Lifestyle interventions to reduce sedentary behaviour in clinical populations

Preventive Medicine 148 (2021) 106593

Contents lists available at ScienceDirect

Preventive Medicine

journal homepage: www.elsevier.com/locate/ypmed

Review Article

Lifestyle interventions to reduce sedentary behaviour in clinical populations: A systematic review and meta-analysis of different strategies and effects on cardiometabolic health

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A B S T R A C T

Cardiometabolic comorbidities are highly prevalent in clinical populations, and have been associated (partly) with their sedentary lifestyle. Although lifestyle interventions targeting sedentary behaviour (SB) have been studied extensively in the general population, the effect of such strategies in clinical populations is not yet clear. Therefore, this systematic review and meta-analysis evaluated the effect of different lifestyle interventions on SB and cardiometabolic health in clinical populations.

Randomised controlled trials were collected from five bibliographic databases (PubMed, Embase, Web of Science, The Cochrane Central Register of Controlled Trials, and Scopus). Studies were eligible for inclusion if they evaluated a lifestyle intervention to reduce objectively measured SB, in comparison with a control intervention among persons with a clinical condition. Data were pooled using a random-effects meta-analysis.

In total, 7094 studies were identified. Eighteen studies met the inclusion criteria and were categorised in five population groups: overweight/obesity, type 2 diabetes mellitus, cardiovascular, neurological/cognitive and musculoskeletal diseases. Participants reduced their SB by 64 min/day (95%CI: [−91, −38] min/day; $p < 0.001$), with larger within-group differences of multicomponent behavioural interventions including motivational counselling, self-monitoring, social facilitation and technologies (−89 min/day; 95%CI: [−132, −46] min/day; $p < 0.001$). Blood glycated haemoglobin concentration (−0.17%; 95% CI: [−0.30, −0.04]%; $p = 0.01$), fat percentage (−0.66%; 95% CI: [−1.26, −0.06]%, $p = 0.03$) and waist circumference (−1.52 cm; 95%CI: [−2.84, −0.21] cm; $p = 0.02$) were significantly reduced in the intervention groups compared to control groups.

Behavioural lifestyle interventions reduce SB among clinical populations and improve cardiometabolic risk markers such as waist circumference, fat percentage, and glycaemic control.

Sedentary behaviour, Cardiometabolic health, Clinical populations.

1. Introduction

Cardiometabolic comorbidities, such as hypertension, dyslipidaemia and glucose tolerance are highly prevalent among populations with clinical conditions (Ferguson et al., 2019; Hubert et al., 1983; Keytsman et al., 2017; Sin and Man, 2005; Yogaratnam et al., 2013). These comorbidities increase the hospitalization rate and often accelerate disability progression (Sin and Man, 2005; Michaud et al., 2011; Marrie et al., 2010). As such, it is crucial to explore strategies to improve the cardiometabolic health of clinical populations. Besides (*epi*)genetics, environmental, hormonal and medicinal factors, lifestyle is a crucial determinant for the development of cardiometabolic risk factors (Gakidou et al., 2017). Lifestyle interventions have already been shown to significantly improve the cardiometabolic health of high-risk populations (Gillies et al., 2007; Mudaliar et al., 2016; Seib et al., 2018; Madden et al., 2008; Malakou et al., 2018). Such interventions usually combine education on risk factors such as smoking, diet, and moderate-to-vigorous physical activity (MVPA) exercise (Gillies et al., 2007; Mudaliar et al., 2016; Seib et al., 2018; Madden et al., 2008; Malakou et al., 2018). However, the current international physical activity (PA) guidelines, advising 150 min of moderate or 75 min of vigorous intensity PA per week, are not met by 23% of the general population worldwide

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https://doi.org/10.1016/j.ypmed.2021.106593
Received 17 December 2020; Received in revised form 23 February 2021; Accepted 25 April 2021
Available online 28 April 2021

(WHO, 2018). In clinical populations, inactivity percentages are even higher. This is due to disease-specific barriers such as pain, transportation, disability, specialist availability, fatigue, health concerns, inaccessibility, comorbidities, and the time burden of treatment (Sawicki et al., 2009; Asano et al., 2013; Conroy et al., 2017; Veldhuijzen van Zanten et al., 2015; Nicholson et al., 2013; Kinnett-Hopkins et al., 2017; Manns et al., 2012; van Sloten et al., 2011).

Furthermore, clinical populations spend substantially more time engaged in sedentary behaviours than the general population (8.9–10.1 h/day vs 7.7 h/day respectively (Prince, 2018)). Sedentary behaviour (SB) is defined as any waking behaviour characterized by an energy expenditure $\leq$1.5 metabolic equivalents while in a sitting, reclining or lying posture (Tremblay et al., 2017). Recent evidence shows that SB is inversely related to several markers of cardiometabolic health, especially in individuals not meeting the recommended PA guidelines (Wilmot et al., 2012; Henson et al., 2013; Cooper et al., 2012; Brocklebank et al., 2015; Same et al., 2016; Ekelund et al., 2020) and clinical populations (Cooper et al., 2012; Fitzgerald Jodi et al., n.d.; King et al., 2016; Motl et al., 2011; Liu et al., 2015). Reallocating SB to low-intensity non-exercise PA (NEPA) is feasible for individuals with clinical conditions (Manns et al., 2012) and positive effects on cardiometabolic health have been shown in laboratory-based interventions (English et al., 2018; Bailey et al., 2020; Dempsey et al., 2016). The effects of free-living SB interventions on cardiometabolic health have been investigated in the general population and are summarized in two meta-analyses (Hadgraft et al., 2020; Martin et al., 2015). Martin et al. reported a significant SB reduction (−22 min/day), but could not identify studies with SB-only interventions and cardiometabolic health (Martin et al., 2015). Hadgraft et al. found significant improvements in some cardiometabolic measures (anthropometrics, blood pressure, insulin and lipids), but did not perform a pooled analysis of SB changes (Hadgraft et al., 2020). Furthermore, evidence in both studies was mostly based on healthy populations, limiting extrapolation to clinical populations (Hadgraft et al., 2020; Martin et al., 2015). Additionally, the interpretation of intervention effects is limited by the inclusion of multifactorial interventions (SB and PA and/or diet components) and subjective SB measures (Martin et al., 2015; Blackburn et al., 2020; Prince et al., 2020). A recent meta-analysis of Franssen et al. showed the ability of consumer wearable activity trackers to improve PA and cardiometabolic health in clinical populations, but SB changes were not clear (Franssen et al., 2020). Therefore, the present study aims to summarize and pool the SB and cardiometabolic effects of free-living SB interventions in clinical populations.

Environmental adaptations, education, motivational counselling, and technologies such as wearable devices and smartphones are reported to significantly reduce SB in the general population (Gardner et al., 2016; Peachey et al., 2020; Stephenson et al., 2017a). However, interventions are often conducted in workplace settings with low external validity regarding clinical populations who are often un- or not fully employed (de Boer et al., 2018). Moreover, disease-specific symptoms offer further challenges to reduce free-living SB from a symptom or mobility perspective and, require specific intervention components. Here, Prince et al. reported self-monitoring with real-time feedback, goal setting, and individual sessions to discuss barriers and facilitators to be important components. However, this was based on only two interventions (Prince, 2018). Therefore, the aim of this systematic review and meta-analysis is to identify 1) intervention components that objectively reduce SB under free-living conditions in clinical populations and 2) the effect of reducing SB on cardiometabolic health, including the blood lipid profile, glycaemic control, blood pressure, and anthropometric measures.

2. Methods

This systematic review and meta-analysis was registered in the PROSPERO international prospective register of systematic reviews (registration number: CRD42020158537) and was performed according to the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) statement.

2.1. Literature search

Studies were collected from inception until December 2019 in the PubMed, Embase, Web of Science (WoS), The Cochrane Central Register of Controlled Trials (CENTRAL), and Scopus electronic databases. Four main concepts were combined to design the search: diseases included in the 11th Revision of the International Classification of Diseases (ICD-11), strategies to reduce SB, objective time/day in SB, and health measures. For each main concept, different synonyms, related terms and keywords were included (details in Appendix A). Inclusion of articles was restricted to the English and Dutch language.

2.2. Eligibility criteria

Inclusion criteria to select studies were: 1) Study population: adults (>18y) with diseases, disorders or injuries included in the ICD-11 (details in Appendix A); 2) Study types: peer-reviewed randomised cross-over or controlled trials on low-intensity NEPA interventions to reduce free-living SB compared to a usual care/waitlist control group. The following lifestyle interventions are included: a) environmental interventions, involving changes to a particular behaviour setting (e.g. activity-permissible workstations, TV-limiting devices, screen-based prompts), b) behavioural interventions, targeting the individual, or c) combined environmental and behavioural interventions (Peachey et al., 2020). Laboratory-based and multicomponent intervention studies including diet and/or MVPA components were excluded, except when similar MVPA or diet components were included in both the intervention and control group; 3) Primary outcome: objective SB in min/day, with no restrictions in sensor wear location or method to measure SB. To be included, a SB-focused intervention in combination with objectively measured SB as primary or secondary outcome, was mandatory; 4) Secondary outcome: PA-related outcomes (SB breaks, standing time, walking time, steps/day and time in MVPA), cardiometabolic health outcomes including systolic and diastolic blood pressure, blood lipids (total cholesterol, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol and triglyceride levels), glycaemic control (blood glycated haemoglobin (HbA1c), glucose and insulin levels) or systemic inflammation (C-reactive protein (CRP) levels) and anthropometric measurements (body weight, waist circumference, body mass index (BMI) or percentage fat mass).

2.3. Study selection

Duplicates were removed using the de-duplication method of Bramer et al. (Bramer et al., 2016). Relevant original research papers were selected based on titles and abstracts, screened and systematically excluded based on the pre-specified eligibility criteria. Review articles, conference abstracts and editorials were excluded. Studies were independently screened by two authors (I.N. and W.M.A.F.) and disagreements between authors were resolved by consensus with a third reviewer (B.O.E).

2.4. Data extraction

Data extraction was performed with the aid of a predesigned data-collection form, adapted from the Cochrane Collaboration extraction form (Appendix B). Information on study characteristics, study participants, methods and outcome variables were extracted. For studies with multiple intervention groups, data from interventions not (only) targeting SB were not included.

Continuous data, including means, standard deviations and sample size numbers were extracted. When mean differences over time were not

available, authors were contacted to request additional data. When standard deviations were not provided, variances were estimated from the confidence intervals according to the Cochrane Handbook for Systematic Reviews of Interventions (Version 5.2, chapter 7) (Higgins, 2017). Additionally, when data were presented as median and interquartile range, the mean and standard deviations were estimated using the formula from Hozo et al. (Hozo et al., 2005). Blood parameters were converted to the same unit, from mmol/l to mg/dl (triglycerides: divide by 0.0112, total cholesterol, HDL, and LDL cholesterol by 0.02586, and glucose by 0.5551) (Laposata, 2014). SB and PA variables were converted to min/day.

2.5. Study quality assessment

The risk of bias was evaluated using the 'Cochrane Collaboration's tool for assessing risk of bias in randomised trials' (Higgins et al., 2011). The following domains of bias were assessed: random sequence generation and allocation concealment (selection bias), blinding of participants and personnel (performance bias), blinding of outcome assessment (detection bias), incomplete outcome data (attrition bias) and selective reporting (reporting bias). Each of these criteria were judged and classified as either 'low risk', 'high risk' of 'unclear risk' of bias.

