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How effective and how expensive are interventions to reduce sedentary behavior? An umbrella review and meta-analysis

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Summary

A reduction in sedentary behavior (SB) can contribute to the prevention of chronic diseases. This is the first umbrella review that summarizes the effectiveness and monetary costs of different types of interventions to reduce SB across all age groups and populations in different settings. We comprehensively searched seven databases for systematic reviews and meta-analyses and conducted an umbrella review of the effects of interventions to reduce SB. Additionally, we performed a meta-analysis of primary studies included in the umbrella review. Furthermore, we analyzed health economic aspects of interventions to reduce SB. We included 40 systematic reviews in our umbrella review, with 136 primary studies suitable for further meta-analyses. We found that interventions targeting the physical environment reduce SB most effectively in the majority of populations and settings. Workplace interventions reduced SB by −89.83 min/day (95% CI −124.58 to −55.09; $p \leq 0.0001$). Twenty-two of 169 primary studies (13.0%) contained health economic information. The intervention costs per participant ranged from €0 to €3587. Our findings demonstrate that physical environment interventions most effectively reduce SB in a majority of populations and settings. Health economic information was reported in few studies and was mostly restricted to acquisition costs.

KEYWORDS
costs, interventions, meta-analysis, sedentary behavior

Abbreviations: AMSTAR-2, A MeaSurement Tool to Assess systematic Reviews; CI, confidence interval; FEM, fixed effect model; ICER, incremental cost-effectiveness ratio; *N*, number of studies; *p*, *p* value; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; PRISMA-P, Preferred Reporting Items for Systematic Reviews and Meta-Analyses- Protocol; PROSPERO, International Prospective Register of Systematic Reviews; RCT, randomized control trial; REM, random effects model; REML, restricted maximum likelihood method; SB, sedentary behavior; SD, standard deviation; SE, standard error.

1 | INTRODUCTION

Sedentary behavior is defined as "any waking behaviour characterized by an energy expenditure ≤1.5 METs while in a sitting or reclining posture."[1] Sedentary behavior has increased worldwide in the past decades.[2,3] The estimated prevalence of sedentary behavior is 6.4 h per day in adults, about 9.3 h in teenagers, and 4.4 h in children, and it differs by age, sex, socioeconomic status, and other factors.[4]

Current research suggests that sedentary behavior increases the risk of developing chronic conditions such as coronary heart disease, type 2 diabetes,[5–8] and several types of cancer.[9] In addition, large amounts of time spent sedentary increase the risk of obesity and overweight, particularly during childhood.[10] Furthermore, prolonged sitting increases the risk of premature mortality.[11] Recent meta-analyses of sedentary behavior interventions show improvements in cardiovascular risk factors (e.g., systolic blood pressure, plasma glucose and insulin level)[12–14] and a positive impact on body anthropometry (e.g., body mass, waist circumference, percentage of body fat).[14] Some of these factors also play a role in the development of cancer.[15–17]

Globally, chronic diseases are the principal causes of mortality,[18] contributing considerably to the overall burden of disease[19] and increasing the direct and indirect costs of health care systems.[20,21] From a public health perspective, reducing sedentary behavior as a risk factor can—at least partly—contribute to the prevention of several chronic diseases and reduce health care costs.

The latest WHO Guidelines on physical activity and sedentary behavior[22] recommend decreasing sedentary behavior for all age groups (children, adolescents, adults, older adults) and for people with chronic conditions, pregnant and postpartum women, and people living with disability.

A large number of trials have investigated the effectiveness of interventions to reduce sedentary behavior. Findings have been summarized by several systematic reviews and meta-analyses and they suggest that sedentary behavior interventions are effective for reducing sedentary behavior in specific populations (e.g., children and teenagers, office workers, the elderly, people with overweight, and obesity) and settings (e.g., the workplace, schools, during leisure time).[23–27]

Furthermore, two umbrella reviews summarized findings from existing systematic reviews and meta-analyses.[28,29] However, those umbrella reviews were limited to certain age groups and settings, with one umbrella review[28] focusing on sitting and screen time in children and adolescents and the other[29] concentrating on screen time in children and adolescents and occupational sedentary behavior in adults.

To our knowledge, no umbrella review has evaluated the effectiveness of different types of interventions to reduce sedentary behavior in all age groups (including older adults) and populations (including people with overweight/obesity and people living with chronic conditions) across a broad range of settings. The present study closes this research gap by encompassing both an umbrella review (of systematic reviews and meta-analyses) and a meta-analysis (of individual studies) covering all age groups and populations across a comprehensive range of settings. The current study aimed to address the research question of how effective different sedentary behavior interventions are for reducing sedentary behavior in different populations and in different settings. An additional goal was to investigate the effectiveness, costs, and cost-effectiveness of sedentary behavior interventions for different combinations of target groups and settings to generate information on the economic impact of reducing sedentary behavior for decision makers in the healthcare system and employers.

2 | METHODS

2.1 | Search strategy

2.1.1 | Data sources

KL and CJ conducted a comprehensive literature search until January 31, 2020, using the following databases: MEDLINE, CINAHL, PsycINFO, EMBASE, Cochrane Database of Systematic Reviews, NIHR-HTA Database, and ClinicalTrials.gov. The search terms included items for sedentary behavior, interventional study designs, reviews, and meta-analyses. The search terms for MEDLINE were as follows:

#1 (sedentary[tiab] OR sitting[tiab] OR seated[tiab] OR chair[tiab] OR desk[tiab])

#2 (intervention[tiab] OR evaluation[tiab] OR randomised[tiab] OR control* [tiab] OR trial[tiab] OR behavior* therapy[tiab])

#3 (review[pt] OR meta-analysis[pt])

Those search terms were adapted to the other databases.

2.1.2 | Study inclusion and exclusion criteria

The main outcome of the umbrella review was sedentary behavior.[1] All systematic reviews that included primary studies with this outcome were eligible. We included all systematic reviews that contained intervention studies (e.g., randomized control trials [RCT], cluster randomized studies, cross-over studies, or quasi-randomized studies as well as single arm intervention studies with before/after comparisons as primary studies) that analyzed the effect of interventions on sedentary behavior. All age groups were included. Studies that included individuals with chronic diseases (including for example overweight, obesity, and cancer) were included. We considered no intervention or alternative interventions as control groups. Both objective measurement methods such as objective devices (e.g., accelerometer and video) and subjective measurement methods (e.g., questionnaire, logbook, and parent reports) of sedentary behavior were eligible. No language or date restriction were applied. We excluded systematic reviews that contained only observational studies as well as primary studies that only measured screen time as a sedentary behavior outcome. Health economic evaluation studies were eligible if they contained health economic information (e.g., acquisition costs, costs of implementation, evaluation costs, and cost-effectiveness) or referenced health economic publications.

2.1.3 | Study selection

Two researchers (KL, CJ) independently screened titles and abstracts with no date or language restrictions, read the full texts of potentially eligible systematic reviews, and decided independently if the systematic reviews should be included in the umbrella review. Disagreements were resolved by discussion. The study selection of the systematic reviews was documented by KL according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[30] We removed duplicates manually. Table S1 shows the reasons for exclusions of systematic reviews and meta-analyses. In addition, we searched the reference lists of included systematic reviews to identify potentially eligible primary studies for the meta-analyses. Furthermore, we searched the gray literature (non-peer-reviewed articles) such as dissertations and conference presentations for potentially eligible studies mentioned in the reference lists of the included systematic reviews. In addition, potential eligible primary studies were independently screened by AN and JBS for health economic information.

2.1.4 | Data extraction

CW and HB independently extracted the following information from systematic reviews and meta-analyses: author's name, publication year, target population, assessment of sitting time, type of intervention, type of control, and main findings. KL and CJ independently extracted the following information from eligible primary studies of the selected systematic reviews and meta-analyses: title of the manuscript, author's name, publication year, study name, study design (e.g., RCT and cluster RCT), target population (e.g., office workers, older adults, children), sex and average age of participants, number of participants included in the analysis, country, region, ethnicity, intervention focus (e.g., sedentary behavior, physical activity, nutrition), setting of sedentary behavior (e.g., work place, domestic, leisure, transportation), description of the intervention, type of intervention (personal behavior intervention, physical environment intervention, social environment intervention, and multicomponent intervention), intervention length, outcome measure, length of study, sedentary behavior preintervention/postintervention, sedentary behavior change (within group), sedentary behavior difference (between intervention and control group), adjustment variables, study funding, name of the protocol, trial registry number, and Medline ID. Regarding the health economic evaluation, for each component of the intervention KP, AN, and CR extracted the following data, if available: resource use, price per unit, total costs, currency, and year of intervention.

2.1.5 | Data synthesis

We systematically summarized and described the characteristics of both the included systematic reviews and meta-analyses and the included primary studies in a narrative analysis component of the umbrella review.

