93, -0.48]

Table 4 Effectiveness of SB Interventions in Children Compared to an Active Control

Subgroup 1: Behavioural	Studies (**n**=)	I (**n**=)	C (**n**=)	I²	MD (95%CI)
Outcome 1: SB min/day (≤6mo)	4	87	90	0%	-48.26 [-69.83, -26.69]
Outcome 2: SB min/day (>6mo)	1	255	176	N/A	-4.00 [-13.16, 5.16]
Subgroup 3: Mixed	**Studies (*n*=)**	**I (*n*=)**	**C (*n*=)**	**I²**	**MD (95%CI)**
Outcome 1: SB min/day (≤6mo)	4	46	44	91%	-74.73 [-152.36, 2.90]
Outcome 2: SB min/day (>6mo)	1	22	22	N/A	19.14 [-3.46, 41.74]
Outcome 4: SB % (>6mo)	1	39	37	N/A	3.17 [-7.60, 13.94]
Overall Results	**Studies (*n*=)**	**I (*n*=)**	**C (*n*=)**	**I²**	**MD (95%CI)**
Outcome 1: SB min/day (≤6mo)	8	133	134	86%	-59.90 [-102.16, -17.65]
Outcome 2: SB min/day (>6mo)	2	277	198	71%	5.17 [-17.01, 27.35]
Outcome 4: SB % (>6mo)	1	39	37	N/A	3.17 [-7.60, 13.94]

Adult Interventions

Our findings are supported by previous systematic reviews in adults [23, 27, 29, 30], demonstrating that the interventions had a positive effect on reducing SB. In line with the findings from Peachey *et al.* which included studies published up to July 2017 [27], the findings from this review demonstrated the greatest reduction in sitting time from environmental interventions. These findings are interesting considering that the global complexity scores in environmental interventions were considerably lower than that of behavioural and mixed interventions. This suggests that within certain contexts where there is more control (i.e. workplace settings), less complex interventions targeting environmental determinants may be required. This finding is supported by a previous review by Gardner and colleagues [24] focusing on behaviour change strategies used in SB reduction interventions among adults, where interventions based on environmental restructuring, persuasion, or education were the most promising in terms of reducing SB. They also highlighted the most promising behaviour change techniques were self-monitoring, problem solving, and restructuring the social or physical environment [24].

Many of the environmental interventions included in the current review were based in the workplace and mainly involved adding height-adjustable desks or standing tables. However, most provided few details to individuals on how to effectively use the new apparatus which could account for the lack of change in daily SB time. Additionally, individuals may have needed extra behavioural elements to sustain the change (e.g. education on the benefits of reducing sitting in the long-term or activity trackers to provide feedback on progress towards goals). A systematic review of interventions for reducing non-occupational SB in adults and older adults found that interventions could 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) [192]. Similarly, the current study found greater reductions in SB were evident at short-term compared to medium-term across all outcomes with the exception of mixed interventions including an active control. However, this outcome only considered one study with a small sample size (n=36).

In terms of determining whether these reductions in daily SB are clinically meaningful, Healy and colleagues have modelled the impact of reallocating two daily hours of sitting to standing or to stepping on cardio-metabolic risk factors in adults [193]. This two-hour reduction is in line with recommendations from Public Health England and the Active Working Community Interest Company for office-based workers [194]. They found significant associations with sitting-to-standing reallocations included small-to-medium reductions in fasting plasma glucose (2%), triglycerides (11%) and total/HDL-cholesterol ratio (6%) while sitting-to-stepping reallocations were significantly associated with medium reductions in body mass index (11%), waist circumference (7.5cm), triglycerides (14%) and two-hour plasma glucose (11%) [193]. Despite the comparatively smaller reductions in SB time found in our review, these changes in SB could still have a clinically meaningful impact on adult's health as a 30-minute per day reduction in daily sitting time has been suggested as an effective target for observing long-term health benefits in another systematic review [27].