2.6. Statistical analysis

Statistical analyses were performed with Review Manager 5.4. For SB, PA and cardiometabolic health, baseline differences and mean post- and pre intervention differences between control and intervention groups were calculated and are presented with 95% confidence intervals. Due to the inclusion of different population groups and intervention types/components, there was a large heterogeneity among studies. As such, a random-effects meta-analysis was used to obtain the pooled effect estimates. To evaluate the effect of population group, intervention component, SB sensor, intervention duration, age, gender, and baseline SB on SB change of the intervention groups, univariate

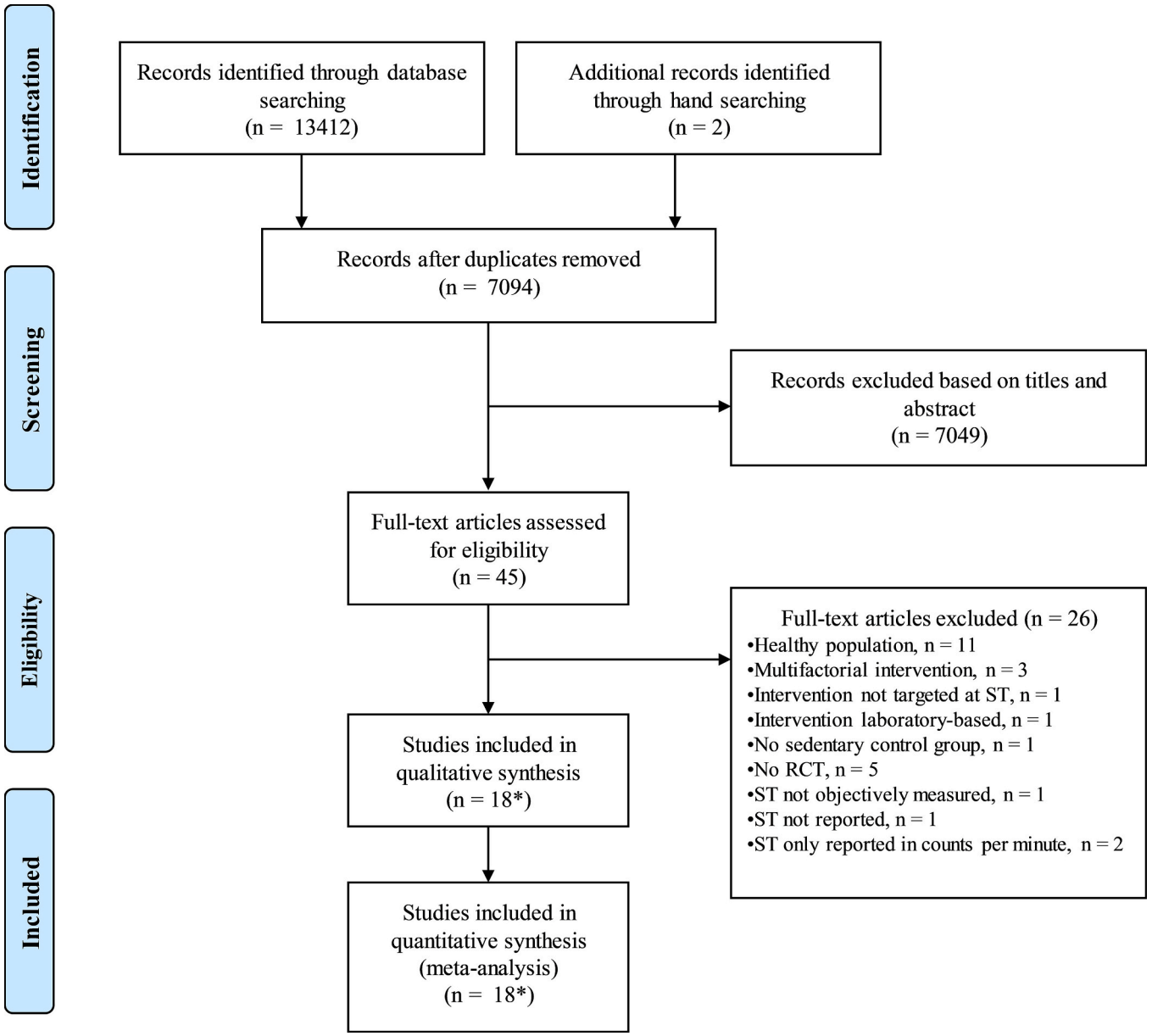

Fig. 1. PRISMA flow diagram. *Nineteen full-text articles met the inclusion criteria, but one article only reports follow-up measures of another included article, resulting in the inclusion of 18 different interventions.

(including one predictor) random-effects meta-regression analyses (R version 3.6.0) were used. A multiple meta-regression model, including several predictors, was not used due to multicollinearity and overfitting problems. Sensitivity analyses were performed to assess robustness of the results. Publication bias was assessed using funnel plots (Appendix C). The effect of heterogeneity of each summary effect size was quantified using a chi-squared test and the I^2 statistic, in which the boundary limits 25, 50 and 75% were designated as low, moderate, and high heterogeneity values (Higgins et al., 2003).

3. Results

The systematic literature search identified 13,414 potentially relevant articles, of which 7094 remained after deduplication. Nineteen full-text articles met all inclusion criteria. Because one article (Thomsen et al., 2019) only reports follow-up measures of another included article (Thomsen et al., 2017), the remainder of this review will consider 18 studies for qualitative and quantitative synthesis (Fig. 1). All included studies were published in the last 10 years (2010 to 2019), with the majority originating after 2017 ($n = 10$). Six studies included a follow-up measure 7 to 40 weeks post-intervention (Thomsen et al., 2019; Biddle et al., 2020; De Greef et al., 2010; De Greef et al., 2011; Williams et al., 2019; Ryan et al., 2019). All studies were written in the English language and could be categorised in five clinical population groups, including overweight/obesity ($n = 6$), (pre) diabetes mellitus type 2 (T2DM, $n = 4$), cardiovascular diseases (CVD; n = 4), neurological and cognitive disorders ($n = 2$) and musculoskeletal disorders (n = 2). Study characteristics are presented in Table 1.

3.1. Risk of bias

The overall risk of bias in the included studies was relatively low (Fig. 2). Eight studies met either two (n: 5) (De Greef et al., 2010; De Greef et al., 2011; Ryan et al., 2019; Laslovich et al., 2019; Lyons et al., 2017) or one (n: 3) (Biddle et al., 2020; Paul et al., 2016; Prince et al., 2018) of the six risk of bias criteria. However, 13 studies provided insufficient information to assess three (n: 3) (Kozey Keadle et al., 2014; MacEwen et al., 2017; Yang et al., 2017), two (n: 4) (Paul et al., 2016; English et al., 2016; Holliday et al., 2020; Miyamoto et al., 2017) and one (n: 6) (Thomsen et al., 2017; Biddle et al., 2020; Williams et al., 2019; Laslovich et al., 2019; Carr et al., 2013; Thomsen et al., 2016) risk of bias criteria. Although a selection bias could be precluded in all studies, five studies did not describe the concealment procedure in sufficient detail. Due to the intervention type, no study was able to blind study participants. However, this was only explicitly stated in seven of 18 studies. Only five studies blinded the outcome assessors, seven did not adequately report blinding of those assessing outcomes and six could not preclude a detection bias. Two studies had large amounts of missing data (23% (Carr et al., 2013) and 30% (Biddle et al., 2020)). However, missing data were balanced in numbers and had similar reasons across groups, limiting the risk of an attrition bias (Higgins, 2017). The risk of a reporting bias was judged to be non-existing in all studies included in the current meta-analysis. Furthermore, no publication bias could be detected (Appendix C).

3.2. Population characteristics

The included studies evaluated a total of 1040 participants (intervention: n: 541, control: n: 499), of which the majority had T2DM (n: 342, drop-out 11%) or was overweight or obese (n: 291, drop-out 13%). One hundred and seventy participants had a musculoskeletal disorder (rheumatoid arthritis, drop-out 4%), 137 participants had a CVD (stroke, peripheral or coronary artery disease, drop-out 4%) and 100 participants had a neurological or cognitive disorder (multiple sclerosis and serious mental illness, drop-out 13%). Study participants had a mean age of 53 ± 11 years (range: 33–67 years) and were predominantly female (66%). One study included exclusively women (Holliday et al., 2020), and in two studies no information on gender was provided (De Greef et al., 2011; Kozey Keadle et al., 2014).

3.3. Intervention characteristics

All study designs were randomised controlled trials, except for one study in which a randomised cross-over design was used (Yang et al., 2017). In 10 out of 18 included articles, the duration of the intervention period comprised 12 weeks, with a mean duration of 13 ± 5 weeks, ranging from 6 to 24 weeks. Sixteen studies implemented a behavioural intervention, one study combined behavioural and environmental (portable pedal machine) components (Carr et al., 2013) and only one intervention was environmentally based (MacEwen et al., 2017). The following four behavioural components could be identified: 1) self-monitoring (Prince et al., 2018; Miyamoto et al., 2017), 2) education in combination with motivational counselling (Thomsen et al., 2017; English et al., 2016; Thomsen et al., 2016), where the overall goal was to increase the participant's intrinsic motivation to change (Rubak et al., 2005), 3) the use of a website/app and 4) social facilitation. In six studies self-monitoring and motivational counselling were combined (Biddle et al., 2020; De Greef et al., 2010; De Greef et al., 2011; Ryan et al., 2019; Kozey Keadle et al., 2014; Holliday et al., 2020) and six other studies also added the use of a website/app and/or social facilitation (Williams et al., 2019; Laslovich et al., 2019; Lyons et al., 2017; Paul et al., 2016; Yang et al., 2017; Carr et al., 2013). Self-monitoring devices were mostly focused on PA (steps/day (De Greef et al., 2010; De Greef et al., 2011; Williams et al., 2019; Ryan et al., 2019; Kozey Keadle et al., 2014; Carr et al., 2013) or minutes of PA/day (Holliday et al., 2020; Miyamoto et al., 2017)), whereas five studies also included prompts to interrupt SB (Biddle et al., 2020; Laslovich et al., 2019; Lyons et al., 2017; Prince et al., 2018; Yang et al., 2017).

Motivational counselling and education were provided in different formats; via the study website or app (Laslovich et al., 2019; Paul et al., 2016), face-to-face sessions (Ryan et al., 2019; Kozey Keadle et al., 2014), combined face-to-face and group sessions (Williams et al., 2019), phone calls, text messages or emails (Lyons et al., 2017; Yang et al., 2017; Holliday et al., 2020; Carr et al., 2013) or a combination of group/face-to-face sessions with follow-up phone calls, text messages or emails (Thomsen et al., 2017; Biddle et al., 2020; De Greef et al., 2010; De Greef et al., 2011; English et al., 2016; Thomsen et al., 2016). Social facilitation was organized by showing results of peers in the website or app with the possibility to comment or like activity (Lyons et al., 2017; Paul et al., 2016; Yang et al., 2017) or by optional weekly walks (Williams et al., 2019). One of 18 studies applied an environmental intervention by providing a height-adjustable desk in the office, without further additional information or prompting (MacEwen et al., 2017). Excluded intervention groups (Kozey Keadle et al., 2014; Holliday et al., 2020; Miyamoto et al., 2017) are described in Table 1.