2.2 | Statistical analysis

2.2.1 | Primary analysis

In addition to the narrative umbrella review, we conducted a meta-analysis of individual primary studies. We evaluated the effectiveness of interventions for specific combinations of target populations and settings as follows: (a) interventions that influence personal behavior directly through information (e.g., consultations and apps); (b) interventions that influence the physical environment (e.g., sit-stand desks, movement friendly buildings); (c) interventions that influence the social environment (e.g., parents-children dyads and walk and talk meetings); (d) multicomponent interventions (combination of at least two distinct interventions).

We conducted random effects model (REM) meta-analysis to quantify the effectiveness of interventions to reduce sedentary behavior for different combinations of populations (adults, office workers, older adults, teenagers, school children, preschoolers, people with chronic diseases, and people with overweight/obesity) and settings (office workplace, nonoffice workplace, leisure time, and school) and total sedentary behavior (independent of setting). If studies assessed sedentary behavior with both objective and subjective methods, we included objectively assessed sedentary behavior in our analyses.

We meta-analyzed the results of primary studies if the standard error (SE) was given or could be calculated from the standard deviation (SD) ($SE = SD/\sqrt{n}$; n = number of participants), the 95% confidence interval (CI), or the 25th/75th percentile (assuming a normal distribution). We applied the restricted maximum likelihood method (REML)[31] to estimate the between-study variance in order to assess heterogeneity across types of interventions, study designs, and outcome definitions. Furthermore, we determined study heterogeneity using the Q statistic and its derivatives.[32]

In the primary studies, sedentary behavior was measured as change in sedentary behavior (within-group change in sedentary behavior) or sedentary behavior preintervention/and postintervention. Assuming a normal distribution, we approximated change in sedentary behavior by the differences of the averages of sedentary behavior preintervention/postintervention and performed two meta-analyses with the two distinct outcomes. The REM meta-analyses only included data measured as minutes per day or data that could be converted to minutes per day to ensure comparability and to permit meta-analyses of the data across primary studies.

We applied REM meta-analyses if at least 10 primary studies were available for a specific combination of target population and setting to obtain meaningful results.

2.2.2 | Subgroup analyses

We performed subgroup analyses according to the main target of the intervention, that is, interventions aiming to reduce sedentary

behavior of participants, interventions aiming to increase physical activity of participants, and interventions targeting both outcomes. Furthermore, we performed a subgroup analysis that compared the effect on sedentary behavior reduction <6 months and ≥6 months after the intervention. In addition, we performed a subgroup analysis that compared objective and subjective assessments of sedentary behavior.

If studies reported multiple settings of sedentary behavior for the same participant, we included the total sedentary behavior measure in the subgroup analyses.

2.2.3 | Publication bias

We investigated potential publication bias using funnel plots,[33] the rank correlation test by Begg and Mazumdar,[34] and the linear regression test by Egger.[33]

2.2.4 | Sensitivity analyses

We performed sensitivity analyses using fixed effect models (FEM) and REMs with alternative between-study heterogeneity estimators (e.g., DerSimonian and Laird [DL][35] or Sidik & Jonkman[36]). In addition, we conducted outlier and influence diagnostics.[37]

2.2.5 | Data management

All systematic reviews and primary studies were recorded and organized with EndNote X9.[38] All statistical analyses were conducted with R 4.0.0, a software tool for statistical computing and graphics.[39] The R packages "metafor" (version 2.4–0) and "meta" (version 4.16-2) were used to conduct the meta-analyses. Additional R packages applied were "readxl" (version 1.3.1), "data.table" (version 1.13.2), "tidyverse" (version 1.3.0), "flextable" (version 0.5.11), "officer" (version 0.3.15), "tidyr" (version 1.1.2), "robumeta" (version 2.0) and "dplyr" 1.0.2.

2.2.6 | Methodical quality assessment of systematic reviews and meta-analyses

Two researchers (NM, CW) evaluated in duplicate the methodical quality of the included systematic reviews and meta-analyses with the A MeaSurement Tool to Assess systematic Reviews (AMSTAR-2).[40] This tool was specifically developed for the assessment of the methodological quality of systematic reviews of randomized and non-randomized studies.[40] It contains 16 items such as risk of bias assessment or availability of a study protocol. The results of the AMSTAR-2 evaluation are summarized in Table S2.

2.2.7 | Health economic consideration

If total costs were not mentioned, they were calculated from the product of resource use and price per unit. If year of intervention was not specified in the publication, we searched for the clinical trials registration number to determine the year of first participant enrolment. Publication year was approximated if year of intervention or year of cost determination was not specified. Costs incurred in the control group were also extracted. For comparability, the cost data were currency-converted using purchasing power parities for gross domestic product given by OECD. Stat[41] and adjusted for inflation to 2020 using the harmonized consumer price index[42]—following the procedure described by Scholz et al.[43] If more than one cost component of an intervention was described, the total sum was calculated over the individual components. For further comparability, the total costs were allocated to the number of participants.

3 | RESULTS

3.1 | Literature search results

In total, 6583 records were obtained from the bibliographic databases. After removing all duplicates ($N = 1900$), we screened 4683 potential studies for titles and abstracts and excluded 4365 studies due to their irrelevance for the investigation. We read the full texts and evaluated the eligibility of the remaining 318 studies. We excluded 278 studies and categorized those by exclusion reason. The remaining 40 systematic reviews were deemed eligible for the umbrella review. After excluding overlapping primary studies, the included systematic reviews contained a total of 169 eligible primary studies. Both the characteristics of the 40 systematic reviews and meta-analyses and of the 169 primary studies are described in the narrative synthesis.

Of the 169 primary studies, 33 articles could not be included in the meta-analyses because information on post-intervention sedentary behavior was missing or the standard error was not available or could not be calculated. The results of remaining 136 primary studies were included in the meta-analysis. Twenty-two of the 169 eligible primary studies (13.0%) contained health economic information. In two cases, separate health economic publications were referenced, so these were used for further analysis instead of the primary study.[44,45] One study provided a detailed list of intervention costs upon request.[44] Figure 1 documents the literature search according to the PRISMA statement.[30]

3.2 | Description of included systematic reviews, meta-analyses and individual studies

Of the 40 systematic reviews and meta-analyses, 20 studies reported quantitatively pooled data from meta-analyses. In total, 15 systematic