Although this review appears to demonstrate the potential utility of SB-reducing interventions in adults in the medium-term (i.e. >6 months), stronger evidence exists for SB-reducing interventions in the short-term (≤6 months). There is a need for more high-quality studies to fully consider how to effectively reduce daily SB time in the months and years after interventions have been implemented. Findings demonstrate that SB interventions are effective, with environmental interventions demonstrating a window for opportunity. A range of theoretical frameworks were implemented across the SB

interventions including, social cognitive theory, self-determination theory and the theory of planned behaviour. A recent systematic review described the behaviour change strategies used within interventions that sought to reduce SB [195]. In support of the current study, authors concluded that interventions based on environmental restructuring, persuasion or education were most effective. In addition, self-monitoring, problem solving and restructuring the social or physical environment were particularly promising behaviour change techniques. Future studies should consider theory-driven SB interventions delivered in the work-place as they could result in benefits for both the individual and the employer, high-quality studies need to be conducted to confirm these effects.

Children Interventions

A body of evidence recognises that SB in childhood may have significant consequences for poor health outcomes in adulthood [19], making the development of effective interventions an important public health concern [196]. The current review included 84 studies in children (mean age 2-19 years) of which 62% [52] were carried out in a school setting. All interventions with the exceptions of those that were mixed including an active control in the medium-term demonstrated reductions in SB. A recent systematic review of interventions to reduce SB in 0-5 year olds found overall mean reductions in SB of -18.91 min/day; 95% CI -33.31 to -4.51 [197]. This finding suggests that interventions of ≥6 months duration and those conducted in community settings were more effective. The findings within the current review demonstrated stronger evidence for effectiveness in the short-term, however due to a lack of studies included in the medium-term analysis it is difficult to compare findings between the follow-up periods, and hence make conclusions on the available evidence.

Studies of SB interventions targeting children are mainly carried out within a school setting due to ease of access to the target population, with a large proportion of their week days, during term time spent in school [198–200]. Furthermore, evidence supporting the effect of school-based interventions which target out-of-school activity (i.e. changes to screen time) or overall activity are varied with most finding no effect [198–200], and some showing that changes are possible where curriculum changes can be made [201]. In a systematic review of school-based interventions, Hegarty and colleagues [202] demonstrated that multicomponent interventions may be an effective method for reducing device-based measured SB in the short-to-medium term. In line with the current review, multi-component interventions were most promising in terms of effectively reducing SB in children. These findings would suggest that mixed

interventions, incorporating both behavioural and environmental components, may increase the likelihood of reducing sitting time in children. A review of reviews examining interventions designed to reduce SB among children and adolescents was conducted in 2013 [203]. Authors found that all reviews concluded some level of effectiveness in reducing time spent in SB, with most presenting a small but significant reduction in sedentary time. Effective strategies identified from the analysis revealed that involving the family, incorporating behaviour change techniques and including environmental components all positively supported the intervention effect. Consequently, future research should consider non-school settings such as home or community settings or seek to change curricular activity and SB policy to illicit benefits.

Conclusions

The primary aim of this review was to synthesise and evaluate the complexity and effectiveness of current SB interventional approaches to reduce sedentary time across the lifespan. The findings of this review demonstrated that interventions may lead to relevant reductions in daily sedentary time. However, the heterogeneity in reported outcomes, intervention components, and control arms (active versus inactive) prevented us from drawing firmer conclusions from the evidence provided. The complexity assessment also suggested that interventions may need to be more complex to address the multi-faceted nature of SB, but a higher complexity score is not necessarily associated with better outcomes in terms of sustained change.

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1186/s12966-020-00957-0.

Additional file 1: Supplement A. Search Strategy

Additional file 2: Supplement B. Characteristics of Included Studies

Additional file 3: Supplement C. Risk of Bias

Additional file 4. Supplement D. Meta-Analysis and GRADE Assessment

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Authors' contributions
NEB was involved in the conception, design, data screening, data extraction, data analysis and interpretation and write up of the manuscript. MAT was involved in the conception, design, data screening, data extraction, data analysis and interpretation and review of the manuscript. JJW was involved in the data screening, data extraction and review of the manuscript. IIM was involved in the data extraction, data analysis and review up of the manuscript. PC, MGG, LCP, KW and SBA were involved in the data extraction and review of the manuscript. MR was involved in the data analysis and review up of the manuscript. ATK was involved in the design, data screening and review of the manuscript. MD and DD were involved in the review of the manuscript. All authors have approved the submitted version.

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