In 14 of 18 studies the control groups consisted of usual care, in three studies a waitlist was used (Lyons et al., 2017; Holliday et al., 2020; Carr et al., 2013), and one study implemented an attention-matched control group with the message to increase calcium intake for bone health (English et al., 2016). One study included general health recommendations including nutrition to both the intervention and control group (Laslovich et al., 2019). The average drop-out rate among studies was 8.7% and ranged from 0% (Laslovich et al., 2019; Miyamoto et al., 2017) to 30% (Biddle et al., 2020). The average drop-out rate of follow-up measures was 11.9%. One study assessed the effect of the SB intervention on body composition and included SB as a secondary outcome (Holliday et al., 2020), all other studies primarily assessed SB changes. Ten studies measured SB with activPAL3™, in which an inclinometer to assess posture and an accelerometer to assess acceleration, are combined. The remaining studies only measured acceleration with different sensors and wear locations; at the waist (Actigraph GT3X® (Biddle et al., 2020; De Greef et al., 2010; De Greef et al., 2011; Holliday et al., 2020),

Table 1
Characteristics of included studies.

Study	Population	Intervention duration (w)	Participants	Intervention	Outcome parameters (ST monitor; monitor time)
Biddle 2015	Adults at risk of T2DM	12 Follow-up: 52	**Intervention** N: 94 Drop-out: 30 (32%) Age: 32.4 ± 5.4y BMI: 34.6 ± 4.9 M/F: 28/66 *non-attendance at education session: 25% **Control** N: 93 Drop-out: 25 (27%) Age: 33.3 ± 5.8y BMI: 34.5 ± 5 M/F: 31/62	*Behavioural*[3] **MC:** 1 group education session (3h) targeting knowledge and perceptions of prevalent risk factors for T2DM and promoting SB change, goal setting and group discussions + 1 follow-up phone call at 6w **SM:** Gruve with vibration prompts if participant had been sitting for an extended period (feedback on ST via a computer, not real-time) Usual care	**Physical activity** (10d): - ST (AG; WT) - Standing time (AP; W+ST) - ST breaks (AP; W+ST) - Steps/day (AG; WT) - MVPA time (AG; WT) **Cardiometabolic risk:** - HbA1c - Fasting glucose - Total chol - HDL-chol - LDL-chol - Triglycerides - Systolic BP - Diastolic BP **Anthropometrics:** - Body weight - BMI - Fat% - WC
Carr 2013	Overweight/obesity	12	**Intervention** N: 17 Drop-out: 2 (12%) Age: 47.6 ± 9.9y BMI: 33.2 ± 4.5 M/F: 1/16 **Control** N: 23 Drop-out: 7 (30%) Age: 42.6 ± 8.9y BMI: 31.7 ± 4.9 M/F: 3/20	***Multicomponent*** *Behavioural*[4]*:* **MC:** Access to motivational website individually tailored to the local worksite with theory-based messages (content: reducing ST by both increasing active sitting through pedaling and taking breaks from sitting by means of social support, self-efficacy and discussion of perceived environment) + 3 theory-based motivational emails/week targeting goal setting, self-efficacy and perceived environment **SM:** Pedometer (Omron HJ-150) + daily mails to remind participants to self-monitor daily pedal time and steps on website **Social facilitation:** Communication via website in groups of 4-5 participants + virtual competition (groups travelled across the USA) *Environmental:* portable pedal machine + PC interface with real-time feedback + suggestions for daily pedaling time and on how to set goals (no pre-specified goals) Wait list	**Physical activity** (Stepwatch Physical Activity Monitor; 7d - WT): - ST **Cardiometabolic risk:** - Total chol - HDL-chol - LDL-chol - Triglycerides - BP - Diastolic BP **Anthropometrics:** - Body weight - BMI - WC
De Greef 2010	T2DM	12 Follow-up: 52	**Intervention** N: 20 Drop-out 12w: 2 (10%) Drop-out 52w: 3 (15%) Age: 61.3 ± 6.3y BMI: 29 ± 4.2 M/F: 13/7 **Control** N: 21 Drop-out 12w: 2 (9.5%)	*Behavioural*[3] **MC:** 5 group sessions (90 min; week 1, week 3, week 5, week 8, week 12) + booster session (week 23). Sessions start with a motivational interviewing phase, after which lifestyle change plans are developed (the where, when and how the planned behaviour changes would take place). Afterwards pedometer results are discussed and goals reviewed and renewed. **SM:** Pedometer + pedometer diary to record physical activity in order to set goals in the context of their daily routine Usual care + single education session about T2DM and physical activity (similar to first session of intervention group), with information on the benefits of physical activity and the risks of SB and were not motivated to increase physical activity	**Physical activity** (AG; 5d - WT): - ST - Steps/day - MVPA time **Cardiometabolic risk:** - HbA1c - Total chol - Systolic BP - Diastolic BP

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Table 1 (*continued*)

Study	Population	Intervention duration (w)	Participants	Intervention	Outcome parameters (ST monitor; monitor time)
			Drop-out 52w: 2 (9.5%) Age: 61.3 ± 6.9y BMI: 31.5 ± 5 M/F: 15/6		**Anthropometrics:** - Body weight - BMI
De Greef 2011	T2DM	24 Follow-up: 52	**Intervention** N: 60 Drop-out: 2 (3%) Age: 62 ± 9.0y BMI: 30 ± 2.8	*Behavioural*[3]*:* **MC:** 1 face-to-face session (30min) and 7 telephone calls (week 2, week 4, week 8, week 12, week 16, week 20, week 24). Face-to-face session started with a motivational interviewing phase, after which lifestyle change plans were developed (the where, when and how the planned behaviour changes would take place). Phone calls were specifically structured and included counselling on goal-setting, self-monitoring, self-efficacy, benefits, decisional balance, problem-solving strategies, social support and relapse prevention. **SM:** Pedometer + pedometer diary to record physical activity. A gradual increase of steps/days starting from baseline levels was advised (increase baseline steps/day with 1500 in 3 activity goals, unless participants were already sufficiently active (>10.000 steps/day) they were encouraged to maintain that level).	**Physical activity** (AG; 5d - WT): - ST - Steps/day - MVPA time
			Control N: 32 Drop-out: 2 (6%) Age: 62 ± 9.0y BMI: 30 ± 2.8 M/F: 63/29	Usual care	
English 2016	Stroke survivors (3.2 ± 3.4y since stroke, 12/33 require assistance in ADLs, 12/33 require walking aid)	7	**Intervention** N: 19 Drop-out: 0 Age: 65.4 ± 12.3y BMI: 29.3 ± 5.8 M/F: 13/6	*Behavioural*[2]*:* **MC:** 1 face-to-face session, 3 follow-up phone calls (week 1, 3 and 7). Main message: 'Sit less and move more' with encouragement to regularly break up sitting time with short bursts of light intensity activity (standing, walking at a comfortable peace). In first face-to-face session, feedback on baseline ST was provided, action plans, goals and strategies were elicited from participants.	**Physical activity** (AP; 7d - W+ST): - ST - Standing time - Walking time - MVPA time
			Control N: 16 Drop-out: 2 (12.5%) Age: 67.8 ± 13.8y BMI: 27.5 ± 3 M/F: 9/7	Control group participants received the same schedule of interviews as the intervention group, with a placebo message of increasing calcium for bone health. Data from a food frequency questionnaire were used to create personalized feedback	
Holliday 2018	Overweight/ obesity	24	**Intervention** N: 24 Drop-out: 2 (8%) Age: 41 ± 2.0y BMI: 29.2 ± 3.4 M/F: 0/24 *compliance with accelerometer protocol: n = 9	*Behavioural*[3]*:* **MC:** Contact by telephone and email twice weekly for the first 4 weeks, and once fortnightly from weeks 4 to 12 (positive reinforcement when target points/min of SM were achieved, encouragement to persevere and if targets were not achieved, participants were reminded of the typical benefits of being more active for health and general well-being). **SM:** Points-based physical activity monitoring with table. Participants need to accumulate 30 points per week, equating to 5 × 30 min of brisk walking and are provided a table of examples of different activities, each with a points score allocated per ten-minutes of activity. Points values are derived from MET scores (-1.5METs for SB). These activities had to be additional to regular physical activity behaviour. Participants could add specific activities to the table to which points scores were assigned.	**Physical activity** (AG; 3d - WT) - ST - MVPA time **Anthropometrics:** - Body weight - BMI - Fat% - WC
			Control N: 26 Drop-out: 6 (23%) Age: 41 ± 2y BMI: 29.2 ± 3.4 M/F: 0/26	Wait list	

(*continued on next page*)

Table 1 (*continued*)

Study	Population	Intervention duration (w)	Participants	Intervention	Outcome parameters (ST monitor; monitor time)
			*compliance with accelerometer protocol: n = 3		
				Excluded intervention group: Structured exercise (150 min MVPA/week)	
Kozey Keadle 2014	Overweight/obesity	12	**Intervention** N: 18 Drop-out: 4 (22%) Age: 44.5 ± 9.5y BMI: 34.8 ± 4.3	*Behavioural*[3]: **MC:** Education on strategies to reduce sitting time at home and at work (i.e. standing during commercials, taking 5min breaks every hour, etc.) and on benefits of NEPA + recommendation to accumulate NEPA in small bouts throughout day + weekly face-to-face meetings to discuss strategies and feedback on physical activity results **SM:** Omron pedometer + weekly goals based on baseline steps	**Physical activity** (AP; 7d - W+ST): - ST - Standing time - Walking time - Steps/day
			Control N: 10 Drop-out: 2 (20%) Age: 42.7 ± 10.1y BMI: 35.3 ± 5.2	Control group participants had to maintain current levels of activity	**Cardiometabolic risk:** - Fasting glucose - Total chol - HDL-chol - Triglycerides - Systolic BP - Diastolic BP
				Excluded intervention groups: - Structured exercise (exercise 5 days/week for 40 min/session at moderate intensity) - Combination of structured exercise and SB intervention	**Anthropometrics:** - Body weight - BMI - Fat%
Laslovich 2019	Asymptomatic PAD	12	**Intervention** N: 19 Drop-out: 0 Age: 68 ± 7.5y BMI: 29.5 ± 4.1 M/F: 10/9	*Behavioural*[4]: **MC:** 2x/month online video with health recommendations related to PAD (general PAD facts and figures, hypertension, diabetes, cardiovascular disease prevention, tobacco use, and nutrition) + instruction to walk at least 2 or more 10min bouts continuously + planning + goal setting (individualized automated goal setting features in online platform, continuously updated based on uploaded data) **SM:** Wearable activity tracker + real-time feedback (indicator bar with 5 activity levels + vibration prompts when >50min are spent sedentary) + online self-monitoring home page dashboard	**Physical activity** (AP; 7d - W+ST): - ST - Standing time - ST - Walking time - Steps/day
			Control N: 19 Drop-out: 0 Age: 68 ± 10.6y BMI: 28.8 ± 5.2 M/F: 7/12	Control group participants received the same bimonthly videos as the intervention group	
Lyons 2017	Mid-aged and older adults with obesity	12	**Intervention** N: 20 Drop-out: 1 (5%) Age: 61.3 ± 6.0y BMI: 30 ± 2.9 M/F: 3/17	*Behavioural*[4]: **MC:** Orientation visit for guidance on the use of the activity tracker and app, encouragement for social interaction in app and goal-setting. Mobile phone app with individual goals and socialization + weekly telephone counselling (15-20 min, content: adverse events, technical problems, discussion of goals for steps/day and ST alerts, planning, social support, problem solving, self-rewards, relapse prevention, stress and time management) **SM:** Wearable physical activity monitor (Jawbone Up24) + prompts when > 1h is spent sedentary + tablet device **Social facilitation:** Home page in app with possibility to comment and like activity of other participants in the same cohort	**Physical activity** (AP; 7d - W+ST): - ST - Walking time - Steps/day **Anthropometrics:** - Body weight - Fat%
			Control N: 20 Drop-out: 1 (5%) Age: 61.7 ± 6.3y BMI: 30.7 ± 4.0 M/F: 3/17	Waitlist	