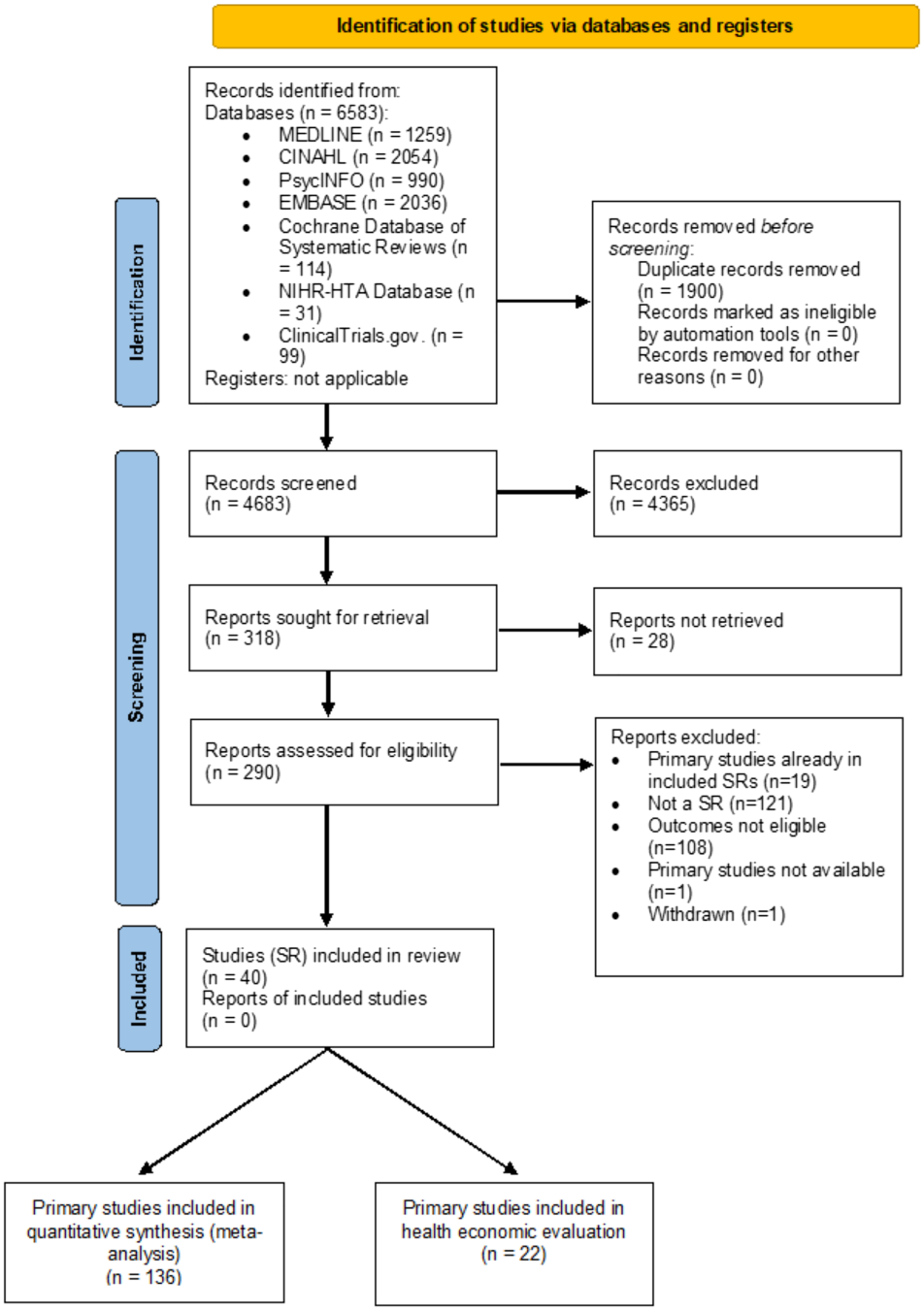

FIGURE 1 PRISMA flow diagram on database search and identification of systematic reviews and primary studies. Abbreviations: *n* = number; SR = systematic review

reviews and meta-analyses focused on children and/or adolescents, 22 focused on adults (one systematic review included studies of cancer survivors, and one included studies of people with overweight and obesity). Two systematic reviews and meta-analyses focused on older adults. One meta-analysis addressed all age groups. Most systematic reviews and meta-analyses ($N = 31$) assessed sedentary behavior with both objective and subjective methods. Four systematic reviews and meta-analyses reported on studies with an objective assessment of sedentary behavior, whereas two reported on studies with a subjective assessment of sedentary behavior. Table S3 provides further details regarding type of interventions, type of controls, and main findings.

The 169 primary studies included data from 42,472 participants. The majority of primary studies measured total sedentary behavior ($N = 133$; 78.7%). Most studies assessed sedentary behavior during leisure ($N = 25$; 14.8%), followed by sitting in the office ($N = 22$; 13%), sitting in schools ($N = 16$; 9.5%), and sitting in nonoffice workplaces ($N = 13$; 7.7%). Settings that were less frequently addressed were sitting during transportation ($N = 5$; 3%), sitting in preschools ($N = 3$; 1.8%), and sitting in day-care facilities ($N = 2$; 1.2%). Most primary studies focused on adults ($N = 54$; 32.0%), office workers ($N = 39$; 23.1%), and school children ($N = 39$; 23.1%). Other target groups were adults aged 65 years and older ($N = 16$; 9.5%), teenagers ($N = 11$; 6.5%), preschoolers ($N = 9$; 5.3%), and toddlers ($N = 2$;

1.2%). Obesity/overweight was an inclusion criterion in 30 (17.8%) primary studies. Twenty studies (11.8%) examined patients with diverse chronic diseases (e.g., cancer, stroke, and rheumatoid arthritis). None of these studies included people who were unable to stand (such as wheelchair users). Table S4 provides an overview of the included primary studies.

Primary studies were mainly conducted in high-income regions. Most primary studies were conducted in Europe ($N = 64$; 37.87%), North America ($N = 63$; 37.28%), and Australia ($N = 36$; 21.3%). A minority of primary studies were conducted in South America ($N = 5$; 2.96%) and Asia ($N = 3$; 1.78%). No primary study was conducted in Africa. Two primary studies[46,47] (1.18%) were conducted both in Europe and in Australia.

Of the 169 primary studies, 67 (39.6%) studies analyzed personal behavior interventions, 27 (16%) studies investigated physical environment interventions, 12 (7.1%) studies considered social environment interventions, and 73 (43.2%) studies examined multicomponent interventions. Several primary studies investigated more than one intervention category.

The majority of primary studies assessed sedentary behavior preintervention/postintervention ($N = 157$; 92.9%). A total of 65 primary studies (38.5%) measured change in sedentary behavior. Three primary studies investigated sedentary behavior according to ethnic group. Besides African and Asian ethnicity, no other ethnic groups were investigated specifically. The long-term effect of sedentary behavior change postintervention was investigated in 36 primary studies (21.3%).

3.3 | Primary statistical analysis

3.3.1 | Effectiveness of interventions

The meta-analysis of primary studies on sedentary behavior preintervention/postintervention showed that physical environment interventions reduced total sedentary behavior of adults, office workers and older adults (Figure S1) by −56.17 min/day (95% CI −92.82 to −19.52). Multicomponent interventions reduced total sedentary behavior by −29.47 min/day (95%; −42.26, −16.67). Similarly, meta-analyses of change in sedentary behavior showed that physical environment interventions reduced total sedentary behavior of adults, office workers, and older adults (Figure 2) by −49.81 min/day (95% CI −79.88 to −19.74) and multicomponent interventions showed a total sedentary behavior reduction of −37.31 min/day (95% CI −49.56, −25.05). All results were statistically significant (Table S5).

Pooled results of sedentary behavior preintervention/postintervention in the office setting (Figure S2) showed that physical environment interventions were most effective (−87.87 min/day; 95% CI −114.59 to −61.16) followed by multiple component interventions (−32.38 min/day; 95% CI −43.90 to −20.85). Sedentary behavior change analyses (Figure 3) showed a sedentary behavior reduction of −89.83 min/day (95% CI −124.58 to −55.09) through physical environment interventions and a sedentary behavior reduction of −31.05 min/day (95% CI −48.56 to −13.53) through multicomponent interventions. All results were statistically significant.

Physical environment interventions were most effective in reducing sedentary behavior in the majority of meta-analyses. However, this did not hold true for leisure sedentary behavior in adults, office workers and older adults (Figure S3). The pooled sedentary behavior preintervention/postintervention of adults, office workers and older adults showed that personal behavior interventions reduced leisure sedentary behavior most effectively (−46.84 min/day; 95% CI −73.71 to −19.96; $p < 0.001$).

In older adults, studies that assessed the effectiveness of physical environment interventions were not available for meta-analyses. In that target group, total sedentary behavior (Figure S4) was most effectively reduced by multicomponent interventions (−85.74 min/day; 95% CI − 157.66 to −13.81; $p = 0.0195$) and personal behavior interventions (−35.31 min/day; 95% CI −66.62, −3.99; $p = 0.0271$).

In school children, physical environment interventions were the most effective intervention, reducing total sedentary behavior (Figure S5) by −80.76 min/day (95% CI −110.69 to −50.84; $p \leq 0.0001$) followed by social environment interventions, which reduced total sedentary behavior by −24.66 min/day (95% CI −49.54 to 0.21; $p = 0.052$).

In the school setting (Figure S6), physical environment interventions showed the highest effectiveness of sedentary behavior reduction (−58.75 min/day; 96% CI −72.05 to −45.44) followed by social environment interventions (−19.32 min/day; 95% CI −29.92 to −8.72). Both types of interventions showed a statistically significant sedentary behavior reduction.

For people with chronic diseases (Figure S7), multicomponent interventions and personal behavior interventions were available for meta-analyses of total sedentary behavior. While personal behavior interventions significantly reduced total sedentary behavior by −26.86 min/day (95% CI −46.20 to −7.52; $p = 0.0065$), results for multicomponent interventions were inconclusive (−31.39 min/day 95% CI −74.85 to 12.07; $p = 0.1569$).

Interventions targeting the physical environment were suggestively the most effective intervention in terms of mean reduction of total sedentary behavior among people with overweight/obesity (Figure 4) (−63.85 min/day; 95% CI −130.05 to 2.35; $p = 0.0587$). The second most effective total sedentary behavior reduction was achieved by personal behavior interventions, significantly reducing total sedentary behavior of people with overweight/obesity by −41.49 min/day (95%, −67.00, −15.97; $p = 0.0014$).