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Table 1 (*continued*)

Study	Population	Intervention duration (w)	Participants	Intervention	Outcome parameters (ST monitor; monitor time)
MacEwen 2017	Office workers with abdominal obesity	12	**Intervention** N: 15 Drop-out: 0 Age: 43.2 ± 9.7y BMI: 36.5 ± 9.0 M/F: 3/13	*Environmental* Height-adjustable desks, without any additional information or prompting. Advice to sit or stand as much as they liked.	**Physical activity** (AP; 7d - W+ST): - ST - Standing time - ST breaks - Steps/day
			Control N: 12 Drop-out: 2 (17%) Age: 48.9 ± 11.4y BMI: 34.6 ± 7.0 M/F: 2/10	Control group participants had to continue work at seated desks with the advice to sit or stand as much as they liked	**Cardiometabolic risk:** - HbA1c[a] - Fasting glucose[a] - Total chol[a] - HDL-chol[a] - LDL-chol[a] - Triglycerides[a] - Systolic BP - Diastolic BP **Anthropometrics:** - Body weight - BMI - Fat% - WC
Miyamoto 2017	T2DM	12	**Intervention** N: 12 Drop-out: 0 Age: 60.0 ± 3.1y BMI: 25.2 ± 1.3 M/F: 9/3	*Behavioural*[1]*:* **SM:** Tri-axial accelerometer + instruction to increase non-locomotive PA (routine domestic or occupational tasks such as sit-to-stand activity or washing dishes)	**Physical activity** (HJA-350IT; 7d - WT): - ST **Cardiometabolic risk:** -HbA1c - Fasting glucose - Total chol - LDL-chol - Triglycerides **Anthropometrics:** - Body weight
			Control N: 10 Drop-out: 0 Age: 60.2 ± 3.0y BMI: 23.9 ± 0.7 M/F: 8/2	Usual care + accelerometer with display turned off and no instruction regarding physical activity **Excluded intervention group:** Tri-axial accelerometer + instruction to increase locomotive PA (which requires moderate-to-vigorous energy consumption)	
Paul 2016	Stroke survivors (3.8 ± 2.5 - 4.9 ± 6.1y since stroke, 10/23 require walking aid)	6	**Intervention** N: 16 Drop-out: 1 (6%) Age: 56.3 ± 8.7y BMI: 24.1 ± 3.5 M/F: 7/8	*Behavioural*[4]*:* **MC:** Participants receive smartphone with 'STARFISH app' + instructions (30min) + feedback session to discuss progress after 3w. App content: Goal setting (daily step count target based on baseline period which is weekly adjusted), planning, feedback and rewards (fish, representing progress, blow bubbles when active and grow when targets are reached), social facilitation (virtual groups of 4 persons, when all persons reach targets another sea creature is added to fish tank + all participants of the group see activity of other participants (fish swims and blows bubbles) **SM:** Visual representation of fish in mobile phone app	**Physical activity** (AP; 7d - W+ST): - ST - Standing time - Walking time - Steps/day **Cardiometabolic risk:** - Systolic BP - Diastolic BP **Anthropometrics:** - BMI
			Control N: 8 Drop-out: 0 Age: 55.3 ± 12.6y BMI: 24.8 ± 1.8 M/F: 4/4	Usual care: No active rehabilitation, only appointments with health care professional as required	
Prince 2018	Coronary artery disease patients	6.5	**Intervention** N: 19 Drop-out: 2 (11%) Age: 62.4 ± 10.7y	*Behavioural*[1]*:* **SM:** Monitor (activPAL VTAP model) with vibration prompts when >30 consecutive minutes are spent sedentary (2min of standing/movement necessary to reset)	**Physical activity** (AP; 7d - W+ST): - ST - Standing time

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Table 1 (*continued*)

Study	Population	Intervention duration (w)	Participants	Intervention	Outcome parameters (ST monitor; monitor time)
			BMI: 28.7 ± 5.8 M/F: 10/7		- ST breaks - Walking time - Steps/day - MVPA time
			Control N: 21 Drop-out: 0 Age: 61.5 ± 9.7y BMI: 30.5 ± 5.4 M/F: 13/8	Usual care: Cardiac rehabilitation	**Cardiometabolic risk:** - HbA1c - Fasting glucose - Total chol - HDL-chol - LDL-chol - Triglycerides - Systolic BP - Diastolic BP **Anthropometrics:** - Body weight - BMI - WC
Ryan 2019	Multiple sclerosis	12 Follow-up: 36		**Intervention** N: 30 Drop-out 12w: 2 (7%) Drop-out 36w: 3 (10%) Age: 56.9 ± 9.0y BMI: 25.9 ± 5.3 M/F: 13/17	*Behavioural*[3]*:* **MC:** 4 face-to-face sessions (30-45min; discussion of step count, ST and goals) + behaviour change techniques + handbook (content: Pre-reading and reflection that needs to be completed prior to each session + goal setting + self-monitoring) **SM:** Yamax SW-200 digiwalker + activity diary in handbook
Control N: 30 Drop-out 12w: 3 (10%) Drop-out 36w: 5 (17%) Age: 56.7 ± 9.2y BMI: 26.3 ± 5.9 M/F: 13/17	Usual care		**Physical activity** (AP; 7d - W+ST): - ST - Standing time - Walking time - Steps/day - MVPA time		
Thomsen 2016 **Thomsen 2017, 2019**	Rheumatoid arthritis	16 Follow-up: 22	**Intervention** *2016* N: 10 Drop-out 16w: 0 Age: 64.5 ± 8.5y BMI: 28.7 ± 6.5 M/F: 4/6 *2017, 2019* N: 75 Drop-out 16w: 1 (1%) Drop-out 22m: 4 (5%) Age: 59.7 ± 10.7y BMI: 26.0 ± 5.5 M/F: 15/60	*Behavioural*[2]*:* **MC:** 3 motivational counselling sessions (week 1, week 3, week 10, content: 4 key messages using motivational interviewing: Reduce TV viewing, substitute sitting with standing when possible at work and/or at home, break up prolonged sitting by standing up frequently, maximum 30min sitting per episode). Session 1: Monitoring and discussion of physical activity and ST (goal setting & action planning). Session 2-3: Discussion and modification of goals + oral and written information about the health benefits of reducing sitting time + text messages to remind participants of their individually set behavioural goals (depending on participants' preference (max 1/day and 5/week)	**Physical activity** (AP; 7d - W+ST): - ST - Standing time - ST breaks - Walking time **Cardiometabolic risk:** - HbA1c - Fasting glucose - Total chol[b] - HDL-chol[b] - LDL-chol[b] - Triglycerides[b] - Systolic BP - Diastolic BP
			Control *2016*	Usual lifestyle	

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Table 1 (*continued*)

Study	Population	Intervention duration (w)	Participants	Intervention	Outcome parameters (ST monitor; monitor time)
			N: 10 Drop-out: 1 (10%) Age: 54.0 ± 14.0y BMI: 21.9 ± 4.2 M/F: 4/6		**Anthropometrics:** - Body weight - BMI - WC
Williams 2019	Serious mental illness	17 Follow-up: 24	*2017, 2019* N: 75 Drop-out 16w: 2 (3%) Drop-out 22m: 11 (14.6%) Age: 59.5 ± 12.7y BMI: 26.8 ± 5.3 M/F: 14/61	**Intervention** N: 20 Drop-out: 4 (20%) Age: 43.0 ± 18.0y M/F: 13/7	*Behavioural*[4]*:* **MC:** 1 group education session at baseline (content: Benefits of being active, harms of being sedentary, strategies to reduce and interrupt ST) + two weekly face-to-face coaching sessions (30min, content: Discussion of barriers) **SM:** Yamax digi-walker + recording on individual calendar **Social facilitation**: Optional weekly walks
Control N: 20 Drop-out: 3 (15%) Age: 43.0 ± 18.0y M/F: 9/11	Usual care		**Physical activity** (Geneactiv 3d - WT): - ST - MVPA time **Anthropometrics:** - WC		
Yang 2017	Overweight	12	**Intervention** N: 53 Drop-out: 5 (9%) Age: 33.9 ± 10.0y BMI: 27.2 ± 3.4 M/F: 21/32	*Behavioural*[4]*:* **MC:** Individual reminder messages (at least 1/week, content: Evidence-based health information, professional personnel counselling and constructive feedback) via Line and email. **SM:** Physical activity sensor + related smartphone app (monitors food intake, physical activity data, sleep hours, sleep efficacy) **Social facilitation:** Interactive webpage (data of smartphone app + specific targets for calories to burn, steps/day (>10.000/day), walking distance (>6.8km/day) and activity intensity (ST < 8h). Results from peer group visible and health recommendations ('good, please continue')	**Physical activity** (wearable sensor module with a neural-network-based activity classification algorithm[1]): - ST - Steps/day **Cardiometabolic risk:** - Fasting glucose - HDL cholesterol - Triglycerides - Systolic blood pressure **Anthropometrics:** - Body weight - BMI - Waist circumference
			Control N: 53 Drop-out: 2 (4%) Age: 32.4 ± 9.2y BMI: 30.3 ± 4.9 M/F: 21/32	Usual care with health education (booklet of MetS prevention published by the Health Promotion Administration of Ministry of Health and Welfare with details on 5 topics: dietary control, PA, quitting tobacco and alcohol, stress management, regular health examination)	

1. Lin CW, Yang YT, Wang JS, et al. A wearable sensor module with a neural-network-based activity classification algorithm for daily energy expenditure estimation. *IEEE transactions on information technology in biomedicine: a publication of the IEEE Engineering in Medicine and Biology Society* 2012; 16: 991–998. 2012/08/10. DOI: https://doi.org/10.1109/titb.2012.2206602.

Abbreviations: **T2DM** diabetes mellitus type 2, **y** year, **BMI** body mass index (kg/m^2), **M** male, **F** female, **MC** motivational counselling, **ED** education, **SM** self-monitoring, **E** environmental, **ST** sedentary time, **d** days, **WT** waking time, **W + ST** waking and sleeping time, **h** hour, **w** weeks, **SB** sedentary behaviour, **AG** ActiGraph, **AP** activPAL, **MVPA** moderate-to-vigorous physical activity, **chol** cholesterol, **HDL-chol** high-density lipoprotein cholesterol, **LDL-chol** low-density lipoprotein cholesterol, **BP** blood pressure, **WC** waist circumference, **ADL** activities of daily living, **NEPA** non-exercise physical activity, **PAD** peripheral arterial disease, **m** months.

[a] via finger stick samples
[b] non-fasted
[1] self-monitoring
[2] motivational counselling
[3] self-monitoring and motivational counselling
[4] self-monitoring and motivation counselling and website/app and/or social facilitation

HJA-350IT Omron (Miyamoto et al., 2017)), wrist (GENEActiv (Williams et al., 2019)), ankle (StepWatch™ physical activity monitor (Carr et al., 2013)), or a combination of wrist, ankle and waist (wearable sensor system (Yang et al., 2017)). Three studies also evaluated the impact of reducing sitting time on anthropometrics (Williams et al., 2019; Lyons et al., 2017; Holliday et al., 2020), and 11 studies also added cardiometabolic health measures (Thomsen et al., 2017; Biddle et al., 2020; De Greef et al., 2010; Paul et al., 2016; Prince et al., 2018; Kozey Keadle et al., 2014; MacEwen et al., 2017; Yang et al., 2017; Miyamoto et al., 2017; Carr et al., 2013; Thomsen et al., 2016).

3.4. Sedentary behaviour (SB) & physical activity (PA)

All studies reported baseline SB and mean pre-post differences, expressed in min/day. Walking time (Thomsen et al., 2017; Ryan et al., 2019; Laslovich et al., 2019; Lyons et al., 2017; Paul et al., 2016; Prince et al., 2018; Kozey Keadle et al., 2014; English et al., 2016) and time in MVPA (Biddle et al., 2020; De Greef et al., 2010; De Greef et al., 2011; Williams et al., 2019; Ryan et al., 2019; Prince et al., 2018; English et al., 2016; Holliday et al., 2020) were reported in eight studies, step counts in 11 studies (Biddle et al., 2020; De Greef et al., 2010; De Greef et al., 2011; Laslovich et al., 2019; Paul et al., 2016; Prince et al., 2018; Kozey Keadle et al., 2014; MacEwen et al., 2017; Yang et al., 2017; Lyons et al., 2017; Ryan et al., 2019) and nine of 10 studies using an inclinometer reported standing time (Thomsen et al., 2017; Biddle et al., 2020; Laslovich et al., 2019; Paul et al., 2016; Prince et al., 2018; Kozey Keadle et al., 2014; MacEwen et al., 2017; English et al., 2016; Ryan et al., 2019). Baseline SB was comparable between all groups (10.0 ± 1.2 h, population groups: $p = 0.59$; intervention and control groups: $p = 0.38$) when excluding four studies where sleeping time and SB were combined (De Greef et al., 2010; De Greef et al., 2011; Lyons et al., 2017; Paul et al., 2016). Patients with a clinical condition or disability reduced their SB by 64 min/day following an intervention to reduce SB (95%CI: [−91,-38] min/day; $p < 0.001$) compared to control groups without intervention (Fig. 3). Furthermore, participants of the intervention groups significantly increased their walking time (+27 [13,41] min/day; $p < 0.001$) and step count (+1976 [785,3167] steps/day, $p = 0.001$), but not standing time (+28 [−1,57] min/day; $p = 0.06$) nor MVPA (+0.3 [−5,6] min/day; $p = 0.92$; Table 3). At follow-up, only changes in walking time remained statistically significant (+13 [0,26] min/day, $p = 0.04$), whereas sitting time, standing time, steps, and MVPA changes were not significantly different from baseline values.

3.5. Impact of population group and intervention characteristics on SB changes

Meta-regression analysis showed no significant effect of population on SB changes over time ($p = 0.12$), indicating a similar intervention effect between population groups. The overall and subgroup analyses showed significant heterogeneity within obese/overweight persons, T2DM, neurological/cognitive, and musculoskeletal patients, but not CVD patients. Changes in SB following an intervention were not associated with the type of sensor used to measure SB ($p = 0.15$), intervention duration ($p = 0.26$), age ($p = 0.96$), gender ($p = 0.57$), or baseline SB ($p = 0.47$). Furthermore, within-group changes for the different behavioural components showed that SB reductions were only significant when self-monitoring and motivational counselling were combined and when social facilitation and/or the use of an app/website were added to the intervention (Table 2). However, no significant difference between intervention components was found in the meta-regression analysis ($p = 0.30$).

3.6. Cardiometabolic health

The intervention groups significantly improved their HbA1c (−0.17%; 95%CI: [−0.30,-0.04]%; p = 0.01), fat percentage (−0.66%; 95%CI: [−1.26,-0.06]%, p = 0.03) and waist circumference (−1.52 cm; 95%CI: [−2.84,-0.21] cm; p = 0.02) compared to the control groups. HbA1c and waist circumference results were substantially heterogeneous ($p = 0.01$, $I^2 = 63\%$ and $p = 0.004$, $I^2 = 64\%$, respectively). Other cardiometabolic health measures did not significantly change (Table 3).

4. Discussion

This review is, to the best of our knowledge, the first that systematically evaluated the effect of lifestyle interventions to reduce SB under free-living conditions in clinical populations. Results showed that persons with overweight/obesity, T2DM, CVD, neurological/cognitive, or musculoskeletal disorders significantly reduced their SB by 64 min/day following a lifestyle intervention targeting SB.

The SB reduction in this meta-analysis is larger than what is reported for the general population with similar behavioural interventions (−30 to −56.86 min/day) (Martin et al., 2015; Blackburn et al., 2020; Peachey et al., 2020; Stephenson et al., 2017b). Importantly, the inclusion of subjective SB measures in previous meta-analyses limits comparison with the current objective results. Nevertheless, clinical populations might have more opportunities to reduce SB as they are more often un- or not fully employed (de Boer et al., 2018) and have higher baseline SB (current results: 10.0 ± 1.2 h vs general population: 7.7 ± 3.2 h (Matthews et al., 2008)). Importantly, the largest SB reductions in the current results were found with the multicomponent behavioural interventions (Table 2), which is in line with findings in the general population (Blackburn et al., 2020; Brickwood et al., 2019). A previous review on behavioural interventions to reduce SB in clinical populations already reported self-monitoring and motivational counselling, including goal setting and one-to-one sessions, as important components (Prince, 2018). The current findings further complement these intervention components with social facilitation and the use of technologies such as wearable devices, and smartphone/computer applications. The lack of a significant difference between the four

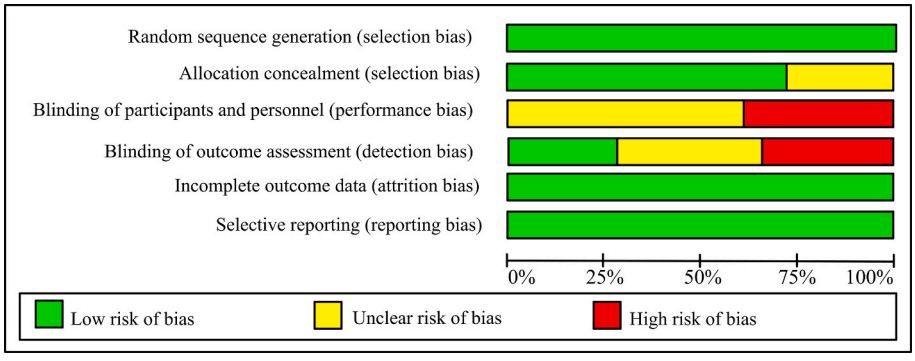

Fig. 2. Risk of bias graph for included studies ($n = 18$).

intervention strategies is probably due to the low statistical power (post hoc analysis: 9%), as only a few single-component intervention studies could be included. Furthermore, environmental interventions in the general population are reported to have greater reductions in SB than behavioural interventions (Blackburn et al., 2020; Peachey et al., 2020), but are studied to a limited extent in clinical populations. Only two interventions of the current meta-analysis included environmental adaptations, with SB reductions of larger magnitudes (114 (Carr et al., 2013) and 97 (MacEwen et al., 2017) min/day). However, no recommendations on environmental restructuring to reduce SB in clinical populations can be made.

Although all diseases of the ICD-11 were included in the current search, only five population groups could be identified, from which the majority were metabolically related. Here, the question arises whether the 'clinical disorder' of these participants is a consequence of their sedentary lifestyle or that participants become sedentary due to their clinical symptoms. However, the exact sequence of events is negligible, because a vicious inactivity circle is initiated (Prince, 2018). Nonetheless, to increase the generalisability of the present results, research on SB interventions in other clinical populations is warranted. Furthermore, even though no significant differences between intervention effects across population groups were identified, the high heterogeneity in current results might indicate possible different responses per group (Fig. 3). Higgens et al. previously reported that moderate to considerable

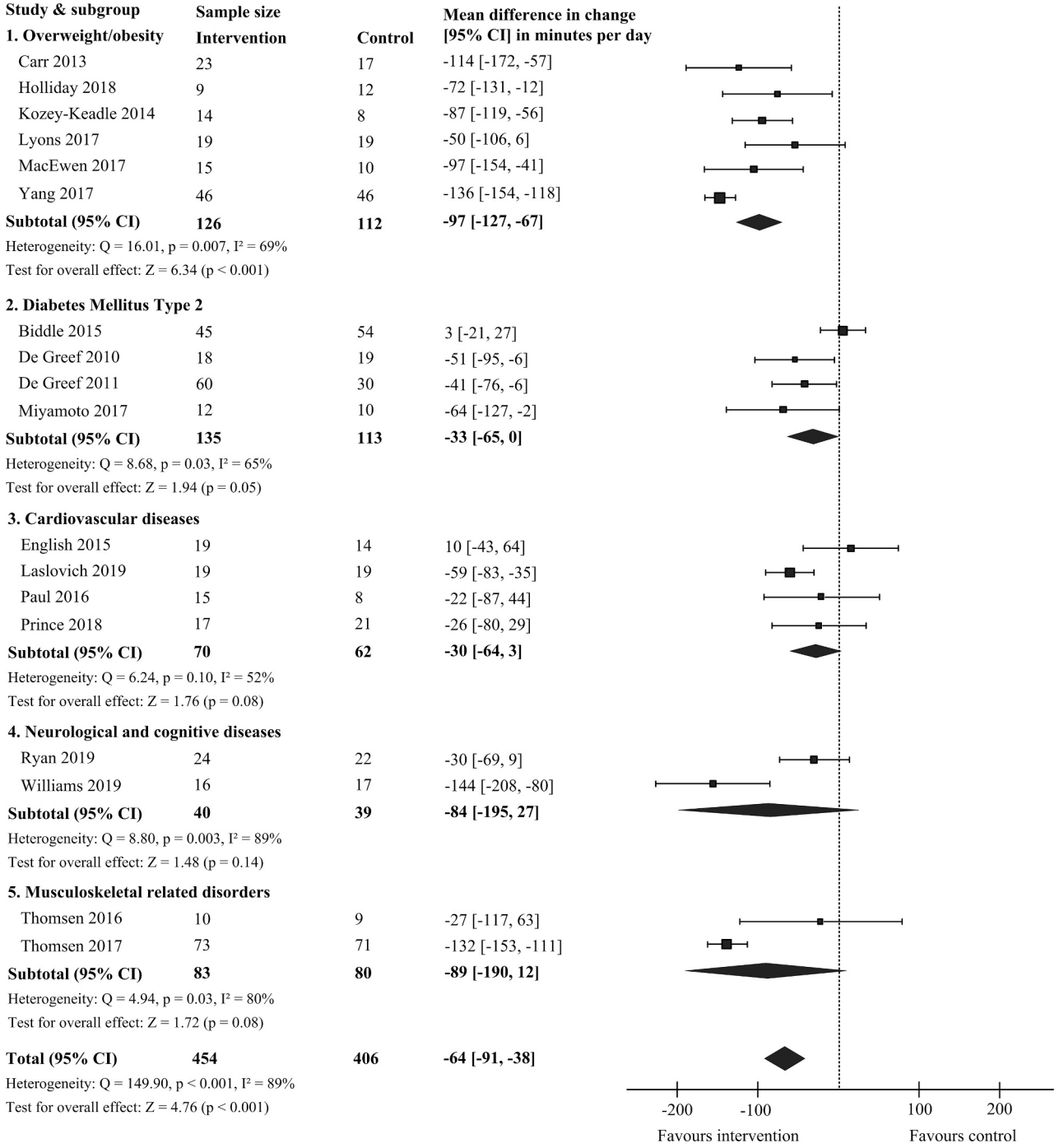

Fig. 3. Forest plot of weighted mean pre-post differences in sedentary behaviour (minutes per day) between control and intervention groups. Abbreviations: **CI** confidence interval, **I^2** variation in pooled effect size attributable to heterogeneity within that group.

Table 2
Sedentary time changes in minutes per day for the behavioural intervention components.