3.4 | Assessment of publication bias

Visual inspection of funnel plots (Figures S8 and S9) of all primary studies showed asymmetry for pooled sedentary behavior preintervention/postintervention and change in sedentary behavior analyses, indicating that studies yielding no intervention effect remain unpublished. The rank correlation test by Begg and Mazumdar

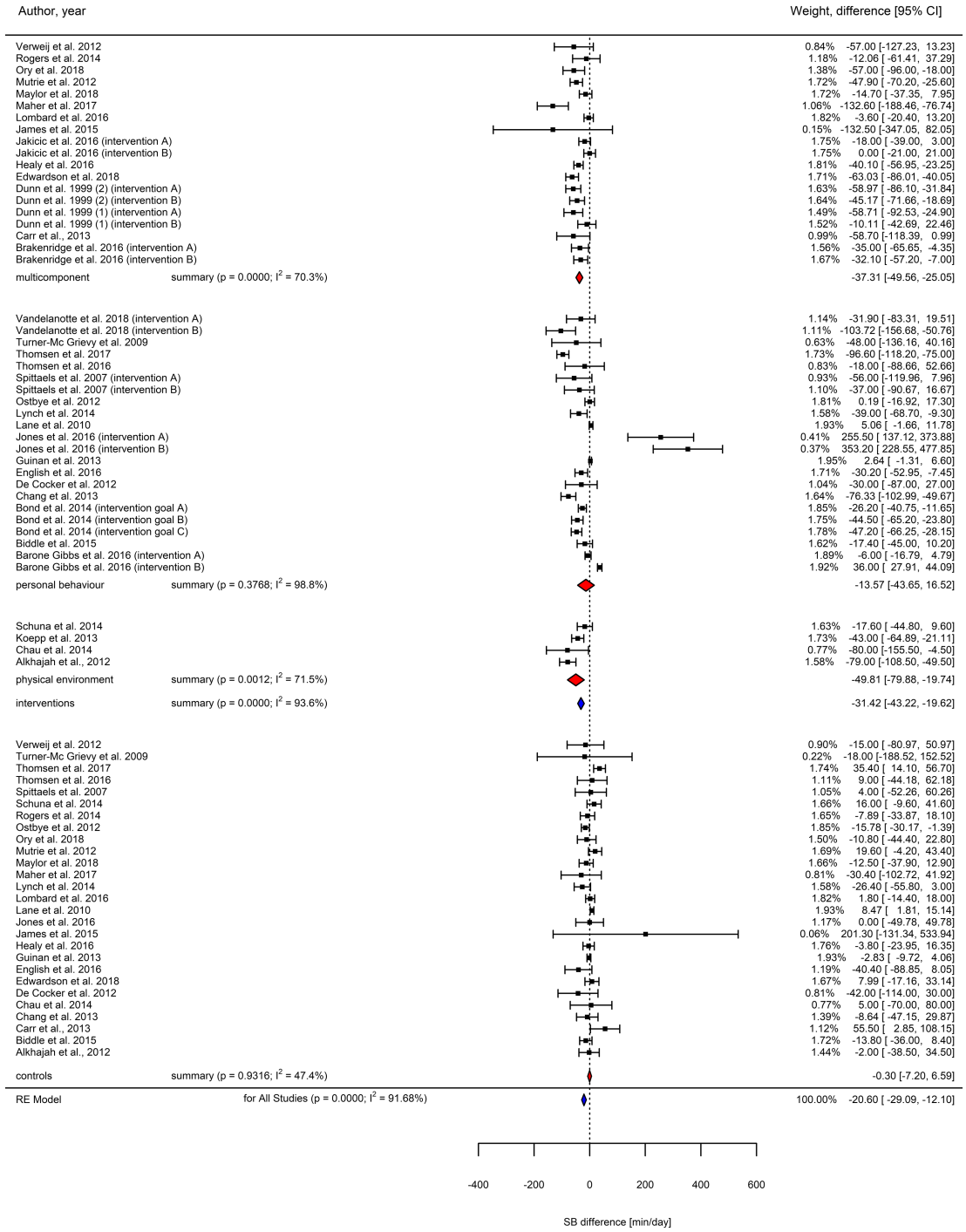

FIGURE 2 Meta-analysis of the effectiveness of different types of interventions on total sedentary behavior in adults, office workers and older adults. Abbreviations: CI = confidence interval; RE model = random effects model; SB difference = within-group change in sedentary behavior

confirmed the observed asymmetry for sedentary behavior change ($p < 0.0001$), whereas Egger's linear regression test did not ($p = 0.07992$). For interventions that measured sedentary behavior preintervention/postintervention, the linear regression test by Egger confirmed the observed asymmetry ($p < 0.0001$), whereas Begg's and Mazumdar's rank correlation test did not ($p = 0.6527$).

3.5 | Subgroup and sensitivity analyses

3.5.1 | Intervention focus

Total sedentary behavior of all populations was analyzed in the intervention focus subgroup analyses.

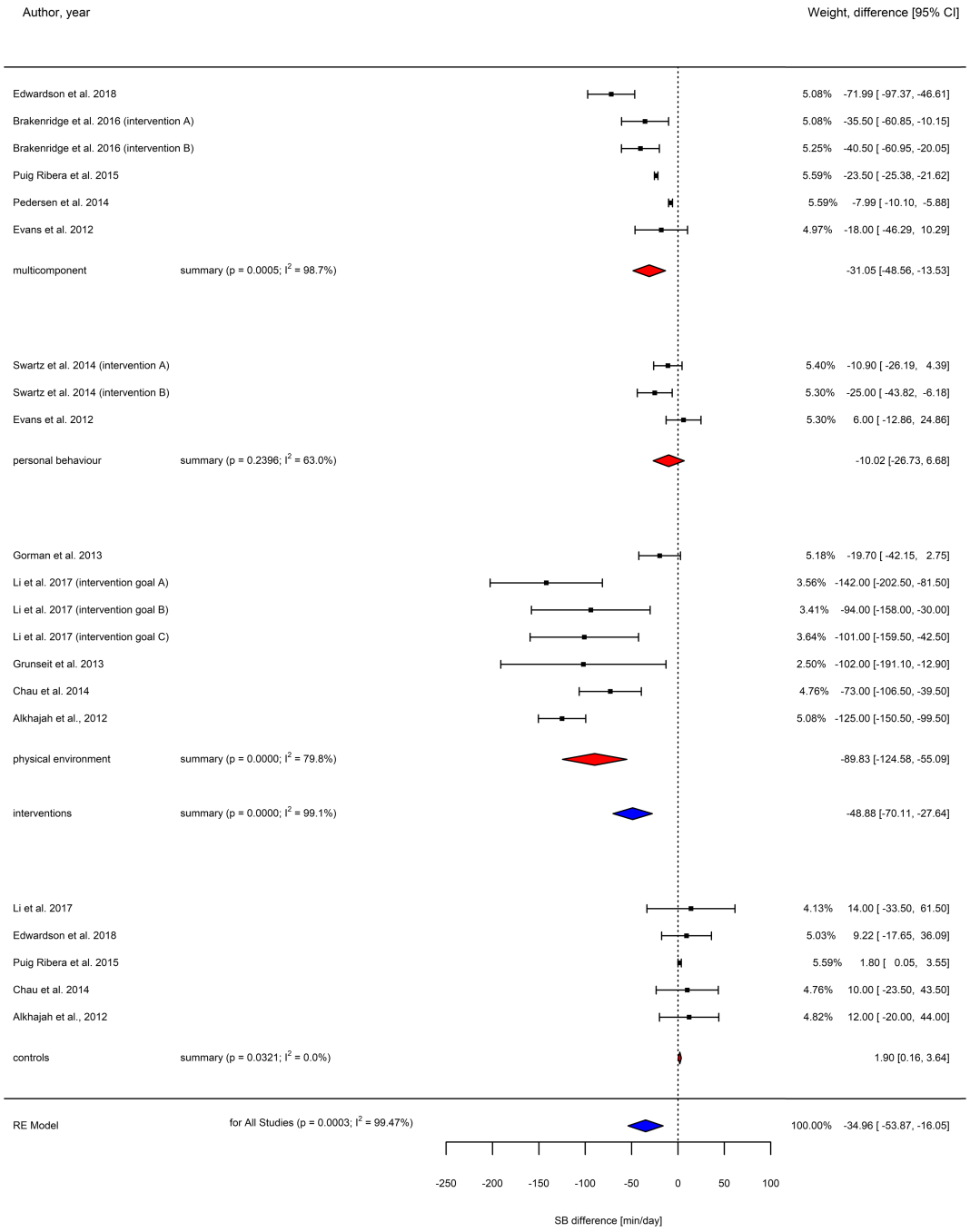

FIGURE 3 Meta-analysis of the effectiveness of different types of interventions on sedentary behavior in office workers. Abbreviations: CI = confidence interval; RE model = random effects model; SB difference = within-group change in sedentary behavior

Sedentary behavior-focused interventions were the most effective interventions and significantly reduced sedentary behavior by −43.09 min/day (95% CI −61.02 to −25.15). Among sedentary behavior-focused interventions, physical environment interventions showed the largest sedentary behavior reduction (−64.44 min/day; 95% CI −84.63 to −44.26).

Physical activity-focused interventions and combined physical activity/sedentary behavior-focused interventions were less effective in reducing sedentary behavior. While physical activity-focused interventions significantly reduced sedentary behavior by −18.33 min/day (95% CI −27.64, −9.02), the reduction of sedentary behavior by a combination of physical activity/sedentary behavior-focused interventions were inconclusive (−15.96 min/day 95% CI −60.50 to 28.59)

3.5.2 | Long-term effect

Meta-analyses of sedentary behavior change showed a weaker effect at < 6 months (−17.45 min/day; 95% CI −40.53 to 5.63; $p = 0.1385$)

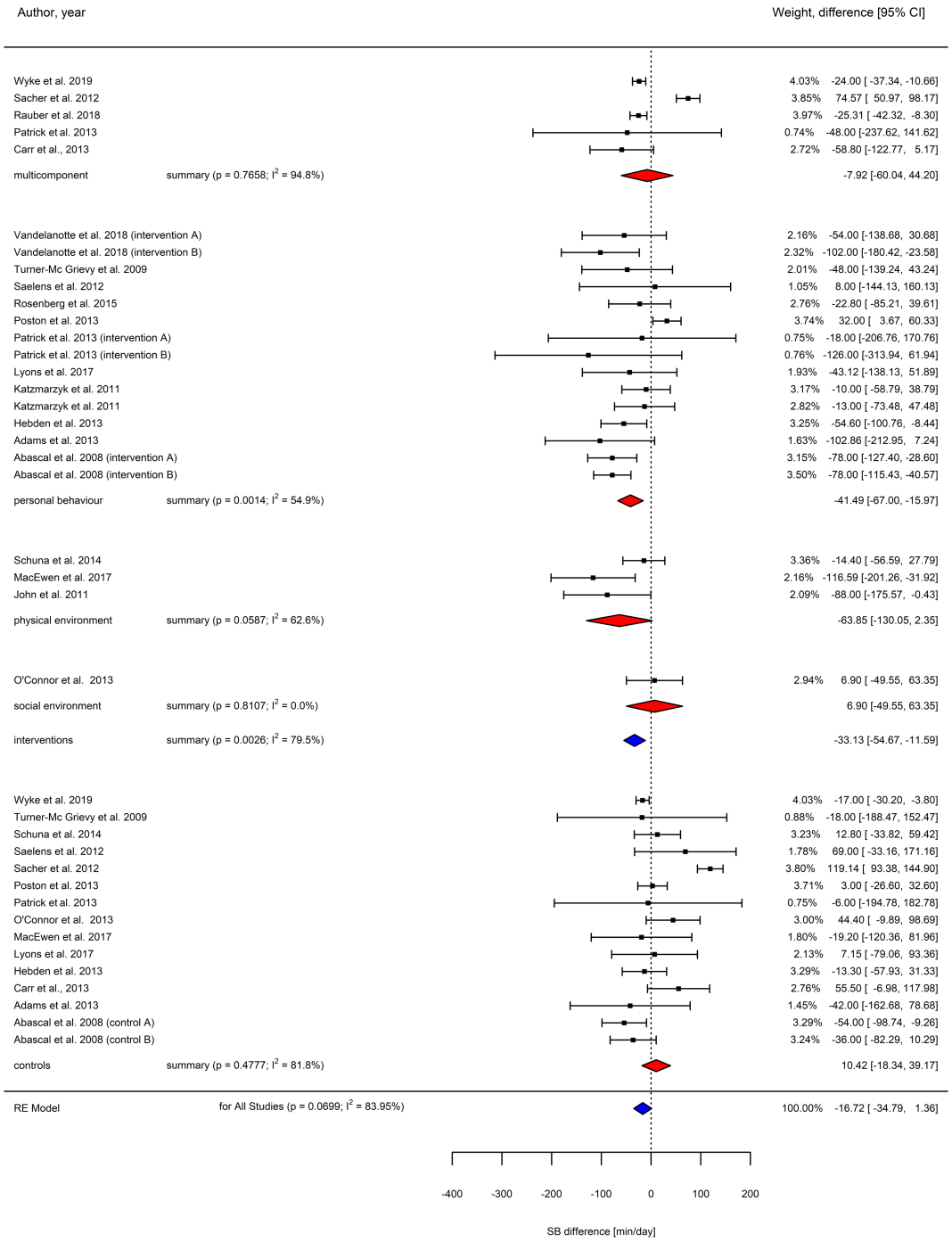

FIGURE 4 Meta-analysis of the effectiveness of different types of interventions on total sedentary behavior among people with overweight/obesity. Abbreviations: CI = confidence interval; RE model = random effects model, SB difference = preintervention/postintervention difference in sedentary behavior

than after ≥ 6 months (−34 min/day; 95% CI −73.19 to 5.19; $p = 0.089$). In the meta-analysis of sedentary behavior preintervention/postintervention, a stronger effect was observed after < 6 months (−18.39 min/day; 95% CI −37.97 to 1.19; $p = 0.0656$) than after ≥ 6 months (−11.92 min/day; 95% CI −25.48 to 1.63; $p = 0.0847$).

3.5.3 | Sensitivity analyses

In a sensitivity analysis, we excluded one primary study[48] due to its wide 95% confidence interval (95% CI −1893.52 to 1803.52), which was 241 times larger than the variance of the pooled results of all

interventions (95% CI − 34.85 to −19.52). Overall results did not substantially change (compare Figure S10 with Figure S1).

Influence and outlier diagnostics[37] identified two primary studies[49,50] as potential outliers. After exclusion of both primary studies, the order of intervention category effectiveness did not change.

3.5.4 | Objective and subjective measurement methods

Primary studies that assessed sedentary behavior with objective methods showed a statistically significantly less pronounced sedentary behavior reduction (−21.9 min/day; 95% CI −33.28, −10.51; $p = 0.0002$) than interventions with a subjective measurement of the outcome (−41.09 min/day; 95% CI −57.36, −24.83; $p \leq 0.0001$).

3.5.5 | Health economic consideration

In most cases, primary studies with health economic information focused on office workers ($N = 7$; 31.8%) or school children ($N = 6$; 27.3%). Other populations considered were older adults ($N = 3$; 13.6%), adults with overweight or obesity ($N = 2$; 9.1%) and, in one study each (4.5%), adults, office workers with overweight or obesity, teenagers, and preschoolers.

Of 22 primary studies, 10 (45.5%) studies analyzed multicomponent interventions, seven studies (31.8%) examined physical environment interventions, four studies (18.2%) investigated personal behavior interventions, and one study (4.5%) addressed study social environment interventions.

Table S6 shows the average intervention costs of the included 22 studies. Due to the fact that mostly just acquisition costs were mentioned, the costs in the table do not include costs for the development (e.g., writing of a manual), implementation, or evaluation of the intervention. In some cases, intervention costs could not be reported per participant, but only per family, per teacher, per class, or per school. The intervention costs per participant ranged from €0 to €3587.

Due to the heterogeneity of the interventions implemented, even within intervention categories, a comparison of studies was only meaningful for physical environment and personal behavior interventions. Studies with physical environment interventions were mostly classified as the most effective intervention category, with statistically significant results. Depending on the desk used (sit-stand workstation, electrically or manually adjustable, treadmill desk), the intervention costs amounted to €334 to €3587 per participant, whereby the cost of a treadmill desk was significantly higher than the cost of a sit-stand workstation. Personal behavior interventions included in the health economic analysis and classified in the meta-analysis as the second most effective intervention category used booklets and manuals. One study used further intervention materials like pedometers and a resistance band. In these studies, the costs amounted to €5 to €57 per participant.

As described above, two studies referenced separate health economic publications,[44,45] one study using a cost and cost–benefit analysis, and the second a cost-effectiveness analysis. Munir et al.[44] measured the increase in productivity in monetary units. After subtracting the cost of the intervention and costs for lost work time due to the implementation of the intervention, they reported net cost savings of £1770 (currency-converted and inflation-adjusted: €2039). The incremental cost-effectiveness ratio (ICER) was between £8 and £17 (€10 and €19) per minute per workday. Sevick et al.[45] calculated the mean incremental cost per mean unit of improvement at 6 and 24 months. In terms of cost per month per hour of reduced sedentary behavior per week, costs of $9 (IG 1; €12) and $28 (IG 2; €36) were reported at 6 months of follow-up and $15 (IG 1; €19) and $7 (IG 2; €9) at 24 months of follow-up.

4 | QUALITY ASSESSMENT

Table S2 shows the results of the AMSTAR-2 evaluation. The methodologic quality of 10 of the 40 included systematic reviews was rated critically low according to the AMSTAR-2 criteria. The methodical quality of 11 systematic reviews was rated low and the quality of 16 reviews was rated moderate. The AMSTAR-2 scores of three systematic reviews were rated high. Very few systematic reviews included a list of excluded studies and justifications for their exclusion ($N = 6$) or listed the sources of funding of the included primary studies ($N = 3$). Only half of the reviews investigated and discussed potential risk of bias in their included primary studies and its influence on their results ($N = 22$) or published in an a priori written protocol ($N = 21$).