Behavioural intervention component	No. of studies	No. of participants			Mean change (95% CI)	*p*-value
		Int.	Con.	Drop-out		
Self-monitoring	2	31	31	3%	−42 [−83, −1]	0.36
Motivational counselling	3	104	101	3%	−53 [−159, 54]	0.33
Self-monitoring and motivational counselling	6	246	212	18%	−44 [−76, −13]	0.006
Self-monitoring and motivational counselling and website/app and/or socialization	6	145	143	9%	−89 [−132, −46.]	<0.001

Abbreviations: **Int.** intervention group, **Con.** control group, **CI** confidence interval

statistical heterogeneity is often inevitable in meta-analysis due to clinical and methodological diversity (Higgins et al., 2003), but future research should take sub analyses per population group and information on disease severity and feasibility into account.

Participants replaced their SB with approximately 30 min of standing and 30 min of walking. MVPA did not significantly change. Previous research also shows that participants following a MVPA intervention, increase the intensity of their PA (e.g. from light to moderate/vigorous intensity), without reducing their SB (Martin et al., 2015; Gardner et al., 2016; Prince et al., 2014). This shows the specificity of SB and PA interventions and indicates that when SB and MVPA need to be improved simultaneously, both behaviours should be targeted. Furthermore, the extra 30 min walking time corresponded with an additional 1976 steps/day, or 73 steps/min, in the intervention group. Moderate-intensity PA is associated with 100 steps/min (Marshall et al., 2009), which demonstrates the low walking intensity of participants in the current review. This is however evident because most interventions aimed to specifically increase low-intensity household activities. At follow-up, walking time was the only significantly improved variable. Follow-up duration varied however largely, and only six studies included a follow-up measure of which only three could assess standing time by the means of an inclinometer. Hence, no solid conclusions can be drawn on SB changes on the longer term and, therefore, more comprehensive follow-up measures are recommended in future research.

The present results show the large window of opportunity of SB interventions in clinical populations. Moreover, previous work showed better adherence rates with lower activity intensities for sedentary adults (Perri et al., 2002), and the low drop-out rate (< 10%) in current results supports the feasibility of low-intensity NEPA for clinical populations. A recent meta-analysis of Hadgraft et al. showed positive cardiometabolic health effects of free-living SB interventions in the general population, in which clinical populations were only very limited represented (Hadgraft et al., 2020). The current results complement these findings for persons with a clinical condition. Here, a significant improvement in anthropometrics (fat percentage and waist circumference) and glycaemic control (HbA1c) was found following a SB reduction under free-living conditions in clinical populations. The most evident improvement was found in anthropometrics. Baseline waist circumference values indicated an increased cardiometabolic risk (men >102 cm, women >88 cm) (Klein et al., 2007). According to De Koning et al., the relative risk of a CVD event is reduced by 2% for every 1 cm reduction in waist circumference (de Koning et al., 2007). Moreover, waist circumference and fat percentage changes were twice the magnitude of the changes in Hadgraft et al. (−1.52 vs −0.7 cm and − 0.7 vs −0.3%), implying more substantial health benefits of light-intensity NEPA in clinical populations. Fasting glucose concentrations and HbA1c values at baseline also indicated an increased cardiometabolic risk (Zhang et al., 2005) (range 87 to 134 mg/dl and 5.6 to 8.0% respectively). Although T2DM patients represented a large subsample (35%) of the total study population, risk markers remained unchanged after exclusion of the diabetic studies (HbA1c 6.1 ± 0.6%; fasting glucose 102.7 ± 8.1 mg/dl). In line with findings of Hadgraft et al. (Hadgraft et al., 2020), the glucose metabolism was improved after the intervention, indicated by the glycated haemoglobin measures. This effect was still present after exclusion of all studies with T2DM patients (−0.24%, 95%CI: [−0.36, −0.11]%, $p < 0.001$). The measurement of HbA1c is less subject to dietary changes of participants compared to fasting glucose variables (Barr et al., 2002), which remained unchanged

Table 3
Effects of sedentary behaviour interventions on activity parameters and cardiometabolic health.

	No. of studies	No. of participants		Baseline values (SD)		Mean difference [95% CI]	p-value
		Int.	Con.	Int.	Con.		
Physical activity							
Standing time (min/day)	9	232	199	225 (33)	231 (35)	28 [−1, 57]	0.06
Walking time (min/day)	15	416	368	136 (116)	141 (128)	27 [13, 41]	<0.001
Steps/day	11	294	255	6176 (1790)	6098 (2163)	1976 [785, 3167]	0.001
MVPA (min/day)	8	177	209	42 (38)	35 (29)	0.27 [−5, 6]	0.92
Blood lipids[a]							
Triglycerides (mg/dl)	7	193	185	125.4 (29.5)	131 (17.4)	0.10 [−12.7, 12.5]	0.99
Total cholesterol (mg/dl)	7	165	158	185.1 (27.8)	177.5 (26.9)	1.17 [−3.0, 5.3]	0.58
HDL cholesterol (mg/dl)	6	181	172	52.8 (9.0)	52.7 (7.7)	−0.5 [−2.2, 1.2]	0.54
LDL cholesterol (mg/dl)	5	132	125	105.8 (29.1)	104.5 (27.4)	−0.4 [−6.0, 5.2]	0.89
Glycaemic control							
Fasting glucose (mg/dl)[a]	6	170	171	103.4 (13.2)	104.6 (16)	3.2 [−1.8, 8.2]	0.20
HbA1c (%)	7	211	215	6.4 (0.8)	6.4 (0.9)	−0.2 [−0.3, −0.04]	**0.01**
Blood pressure							
Systolic (mm Hg)	10	303	287	129.1 (12.7)	127.5 (11)	−0.5 [−2.1, 1.1]	0.55
Diastolic (mm Hg)	9	257	241	80.9 (3.4)	79.2 (4.8)	−0.8 [−2.0, 0.4]	0.21
Anthropometrics							
Body weight (kg)	12	341	325	85 (10.6)	84 (10.7)	−0.4 [−1, 0.2]	0.16
BMI (kg/m^2)	11	325	304	30.1 (3.9)	30 (4.3)	−0.1 [−0.2, 0.1]	0.32
Body fat (%)	5	141	129	43 (2.1)	43.2 (2.5)	−0.7 [−1.3, −0.1]	**0.03**
Waist circumference (cm)	9	294	286	97.3 (9.8)	97.1 (11.4)	−1.5 [−2.8, −0.2]	**0.02**

Mean differences are pre-post differences between control and intervention groups.
Abbreviations: **Int**. intervention, **Ccon**. control, **CI** confidence interval, **MVPA** moderate-to-vigorous physical activity.
[a] Blood parameters were converted to the same unit (from mmol/l to mg/dl).

in the current findings.

Blood pressure and blood lipids did not significantly change following a SB reduction of 64 min/day. It is however important to note that the included studies were not powered to detect changes in cardiometabolic health, because SB was in almost all studies the primary outcome measure. Nonetheless, the SB reduction in the current review might not be sufficient to improve these variables, as post-intervention SB of participants was still 1 h higher than SB of the general population (Matthews et al., 2008). Although the baseline systolic and diastolic blood pressure was within the 'high normal' spectrum according to the European Society of Cardiology guidelines, therapeutic targets of <130/80 mm Hg are recommended (Bergler-Klein, 2019). Furthermore, a blood pressure of 120–139/80-89 mm Hg is defined as prehypertension and associated with an increased risk of major CVD events (Guo et al., 2011). In contrast with the SB interventions of Hadgraft et al. (Hadgraft et al., 2020) and the activity tracking-based behaviour interventions of Franssen et al. (Franssen et al., 2020), blood pressure did not significantly change in the current findings. This may be due to the intensity of reallocated PA minutes, as higher intensity PA is already shown to lead to superior blood pressure reductions (Way et al., 2019). Furthermore, interrupting sitting time with half-hourly light-intensity walking bouts significantly improved blood pressure in previous research (Dempsey et al., 2016), implying a greater impact of the SB accumulation pattern and the number of SB breaks compared to the total SB per day (Healy et al., 2008). Hence, future research should also include and report measures on PA intensity and the SB accumulation pattern. Additionally, it might be relevant to add simple resistance activities (e.g. calf-, knee raises, and squats) to interrupt SB in future interventions. Dempsey et al. for example found more profound effects with this approach compared to light-intensity walking bouts (Dempsey et al., 2016).

The blood lipid profile of participants at baseline is within the current recommendations of the American Expert Panel on Blood Cholesterol (NCEP, 2001), except for LDL-cholesterol which is slightly elevated. This may explain why no significant improvements could be detected. Furthermore, the amount of studies including lipid measures is rather low and lipid measures are subject to standardization methods and patient adherence. However, the lack of effects on the blood lipid profile is consistent with findings in meta-analyses of laboratory-based SB interventions (Chastin et al., 2015; Saunders et al., 2018) and findings of Hadgraft et al., where only a significant though very small improvement on HDL-cholesterol concentration was found (Hadgraft et al., 2020). This seemingly contradicts our current understanding of the metabolic effects of SB or inactivity, because muscle inactivity has been linked with reduced lipoprotein lipase (LPL) activity. LPL is the rate-limiting enzyme in the breakdown of triglycerides and uptake of free fatty acids, and decreases in LPL activity have been associated with decreased HDL cholesterol and increased triglyceride levels (Hamilton et al., 2004). However, this is solely based on animal or human bed rest studies, further research on the association between LPL activity and lipid measures in free-living SB (changes) is warranted.

4.1. Study limitation and strengths

An important strength of the current systematic review is that evidence is solely based on objective SB measures and randomised controlled trials. Moreover, the overall risk of bias was low. Therapist blinding is difficult in behavioural interventions and the inclusion of objective outcome measures limits the risk of a detection bias, which were the main threats of quality in this systematic review. Furthermore, SB and cardiometabolic health measures were measured simultaneously in all but four studies, allowing direct associations between SB changes and cardiometabolic health. However, several limitations were also observed. Although all SB measures were objective, different measurement methods and sensor wear locations were used, limiting comparison between studies. Sample sizes were relatively low, and while five different clinical population groups were identified, the majority of diseases was metabolically related. Furthermore, four main behavioural intervention components were distinguished, but the variation within components was still high. Frequency and means of contact for the motivational counselling (face-to-face or group sessions, telephone calls, text messages, mail), the focus of self-monitoring devices (PA or SB), and the structure of the website/app differed between studies. The social aspect was also organized differently in each intervention (optional group walks, competition/collaboration to achieve a goal). This variation in components between studies in combination with different intervention durations probably explains the high heterogeneity of SB results and limits interpretation of the independent contribution of each component. Furthermore, future research should be sufficiently powered to detect changes in cardiometabolic risk factors to explore dose-response relationships of SB reallocations to standing and walking. The accumulation pattern of SB and changes herein should also be reported (Healy et al., 2008).

5. Conclusion

The current results suggest that persons with various clinical conditions can significantly reduce their SB via behavioural interventions and that SB reductions are larger following multicomponent interventions including motivational counselling, self-monitoring, social facilitation, and technologies. Furthermore, replacing SB with one hour of light-intensity NEPA reduces the cardiometabolic risk in clinical populations, with the most evident effect on anthropometrics. Future studies are warranted to complement MVPA guidelines with appropriate low-intensity NEPA recommendations.

Declaration of interest

None.

Funding

The corresponding author (I.N.) is funded by the Flemish Fund for Scientific Research (FWO Vlaanderen; 11E9221N). The funding source was not involved in the preparation of the article.