5 | DISCUSSION

The goal of this umbrella review was to provide a comprehensive overview of the current state of research on sedentary behavior interventions and to analyze the effectiveness of sedentary behavior intervention categories for different combinations of relevant target groups and settings. Our main findings show that physical environment interventions constitute the most effective type of intervention to reduce sedentary behavior for most populations and in most settings—with the exception of leisure time, where personal behavior interventions are the most effective type of intervention. Furthermore, our meta-analysis indicates that social environment interventions are more effective for school children than for adults and that personal behavior interventions represent an effective type of intervention for people with overweight/obesity.

The results of our meta-analysis indicate that physical environment interventions are particularly effective in reducing sedentary behavior in the workplace like the office but also in non-office workplace settings. Our findings reflect the results of several systematic reviews[51–53] suggesting that physical environment interventions

reduce daily sedentary behavior of adults more effectively than personal behavior interventions or multicomponent interventions.

The majority of physical environment interventions are activity-permissive workstations targeting workplace sedentary behavior. Activity-permissive workstations have been shown to reduce sedentary behavior in the workplace.[25] A reduction of workplace sedentary behavior results in a sizeable reduction of total sedentary behavior since up to 48.5% of total weekly sedentary behavior can be attributed to the workplace.[54]

Interestingly, our umbrella review shows that multicomponent interventions do not represent the most effective intervention category. This contrasts with ecological models of health behavior that imply that multicomponent interventions reduce sedentary behavior more effectively that single level interventions.[55]

Our meta-analysis shows that physical environment interventions are more effective than personal behavior and social environment interventions. Based on ecological models of health and behavior, we theorize that multicomponent interventions that include a physical environment intervention are more effective than physical environment interventions. However, we defined multicomponent interventions as any combination of intervention categories. To investigate our theory, additional analysis that further differentiate multicomponent interventions are required.

Our meta-analysis indicates that personal behavior interventions are most effective in reducing leisure sedentary behavior in adults, office workers and older adults. This result contrasts with a small systematic review of 14 studies[27] that investigated the effect of physical environment, personal behavior and multicomponent interventions on nonoccupational sedentary behavior and showed that multicomponent interventions are more effective in reducing leisure sedentary behavior compared to physical environment and personal behavior interventions.

One possible explanation for why physical environment interventions do not constitute the most effective intervention in leisure time in contrast to the workplace or schools is that physical environment interventions (e.g., sit-stand desks and modification of school playgrounds) are more frequently applied in workplaces or schools. None of the examined physical environment intervention specifically targeted leisure time. Personal behavior interventions on the other hand provided general information on how to reduce sedentary behavior, which could be applied during leisure time.

Our meta-analysis of sedentary behavior interventions targeting school children indicates that social environment interventions are effective in reducing sedentary behavior. The effect of social environment interventions was stronger for school children than for adults. Sedentary behavior can be a consequence of unconscious decisions and habits which are influenced by the physical (e.g., chairs in schools) and social environment (parents, teachers, carers).[56,57] The observation that physical and social environment interventions are the most effective intervention for school children suggests that health behavioral change for children works better with strategies targeting unconscious processes. Based on our findings, we assume that interventions that work with conscious decision-making processes like personal behavior interventions and multicomponent interventions, which often include personal behavior elements, might be more effective for adults than for children.

The pooled results of our analyses suggest that personal behavior interventions reduce total sedentary behavior in people with overweight/obesity more effectively than multicomponent and social environment interventions. This finding is in contrast to our findings from other population groups like adults, where multicomponent interventions were more effective than personal behavior interventions.

According to qualitative research,[58] the main barriers for people with overweight/obesity to reduce sedentary behavior are a lack of awareness of personal sedentary behavior and the negative health consequences of sedentary behavior. Difficulties in identifying alternative behaviors to sitting and strategies to reduce sedentary behavior represent additional barriers.[58] Personal behavior interventions target these barriers and provide information on health benefits of sedentary behavior reduction, strategies to reduce sedentary behavior, and awareness of personal sedentary behavior.[59]

While multicomponent interventions provide similar information and should be more effective than single level personal behavior interventions according to the ecological models of health and behavior,[55] we observed that personal behavior intervention were more effective than multicomponent interventions for people with overweight/obesity. One possible explanation is that multicomponent interventions often include a social environment intervention element, which may reduce the overall effectiveness of the intervention.

Our comprehensive umbrella review may inform future recommendations on sedentary behavior reduction by highlighting the effectiveness of different types of interventions in different populations and settings. The estimated prevalence of sedentary behavior varies across populations. Adults and children spend approximately 6.4 and 4.4 h/day, respectively, in a sedentary state.[4] Sedentary behavior among older adults and people with overweight/obesity is even higher, with 9.4 and 8 h/day, respectively.[60,61] There is strong evidence that a sedentary lifestyle is positively associated with all-cause mortality and risk for cardiovascular disease, especially for physically inactive people.[5,62,63] Recent guidelines of the WHO and the United States Department of Health and Human Services[22,64] recommend reducing sedentary behavior for all age groups, people living with disabilities, and people with chronic conditions. More research is necessary to quantify how much sedentary behavior reduction should be recommended.[22] A recent systematic review suggested that a sitting time reduction of 30 min/day is likely clinical meaningful.[51] The findings of our umbrella review identified effective interventions to achieve such sedentary behavior reduction. The results of our meta-analyses could contribute to the development of individual strategies for specific populations and settings.

Our umbrella review identified several research gaps, including a paucity of studies in older adults, teenagers, preschoolers, and toddlers as well as in settings such as transportation, day-care facilities, and preschools that should be addressed in future research. Furthermore, we could not find any primary study that analyzed the effect of physical environment interventions in older adults and people with

chronic diseases. Considering our findings and the results of other systematic reviews[52,53] that suggest that physical environment interventions are very effective in reducing sedentary behavior, we recommend conducting primary studies that investigate physical environment interventions targeting older adults and people with chronic diseases.

Sedentary behavior research has focused on high income countries in North America, Europe, and Australia. Only a minority of primary studies were from South America or Asia. Considering the widespread sedentary behavior in those geographic areas,[65–69] more studies are necessary that investigate the effectiveness of sedentary behavior interventions in those regions.

Regarding our health economic analysis, only 22 of 169 eligible primary studies (13.0%) contained health economic information. Reporting on intervention costs was very heterogeneous. While in two studies reference was made to a separate health economic publication with a detailed list of all costs incurred and a cost–benefit or cost-effectiveness analysis, in the majority of cases only acquisition costs were reported. In this respect, it is questionable whether all relevant components of an intervention have been monetized. Against this background, only the direct investment costs could be considered in the current review. An overview of the total intervention costs (including implementation and evaluation costs) for an overall assessment of the cost–benefit ratio was therefore not possible.

Although the cost data were currency-converted and adjusted for inflation to improve comparability, the costs of interventions are not readily applicable to real world settings. In one case,[45] the year of publication was unknown which could have produced a slight overestimation of costs. However, this had only a marginal effect because the end of the intervention and the publication date were close in time. Furthermore, it should be noted that in most cases, the costs were reported from the perspective of the party who has to pay the acquisition costs, for example, the employer or the school.

5.1 | Strengths and limitations

To our knowledge, the current umbrella review is the first comprehensive overview of sedentary behavior interventions that addresses all populations and all settings. The main strength of our umbrella review is the large number of primary studies and participants included. Our review shows that sedentary behavior research currently focuses on specific populations and settings. Adults, office workers and school children have been analyzed extensively as well as total sedentary behavior and settings such as the workplace, schools, and leisure time.

A further strength of our study is the a priori published protocol (PROSPERO registration number: CRD42020197529) that followed the PRIMSA-P statement. We determined the search strategy with inclusion and exclusion criteria and the analytic plans before conducting the umbrella review to ensure a high quality of our umbrella review. During our literature search, we included all unpublished gray literature deemed eligible. We ensured the high quality of our umbrella review by assessing the methodical quality of the included systematic reviews with the AMSTAR-2 criteria. Additionally, we investigated the heterogeneity of our results with the I^2 statistic. We investigated potential publication bias of the included primary studies via funnel plots, rank correlation analyses and linear regression analyses.

However, our umbrella review has some limitations. In the absence of reported individual changes in sedentary behavior, we determined sedentary behavior change by quantifying the difference between preintervention/and postintervention measurements. Therefore, the results of the analyses of the calculated sedentary behavior change should be interpreted with caution. Furthermore, we identified some asymmetry in the included primary studies, indicating possible publication bias.[70] In addition, the large number of relatively heterogeneous primary studies may weaken the overall value of the results. Furthermore, the quality of our umbrella review was influenced by the methodological quality of the included systematic reviews. Very few systematic reviews included a list of excluded studies and justifications for their exclusion or listed the sources of funding of the included primary studies. A consideration of the risk of bias when interpreting the results is critically important for the methodical quality of a systematic review.[71] All reviews that failed to account for risk of bias when discussing its possible influence on their results were ranked low or critically low. For almost half of the reviews, a prior published protocol was not available. Due to these features of some systematic reviews, some of the included systematic reviews have a low methodical quality.

In addition, the heterogeneity of our key findings was considerable. This may be due to the fact that the primary studies used different target groups, settings and methods of measuring sedentary behavior (objective and subjective) and interventions with varying lengths of time.

5.2 | Conclusion

In conclusion, our umbrella review shows that physical environment interventions constitute the most effective means to reduce sedentary behavior in most populations and settings. Certain populations (older adults, teenagers, preschoolers, and toddlers) as well as certain settings (transportation, day-care facilities, and preschools) are less researched and should be addressed in future research. Additionally, our umbrella review presents an insight into the costs of measures to reduce sedentary behavior.

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CONFLICT OF INTEREST

No conflict of interest statement.

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REFERENCES

1. Tremblay MS, Aubert S, Barnes JD, et al. Sedentary Behavior Research Network (SBRN)—Terminology consensus project process and outcome. *Int J Behav Nutr Phys Act*. 2017;14(1):75. doi:10.1186/s12966-017-0525-8
2. López-Valenciano A, Mayo X, Liguori G, Copeland RJ, Lamb M, Jimenez A. Changes in sedentary behaviour in European Union adults between 2002 and 2017. *BMC Public Health*. 2020;20(1):1206. doi:10.1186/s12889-020-09293-1
3. Ng SW, Popkin BM. Time use and physical activity: a shift away from movement across the globe. *Obes Rev*. 2012;13(8):659-680. doi:10.1111/j.1467-789X.2011.00982.x
4. Bauman AE, Petersen CB, Blond K, Rangul V, Hardy LL. The descriptive epidemiology of sedentary behaviour. In: Leitzmann MF, Jochem C, Schmid D, eds. *Sedentary Behaviour Epidemiology*. Vol. 41. Cham: Springer International Publishing; 2018:73-106.
5. Patterson R, McNamara E, Tainio M, et al. Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. *Eur J Epidemiol*. 2018;33(9):811-829. doi:10.1007/s10654-018-0380-1
6. Wilmot EG, Edwardson CL, Achana FA, et al. Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis. *Diabetologia*. 2012;55(11):2895-2905. doi:10.1007/s00125-012-2677-z
7. de Rezende LFM, Rodrigues Lopes M, Rey-López JP, Matsudo VKR, Luiz OC. Sedentary behavior and health outcomes: an overview of systematic reviews. *PLoS ONE*. 2014;9(8):e105620. doi:10.1371/journal.pone.0105620
8. Biswas A, Oh PI, Faulkner GE, et al. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. *Ann Intern Med*. 2015;162(2):123-132. doi:10.7326/M14-1651
9. Schmid D, Leitzmann MF. Television viewing and time spent sedentary in relation to cancer risk: a meta-analysis. *J Natl Cancer Inst*. 2014;106(7):dju098. doi:10.1093/jnci/dju098
10. Biddle SJH, García Bengoechea E, Wiesner G. Sedentary behaviour and adiposity in youth: a systematic review of reviews and analysis of causality. *Int J Behav Nutr Phys Act*. 2017;14(1):43. doi:10.1186/s12966-017-0497-8
11. Chau JY, Grunseit AC, Chey T, et al. Daily sitting time and all-cause mortality: a meta-analysis. *PLoS ONE*. 2013;8(11):e80000. doi:10.1371/journal.pone.0080000
12. Loh R, Stamatakis E, Folkerts D, Allgrove JE, Moir HJ. Effects of interrupting prolonged sitting with physical activity breaks on blood glucose, insulin and triacylglycerol measures: a systematic review and meta-analysis. *Sports Med (Auckland, NZ)*. 2020;50(2):295-330. doi:10.1007/s40279-019-01183-w
13. Paterson C, Fryer S, Zieff G, et al. The effects of acute exposure to prolonged sitting, with and without interruption, on vascular function among adults: a meta-analysis. *Sports Med (Auckland, NZ)*. 2020;50(11):1929-1942. doi:10.1007/s40279-020-01325-5
14. Hadgraft NT, Winkler E, Climie RE, et al. Effects of sedentary behaviour interventions on biomarkers of cardiometabolic risk in adults: systematic review with meta-analyses. *Br J Sports Med*. 2021;55(3):144-154. doi:10.1136/bjsports-2019-101154
15. Arnold M, Pandeya N, Byrnes G, et al. Global burden of cancer attributable to high body-mass index in 2012: a population-based study. *Lancet Oncol*. 2015;16(1):36-46. doi:10.1016/S1470-2045(14)71123-4
16. Lynch BM. Sedentary behavior and cancer: a systematic review of the literature and proposed biological mechanisms. *Cancer Epidemiol Biomarkers Prev*. 2010;19(11):2691-2709. doi:10.1158/1055-9965.EPI-10-0815
17. Gilchrist SC, Howard VJ, Akinyemiju T, et al. Association of sedentary behavior with cancer mortality in middle-aged and older US adults. *JAMA Oncol*. 2020;6(8):1210-1217. doi:10.1001/jamaoncol.2020.2045
18. World Health Organization. *Global Health Estimates 2016: Deaths by Cause, Age, Sex, by Country and by Region, 2000-2016*. Vol. 2018. Geneva.
19. Vos T, Lim SS, Abbafati C, et al. Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet*. 2020;396(10258):1204-1222. doi:10.1016/S0140-6736(20)30925-9
20. Ding D, Kolbe-Alexander T, Nguyen B, Katzmarzyk PT, Pratt M, Lawson KD. The economic burden of physical inactivity: a systematic review and critical appraisal. *Br J Sports Med*. 2017;51(19):1392-1409. doi:10.1136/bjsports-2016-097385
21. Heron L, O'Neill C, McAneney H, Kee F, Tully MA. Direct healthcare costs of sedentary behaviour in the UK. *J Epidemiol Community Health*. 2019;73(7):625-629. doi:10.1136/jech-2018-211758
22. *WHO Guidelines on Physical Activity and Sedentary Behaviour*. Geneva: World Health Organization; 2020.
23. Stockwell S, Schofield P, Fisher A, et al. Digital behavior change interventions to promote physical activity and/or reduce sedentary behavior in older adults: A systematic review and meta-analysis. *Exp Gerontol*. 2019;120:68-87. doi:10.1016/j.exger.2019.02.020
24. Zabatiero J, Ng L, Clayton R, et al. Effectiveness of interventions aiming at reducing sedentary behaviour in a non-surgical population with overweight or obesity: a systematic review and meta-analysis. *Obes Res Clin Pract*. 2019;13(2):115-128. doi:10.1016/j.orcp.2018.10.004
25. Neuhaus M, Eakin EG, Straker L, et al. Reducing occupational sedentary time: a systematic review and meta-analysis of evidence on activity-permissive workstations. *Obes Rev*. 2014;15(10):822-838. doi:10.1111/obr.12201
26. Minges KE, Chao AM, Irwin ML, et al. Classroom standing desks and sedentary behavior: a systematic review. *Pediatrics*. 2016;137(2):e20153087. doi:10.1542/peds.2015-3087
27. Shrestha N, Grgic J, Wiesner G, et al. Effectiveness of interventions for reducing non-occupational sedentary behaviour in adults and older adults: a systematic review and meta-analysis. *Br J Sports Med*. 2019;53(19):1206-1213. doi:10.1136/bjsports-2017-098270
28. Biddle SJH, Petrolini I, Pearson N. Interventions designed to reduce sedentary behaviours in young people: a review of reviews. *Br J Sports Med*. 2014;48(3):182-186. doi:10.1136/bjsports-2013-093078
29. Nguyen P, Le LK-D, Nguyen D, Gao L, Dunstan DW, Moodie M. The effectiveness of sedentary behaviour interventions on sitting time and screen time in children and adults: an umbrella review of systematic reviews. *Int J Behav Nutr Phys Act*. 2020;17(1):117. doi:10.1186/s12966-020-01009-3
30. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Bmj*. 2021;372:n71. doi:10.1136/bmj.n71
31. Viechtbauer W. Bias and efficiency of meta-analytic variance estimators in the random-effects model. *J Educ Behav Stat*. 2005;30(3):261-293. www.jstor.org/stable/3701379
32. Higgins JPT, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *Bmj*. 2003;327(7414):557-560. doi:10.1136/bmj.327.7414.557
33. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *Bmj*. 1997;315(7109):629-634. doi:10.1136/bmj.315.7109.629