CRediT authorship contribution statement

Ine Nieste: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization, Project administration, Funding acquisition. **Wouter M.A. Franssen:** Conceptualization, Methodology, Validation, Writing - review & editing. **Jan Spaas:** Validation, Writing - review & editing. **Liesbeth Bruckers:** Formal analysis, Writing - review & editing. **Hans H.C.M. Savelberg:** Conceptualization, Writing - review & editing. **Bert O. Eijnde:** Conceptualization, Methodology, Writing - review & editing, Supervision.

Acknowledgements

Not applicable.

Appendix. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2021.106593.

References

Asano, M., Duquette, P., Andersen, R., et al., 2013. Exercise barriers and preferences among women and men with multiple sclerosis. Disabil. Rehabil. 35, 353–361. Article. https://doi.org/10.3109/09638288.2012.742574.

Bailey, D.P., Withers, T.M., Goosey-Tolfrey, V.L., et al., 2020. Acute effects of breaking up prolonged sedentary time on cardiovascular disease risk markers in adults with

paraplegia. Scand. J. Med. Sci. Sports 30, 1398–1408, 2020/04/04. https://doi.org/10.1111/sms.13671.
Barr, R.G., Nathan, D.M., Meigs, J.B., et al., 2002. Tests of glycemia for the diagnosis of type 2 diabetes mellitus. Ann. Intern. Med. 137, 263–272, 2002/08/21. https://doi.org/10.7326/0003-4819-137-4-200208200-00011.
Bergler-Klein, J., 2019. What's new in the ESC 2018 guidelines for arterial hypertension : The ten most important messages. Wien. Klin. Wochenschr. 131, 180–185, 2019/02/05. https://doi.org/10.1007/s00508-018-1435-8.
Biddle, S.J., Edwardson, C.L., Wilmot, E.G., et al., May 2020. A randomised controlled trial to reduce sedentary time in young adults at risk of type 2 diabetes mellitus: project STAND (Sedentary Time ANd Diabetes). PLoS One 10. https://doi.org/10.1371/journal.pone.0143398 e0143398. 2015/12/02.
Blackburn, N.E., Wilson, J.J., McMullan, I.I., et al., 2020. The effectiveness and complexity of interventions targeting sedentary behaviour across the lifespan: a systematic review and meta-analysis. Int. J. Behav. Nutr. Phys. Act. 17, 53, 2020/04/27. https://doi.org/10.1186/s12966-020-00957-0.
Bramer, W.M., Giustini, D., de Jonge, G.B., et al., 2016. De-duplication of database search results for systematic reviews in EndNote. J. Med. Libr. Assoc. 104, 240–243. https://doi.org/10.3163/1536-5050.104.3.014.
Brickwood, K.J., Watson, G., O'Brien, J., et al., 2019. Consumer-based wearable activity trackers increase physical activity participation: systematic review and meta-analysis. JMIR mHealth uHealth 7. https://doi.org/10.2196/11819 e11819. 2019/04/13.
Brocklebank, L.A., Falconer, C.L., Page, A.S., et al., 2015. Accelerometer-measured sedentary time and cardiometabolic biomarkers: A systematic review. Prev. Med. 76, 92–102, 2015/04/29. https://doi.org/10.1016/j.ypmed.2015.04.013.
Carr, L.J., Karvinen, K., Peavler, M., et al., 2013. Multicomponent intervention to reduce daily sedentary time: a randomised controlled trial. BMJ Open 3. https://doi.org/10.1136/bmjopen-2013-003261 e003261. 2013/10/22.
Chastin, S.F.M., Egerton, T., Leask, C., et al., 2015. Meta-analysis of the relationship between breaks in sedentary behavior and cardiometabolic health. Obesity 23, 1800–1810. https://doi.org/10.1002/oby.21180.
Conroy, S.S., Zhan, M., Culpepper 2nd, W.J., et al., 2017. Self-directed exercise in multiple sclerosis: Evaluation of a home automated tele-management system. J. Telemed. Telecare. https://doi.org/10.1177/1357633x17702757, 1357633x17702757. 2017/04/27.
Cooper, A.R., Sebire, S., Montgomery, A.A., et al., 2012. Sedentary time, breaks in sedentary time and metabolic variables in people with newly diagnosed type 2 diabetes. Diabetologia 55, 589–599, 2011/12/15. https://doi.org/10.1007/s00125-011-2408-x.
de Boer, A., Geuskens, G.A., Bültmann, U., et al., 2018. Employment status transitions in employees with and without chronic disease in the Netherlands. Int. J. Public Health 63, 713–722, 2018/05/31. https://doi.org/10.1007/s00038-018-1120-8.
De Greef, K., Deforche, B., Tudor-Locke, C., et al., 2010. A cognitive-behavioural pedometer-based group intervention on physical activity and sedentary behaviour in individuals with type 2 diabetes. Health Educ. Res. 25, 724–736, 2010/03/27. https://doi.org/10.1093/her/cyq017.
De Greef, K.P., Deforche, B.I., Ruige, J.B., et al., 2011. The effects of a pedometer-based behavioral modification program with telephone support on physical activity and sedentary behavior in type 2 diabetes patients. Patient Educ. Couns. 84, 275–279, 2010/08/25. https://doi.org/10.1016/j.pec.2010.07.010.
de Koning, L., Merchant, A.T., Pogue, J., et al., 2007. Waist circumference and waist-to-hip ratio as predictors of cardiovascular events: meta-regression analysis of prospective studies. Eur. Heart J. 28, 850–856. https://doi.org/10.1093/eurheartj/ehm026.
Dempsey, P.C., Sacre, J.W., Larsen, R.N., et al., 2016. Interrupting prolonged sitting with brief bouts of light walking or simple resistance activities reduces resting blood pressure and plasma noradrenaline in type 2 diabetes. J. Hypertens. 34.
Ekelund, U., Tarp, J., Fagerland, M.W., et al., 2020. Joint associations of accelero-meter measured physical activity and sedentary time with all-cause mortality: a harmonised meta-analysis in more than 44 000 middle-aged and older individuals. Br. J. Sports Med. 54, 1499–1506, 2020/11/27. https://doi.org/10.1136/bjsports-2020-103270.
English, C., Healy, G.N., Olds, T., et al., 2016. Reducing sitting time after stroke: a phase II safety and feasibility randomized controlled trial. Arch. Phys. Med. Rehabil. 97, 273–280. Clinical Trial, Phase II; Journal Article; Randomized Controlled Trial; Research Support, Non-U.S. Gov't. https://doi.org/10.1016/j.apmr.2015.10.094.
English, C., Janssen, H., Crowfoot, G., et al., 2018. Frequent, short bouts of light-intensity exercises while standing decreases systolic blood pressure: Breaking Up Sitting Time after Stroke (BUST-Stroke) trial. Int. J. Stroke 13, 932–940, 2018/09/19. https://doi.org/10.1177/1747493018798535.
Ferguson, L.D., Siebert, S., McInnes, I.B., et al., 2019. Cardiometabolic comorbidities in RA and PsA: lessons learned and future directions. Nat. Rev. Rheumatol. 15, 461–474, 2019/07/12. https://doi.org/10.1038/s41584-019-0256-0.
Fitzgerald Jodi, D., Johnson, L., Hire Don, G., et al., 2021. Association of objectively measured physical activity with cardiovascular risk in mobility-limited older adults. J. Am. Heart Assoc. 4 https://doi.org/10.1161/JAHA.114.001288 e001288.
Franssen, W.M.A., Franssen, G.H.L.M., Spaas, J., et al., 2020. Can consumer wearable activity tracker-based interventions improve physical activity and cardiometabolic health in patients with chronic diseases? A systematic review and meta-analysis of randomised controlled trials. Int. J. Behav. Nutr. Phys. Act. 17, 57. https://doi.org/10.1186/s12966-020-00955-2.
Gakidou, E., Afshin, A., Abajobir, A.A., et al., 2017. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. Lancet 390, 1345–1422. https://doi.org/10.1016/S0140-6736(17)32366-8.
Gardner, B., Smith, L., Lorencatto, F., et al., 2016. How to reduce sitting time? A review of behaviour change strategies used in sedentary behaviour reduction interventions among adults. Health Psychol. Rev. 10, 89–112, 2015/09/16. https://doi.org/10.1080/17437199.2015.1082146.
Gillies, C.L., Abrams, K.R., Lambert, P.C., et al., 2007. Pharmacological and lifestyle interventions to prevent or delay type 2 diabetes in people with impaired glucose tolerance: systematic review and meta-analysis. BMJ 334, 299, 2007/01/24. https://doi.org/10.1136/bmj.39063.689375.55.
Guo, X., Zou, L., Zhang, X., et al., 2011. Prehypertension: a meta-analysis of the epidemiology, risk factors, and predictors of progression. Tex. Heart Inst. J. 38, 643–652.
Hadgraft, N.T., Winkler, E., Climie, R.E., et al., 2020. Effects of sedentary behaviour interventions on biomarkers of cardiometabolic risk in adults: systematic review with meta-analyses. Br. J. Sports Med. https://doi.org/10.1136/bjsports-2019-101154, 2020/04/10.
Hamilton, M.T., Hamilton, D.G., Zderic, T.W., 2004. Exercise physiology versus inactivity physiology: an essential concept for understanding lipoprotein lipase regulation. Exerc. Sport Sci. Rev. 32, 161–166, 2004/12/18. https://doi.org/10.1097/00003677-200410000-00007.
Healy, G.N., Dunstan, D.W., Salmon, J., et al., 2008. Breaks in sedentary time: beneficial associations with metabolic risk. Diabetes Care 31, 661–666, 2008/02/07. https://doi.org/10.2337/dc07-2046.
Henson, J., Yates, T., Biddle, S.J., et al., 2013. Associations of objectively measured sedentary behaviour and physical activity with markers of cardiometabolic health. Diabetologia 56, 1012–1020, 2013/03/05. https://doi.org/10.1007/s00125-013-2845-9.
Higgins, J.P.G.S., 2017. Cochrane Handbook for Systematic Reviews of Interventions. Version 5.2.
Higgins, J.P., Thompson, S.G., Deeks, J.J., et al., 2003. Measuring inconsistency in meta-analyses. BMJ 327, 557–560, 2003/09/06. https://doi.org/10.1136/bmj.327.7414.557.
Higgins, J.P.T., Altman, D.G., Gøtzsche, P.C., et al., 2011. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ 343, d5928. https://doi.org/10.1136/bmj.d5928.
Holliday, A., Burgin, A., Fernandez, E.V., et al., May 2020. Points-based physical activity: a novel approach to facilitate changes in body composition in inactive women with overweight and obesity. BMC Public Health 18. https://doi.org/10.1186/s12889-018-5125-2.
Hozo, S.P., Djulbegovic, B., Hozo, I., 2005. Estimating the mean and variance from the median, range, and the size of a sample. BMC Med. Res. Methodol. 5, 13. https://doi.org/10.1186/1471-2288-5-13.
Hubert, H.B., Feinleib, M., McNamara, P.M., et al., 1983. Obesity as an independent risk factor for cardiovascular disease: a 26-year follow-up of participants in the Framingham Heart Study. Circulation 67, 968–977, 1983/05/01. https://doi.org/10.1161/01.cir.67.5.968.
Executive summary of the third report of The National Cholesterol Education Program (NCEP) expert panel on detection, evaluation, and treatment of high blood cholesterol in adults (Adult Treatment Panel III). JAMA 285, 2001, 2486–2497, 2001/05/23. https://doi.org/10.1001/jama.285.19.2486.
Keytsman, C., Eijnde, B.O., Hansen, D., et al., 2017. Elevated cardiovascular risk factors in multiple sclerosis. Mult. Scler. Relat. Disord. 17, 220–223, 2017/10/23. https://doi.org/10.1016/j.msard.2017.08.011.
King, W.C., Chen, J.-Y., Courcoulas, A.P., et al., 2016. Objectively-measured sedentary time and cardiometabolic health in adults with severe obesity. Prev. Med. 84, 12–18. https://doi.org/10.1016/j.ypmed.2015.12.007.
Kinnett-Hopkins, D., Adamson, B., Rougeau, K., et al., 2017. People with MS are less physically active than healthy controls but as active as those with other chronic diseases: An updated meta-analysis. Mult. Scler. Relat. Disord. 13, 38–43, 2017/04/22. https://doi.org/10.1016/j.msard.2017.01.016.
Klein, S., Allison, D.B., Heymsfield, S.B., et al., 2007. Waist circumference and cardiometabolic risk: a consensus statement from shaping America's health: Association for Weight Management and Obesity Prevention; NAASO, the Obesity Society; the American Society for Nutrition; and the American Diabetes Association. Am. J. Clin. Nutr. 85, 1197–1202. https://doi.org/10.1093/ajcn/85.5.1197.
Kozey Keadle, S., Lyden, K., Staudenmayer, J., et al., 2014. The independent and combined effects of exercise training and reducing sedentary behavior on cardiometabolic risk factors. Appl. Physiol. Nutr. Metab. 39, 770–780, 2014/06/28. https://doi.org/10.1139/apnm-2013-0379.
Laslovich, S., Alvar, B.A., Allison, M., et al., 2019. Effects of lifestyle physical activity on vascular function in asymptomatic peripheral arterial disease. Med. Sci. Sports Exerc. https://doi.org/10.1249/MSS.0000000000002109. Article in press.
Liu, S.H., Waring, M.E., Eaton, C.B., et al., 2015. Association of objectively measured physical activity and metabolic syndrome among US adults with osteoarthritis. Arthritis Care Res. 67, 1371–1378, 2015/03/18. https://doi.org/10.1002/acr.22587.
Lyons, E.J., Swartz, M.C., Lewis, Z.H., et al., 2017. Feasibility and acceptability of a wearable technology physical activity intervention with telephone counseling for mid-aged and older adults: a randomized controlled pilot trial. JMIR mHealth uHealth 5. https://doi.org/10.2196/mhealth.6967 e28. 2017/03/08.
Laposata, M., 2014. Laboratory Medicine: The Diagnosis of Disease in the Clinical Laboratory, 2nd ed.
MacEwen, B.T., Saunders, T.J., MacDonald, D.J., et al., 2017. Sit-stand desks to reduce workplace sitting time in office workers with abdominal obesity: a randomized