34. Begg CB, Mazumdar M. Operating characteristics of a rank correlation test for publication bias. *Biometrics [Serial Online]*. 1994;50(4):1088-1101. https://pubmed.ncbi.nlm.nih.gov/7786990/
35. DerSimonian R, Laird N. Meta-analysis in clinical trials. *Control Clin Trials*. 1986;7(3):177-188. doi:10.1016/0197-2456(86)90046-2
36. Röver C, Knapp G, Friede T. Hartung-Knapp-Sidik-Jonkman approach and its modification for random-effects meta-analysis with few studies. *BMC Med Res Methodol*. 2015;15(1):99. doi:10.1186/s12874-015-0091-1
37. Viechtbauer W, Cheung MW-L. Outlier and influence diagnostics for meta-analysis. *Res Synth Methods*. 2010;1(2):112-125. doi:10.1002/jrsm.11
38. EndNote. 2020. https://endnote.com/. Accessed October 5, 2020.
39. R: The R Project for Statistical Computing. 2020. https://www.r-project.org/. Accessed October 5, 2020.
40. Shea BJ, Grimshaw JM, Wells GA, et al. Development of AMSTAR: a measurement tool to assess the methodological quality of systematic reviews. *BMC Med Res Methodol*. 2007;7(1):10. doi:10.1186/1471-2288-7-10
41. OECD. 4. PPPs and exchange rates. 2021. https://stats.oecd.org/Index.aspx? DataSetCode=SNA_TABLE4. Accessed June 11, 2021.
42. Statistisches Bundesamt Deutschland - GENESIS-Online: Ergebnis 61121-0001. 2021. https://www-genesis.destatis.de/genesis/online?operation=abruftabelleBearbeiten&levelindex=1&levelid=1623399813890&auswahloperation=abruftabelleAuspraegungAuswaehlen&auswahlverzeichnis=ordnungsstruktur&auswahlziel=werteabruf&code=61121-0001&auswahltext=&werteabruf=Werteabruf#abreadcrumb. Accessed June 11, 2021.
43. Schwalm A, Neusser S, Mostardt S, et al. Methoden der Kostenberechnung von Arzneimitteln im deutschen Gesundheitssystem: Bericht der Arbeitsgruppe "Standardkosten" des Ausschusses "ökonomische Evaluation" der dggö. *Gesundh ökon Qual Manag*. 2020;25(01):44-51. doi:10.1055/a-1107-0104
44. Munir F, Miller P, Biddle SJH, et al. A cost and cost-benefit analysis of the stand more at work (SMArT Work) intervention. *Int J Environ Res Public Health*. 2020;17(4): doi:10.3390/ijerph17041214
45. Sevick MA, Dunn AL, Morrow MS, Marcus BH, Chen G, Blair SN. Cost-effectiveness of lifestyle and structured exercise interventions in sedentary adults: results of project ACTIVE. *Am J Prev Med*. 2000;19(1):1-8. doi:10.1016/S0749-3797(00)00154-9
46. Gilson ND, Puig-Ribera A, McKenna J, Brown WJ, Burton NW, Cooke CB. Do walking strategies to increase physical activity reduce reported sitting in workplaces: a randomized control trial. *Int J Behav Nutr Phys Act*. 2009;6(1):43. doi:10.1186/1479-5868-6-43
47. Clemes SA, Barber SE, Bingham DD, et al. Reducing children's classroom sitting time using sit-to-stand desks: findings from pilot studies in UK and Australian primary schools. *J Public Health (Oxf)*. 2016;38(3):526-533. doi:10.1093/pubmed/fdv084
48. Lin Y-P, Hong O, Lin C-C, Lu S-H, Chen M-M, Lee K-C. A "sit less, walk more" workplace intervention for office workers: long-term efficacy of a quasi-experimental study. *J Occup Environ Med*. 2018;60(6):e290-e299. doi:10.1097/JOM.0000000000001299
49. 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(10):789-796. doi:10.1001/archinternmed.2012.1044
50. Thomsen T, Aadahl M, Beyer N, et al. The efficacy of motivational counselling and SMS reminders on daily sitting time in patients with rheumatoid arthritis: a randomised controlled trial. *Ann Rheum Dis*. 2017;76(9):1603-1606. doi:10.1136/annrheumdis-2016-210953
51. Peachey MM, Richardson J, Tang AV, Dal-Bello Haas V, Gravesande J. Environmental, behavioural and multicomponent interventions to reduce adults' sitting time: a systematic review and meta-analysis. *Br J Sports Med*. 2020;54(6):315-325. doi:10.1136/bjsports-2017-098968
52. Shrestha N, Kukkonen-Harjula KT, Verbeek JH, Ijaz S, Hermans V, Pedisic Z. Workplace interventions for reducing sitting at work. *Cochrane Database Syst Rev*. 2018;2018(12):CD010912. doi:10.1002/14651858.CD010912.pub5
53. Blackburn NE, Wilson JJ, McMullan II, et al. The effectiveness and complexity of interventions targeting sedentary behaviour across the lifespan: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act*. 2020;17(1):53. doi:10.1186/s12966-020-00957-0
54. Parry S, Straker L. The contribution of office work to sedentary behaviour associated risk. *BMC Public Health*. 2013;13(1):296. doi:10.1186/1471-2458-13-296
55. Sallis JF, Owen N, Fisher EB. Ecological models of health behavior. In: *Health Behavior and Health Education: Theory, Research, and Practice*. 4th ed. San Francisco, CA, US: Jossey-Bass; 2008:465-485.
56. Salmon J, Koorts H, Timperio A. Specific interventions targeting sedentary behaviour in children and adolescents. In: Leitzmann MF, Jochem C, Schmid D, eds. *Sedentary Behaviour Epidemiology*. Cham: Springer International Publishing; 2018:431-443.
57. Biddle SJH. Sedentary behaviour at the individual level: correlates, theories, and interventions. In: Leitzmann MF, Jochem C, Schmid D, eds. *Sedentary Behaviour Epidemiology*. Cham: Springer; 2017:405-429.
58. Martínez-Ramos E, Martín-Borràs C, Trujillo J-M, et al. Prolonged sitting time: barriers, facilitators and views on change among primary healthcare patients who are overweight or moderately obese. *PLoS ONE*. 2015;10(6):e0125739. doi:10.1371/journal.pone.0125739
59. Leitzmann MF, Jochem C, Schmid D (Eds). *Sedentary Behaviour Epidemiology*. Cham: Springer International Publishing; 2018.
60. Harvey JA, Chastin SFM, Skelton DA. How sedentary are older people? A systematic review of the amount of sedentary behavior. *J Aging Phys Act*. 2015;23(3):471-487. doi:10.1123/japa.2014-0164
61. Tudor-Locke C, Brashear MM, Johnson WD, Katzmarzyk PT. Accelerometer profiles of physical activity and inactivity in normal weight, overweight, and obese U.S. men and women. *Int J Behav Nutr Phys Act*. 2010;7(1):60. doi:10.1186/1479-5868-7-60
62. Ekelund U, Steene-Johannessen J, Brown WJ, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. *Lancet*. 2016;388(10051):1302-1310. doi:10.1016/S0140-6736(16)30370-1
63. Ekelund U, Brown WJ, Steene-Johannessen J, et al. Do the associations of sedentary behaviour with cardiovascular disease mortality and cancer mortality differ by physical activity level? A systematic review and harmonised meta-analysis of data from 850 060 participants. *Br J Sports Med*. 2019;53(14):886-894. doi:10.1136/bjsports-2017-098963
64. Piercy KL, Troiano RP, Ballard RM, et al. The physical activity guidelines for Americans. *Jama*. 2018;320(19):2020-2028. doi:10.1001/jama.2018.14854
65. Ferrari GLM, Kovalskys I, Fisberg M, et al. Socio-demographic patterning of objectively measured physical activity and sedentary behaviours in eight Latin American countries: Findings from the ELANS study. *Eur J Sport Sci*. 2020;20(5):670-681. doi:10.1080/17461391.2019.1678671
66. Peters TM, Moore SC, Xiang YB, et al. Accelerometer-measured physical activity in Chinese adults. *Am J Prev Med*. 2010;38(6):583-591. doi:10.1016/j.amepre.2010.02.012
67. Chen T, Kishimoto H, Honda T, et al. Patterns and levels of sedentary behavior and physical activity in a general Japanese population: the Hisayama study. *J Epidemiol*. 2018;28(5):260-265. 10.2188/jea.JE20170012
68. Müller-Riemenschneider F, Ng SHX, Koh D, Chu AHY. Objectively measured patterns of activities of different intensity categories and

steps taken among working adults in a multi-ethnic Asian population. *J Occup Environ Med*. 2016;58(6):e206-e211. doi: 10.1097/JOM.0000000000000745
69. Alkahtani S, Elkilany A, Alhariri M. Association between sedentary and physical activity patterns and risk factors of metabolic syndrome in Saudi men: a cross-sectional study. *BMC Public Health*. 2015;15(1): 1234. doi:10.1186/s12889-015-2578-4
70. Dickersin K, Chan S, Chalmersx TC, Sacks HS, Smith H. Publication bias and clinical trials. *Control Clin Trials*. 1987;8(4):343-353. doi: 10.1016/0197-2456(87)90155-3
71. Shea BJ, Reeves BC, Wells G, et al. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. *Bmj*. 2017;358:j4008. doi:10.1136/bmj.j4008

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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