controlled trial. J. Phys. Act. Health 14, 710–715. https://doi.org/10.1123/pah.2016-0384.
Madden, S.G., Loeb, S.J., Smith, C.A., 2008. An integrative literature review of lifestyle interventions for the prevention of type II diabetes mellitus. J. Clin. Nurs. 17, 2243–2256, 2008/08/19. https://doi.org/10.1111/j.1365-2702.2008.02335.x.
Malakou, E., Linardakis, M., Armstrong, M.E.G., et al., 2018. The combined effect of promoting the mediterranean diet and physical activity on metabolic risk factors in adults: a systematic review and meta-analysis of randomised controlled trials. Nutrients 10. https://doi.org/10.3390/nu10111577. Review.
Manns, P.J., Dunstan, D.W., Owen, N., et al., 2012. Addressing the nonexercise part of the activity continuum: a more realistic and achievable approach to activity programming for adults with mobility disability? Phys. Ther. 92, 614–625, 2011/12/14. https://doi.org/10.2522/ptj.20110284.
Marrie, R.A., Rudick, R., Horwitz, R., et al., 2010. Vascular comorbidity is associated with more rapid disability progression in multiple sclerosis. Neurology 74, 1041–1047, 2010/03/31. https://doi.org/10.1212/WNL.0b013e3181d6b125.
Marshall, S.J., Levy, S.S., Tudor-Locke, C.E., et al., 2009. Translating physical activity recommendations into a pedometer-based step goal: 3000 steps in 30 minutes. Am. J. Prev. Med. 36, 410–415, 2009/04/14. https://doi.org/10.1016/j.amepre.2009.01.021.
Martin, A., Fitzsimons, C., Jepson, R., et al., 2015. Interventions with potential to reduce sedentary time in adults: systematic review and meta-analysis. Br. J. Sports Med. 49, 1056–1063, 2015/04/25. https://doi.org/10.1136/bjsports-2014-094524.
Matthews, C.E., Chen, K.Y., Freedson, P.S., et al., 2008. Amount of time spent in sedentary behaviors in the United States, 2003–2004. Am. J. Epidemiol. 167, 875–881. https://doi.org/10.1093/aje/kwm390.
Michaud, K., Wallenstein, G., Wolfe, F., 2011. Treatment and nontreatment predictors of health assessment questionnaire disability progression in rheumatoid arthritis: a longitudinal study of 18,485 patients. Arthritis Care Res. 63, 366–372, 2010/11/17. https://doi.org/10.1002/acr.20405.
Miyamoto, T., Fukuda, K., Oshima, Y., et al., 2017. Non-locomotive physical activity intervention using a tri-axial accelerometer reduces sedentary time in type 2 diabetes. Phys. Sportsmed. 45, 245–251, 2017/07/01. https://doi.org/10.1080/00913847.2017.1350084.
Motl, R.W., Fernhall, B., McAuley, E., et al., 2011. Physical activity and self-reported cardiovascular comorbidities in persons with multiple sclerosis: evidence from a cross-sectional analysis. Neuroepidemiology 36, 183–191, 2011/05/21. https://doi.org/10.1159/000327749.
Mudaliar, U., Zabetian, A., Goodman, M., et al., 2016. Cardiometabolic risk factor changes observed in diabetes prevention programs in US settings: a systematic review and meta-analysis. PLoS Med. 13 https://doi.org/10.1371/journal.pmed.1002095 e1002095. 2016/07/28.
Nicholson, S., Sniehotta, F.F., van Wijck, F., et al., 2013. A systematic review of perceived barriers and motivators to physical activity after stroke. Int. J. Stroke 8, 357–364, 2012/09/15. https://doi.org/10.1111/j.1747-4949.2012.00880.x.
Paul, L., Wyke, S., Brewster, S., et al., 2016. Increasing physical activity in stroke survivors using STARFISH, an interactive mobile phone application: a pilot study. Top. Stroke Rehabil. 23, 170–177, 2016/04/15. https://doi.org/10.1080/10749357.2015.1122266.
Peachey, M.M., Richardson, J., Ada, V.T., et al., 2020. Environmental, behavioural and multicomponent interventions to reduce adults' sitting time: a systematic review and meta-analysis. Br. J. Sports Med. 54, 315–325, 2018/10/26. https://doi.org/10.1136/bjsports-2017-098968.
Perri, M.G., Anton, S.D., Durning, P.E., et al., 2002. Adherence to exercise prescriptions: effects of prescribing moderate versus higher levels of intensity and frequency. Health Psychol. 21, 452–458 (2002/09/05).
Prince, S.A., 2018. Interventions directed at reducing sedentary behaviour in persons with pre-existing disease or disability. In: Leitzmann, M.F., Jochem, C., Schmid, D. (Eds.), Sedentary Behaviour Epidemiology. Springer International Publishing, Cham, pp. 471–485.
Prince, S.A., Saunders, T.J., Gresty, K., et al., 2014. A comparison of the effectiveness of physical activity and sedentary behaviour interventions in reducing sedentary time in adults: a systematic review and meta-analysis of controlled trials. Obes. Rev. 15, 905–919, 2014/08/13. https://doi.org/10.1111/obr.12215.
Prince, S.A., Reed, J.L., Cotie, L.M., et al., 2018. Results of the Sedentary Intervention Trial in Cardiac Rehabilitation (SIT-CR Study): A pilot randomized controlled trial. Int. J. Cardiol. 269, 317–324, 2018/08/04. https://doi.org/10.1016/j.ijcard.2018.07.082.
Prince, S.A., Cardilli, L., Reed, J.L., et al., 2020. A comparison of self-reported and device measured sedentary behaviour in adults: a systematic review and meta-analysis. Int. J. Behav. Nutr. Phys. Act. 17, 31, 2020/03/07. https://doi.org/10.1186/s12966-020-00938-3.
Rubak, S., Sandbæk, A., Lauritzen, T., et al., 2005. Motivational interviewing: a systematic review and meta-analysis. Br. J. Gen. Pract. 55, 305.
Ryan, J.M., Fortune, J., Stennett, A., et al., 2019. Safety, feasibility, acceptability and effects of a behaviour-change intervention to change physical activity behaviour among people with multiple sclerosis: Results from the iStep-MS randomised controlled trial. Mult. Scler. (Houndmills, Basingstoke, England). https://doi.org/10.1177/1352458519886231, 1352458519886231. 2019/11/02.
Same, R.V., Feldman, D.I., Shah, N., et al., 2016. Relationship between sedentary behavior and cardiovascular risk. Curr. Cardiol. Rep. 18 (6) https://doi.org/10.1007/s11886-015-0678-5, 2015/12/25.
Saunders, T.J., Atkinson, H.F., Burr, J., et al., 2018. The acute metabolic and vascular impact of interrupting prolonged sitting: a systematic review and meta-analysis. Sports Med. 48, 2347–2366. https://doi.org/10.1007/s40279-018-0963-8.
Sawicki, G.S., Sellers, D.E., Robinson, W.M., 2009. High treatment burden in adults with cystic fibrosis: challenges to disease self-management. J. Cystic Fibros. 8, 91–96, 2008/10/28. https://doi.org/10.1016/j.jcf.2008.09.007.
Seib, C., Parkinson, J., McDonald, N., et al., 2018. Lifestyle interventions for improving health and health behaviours in women with type 2 diabetes: A systematic review of the literature 2011-2017. Maturitas 111, 1–14, 2018/04/21. https://doi.org/10.1016/j.maturitas.2018.02.008.
Sin, D.D., Man, S.F., 2005. Chronic obstructive pulmonary disease: a novel risk factor for cardiovascular disease. Can. J. Physiol. Pharmacol. 83, 8–13, 2005/03/11. https://doi.org/10.1139/y04-116.
Stephenson, A., McDonough, S.M., Murphy, M.H., et al., 2017a. Using computer, mobile and wearable technology enhanced interventions to reduce sedentary behaviour: a systematic review and meta-analysis. Int. J. Behav. Nutr. Phys. Act. 14, 105. https://doi.org/10.1186/s12966-017-0561-4.
Stephenson, A., McDonough, S.M., Murphy, M.H., et al., 2017b. Using computer, mobile and wearable technology enhanced interventions to reduce sedentary behaviour: a systematic review and meta-analysis. Int. J. Behav. Nutr. Phys. Act. 14, 105, 2017/08/13. https://doi.org/10.1186/s12966-017-0561-4.
Thomsen, T., Aadahl, M., Beyer, N., et al., 2016. Motivational counselling and SMS-reminders for reduction of daily sitting time in patients with rheumatoid arthritis: a descriptive randomised controlled feasibility study. BMC Musculoskelet. Disord. 17 https://doi.org/10.1186/s12891-016-1266-6.
Thomsen, T., Aadahl, M., Beyer, N., et al., 2017. The efficacy of motivational counselling and SMS reminders on daily sitting time in patients with rheumatoid arthritis: a randomised controlled trial. Ann. Rheum. Dis. 76, 1603–1606. https://doi.org/10.1136/annrheumdis-2016-210953.
Thomsen, T., Aadahl, M., Beyer, N., et al., 2019. Sustained long-term efficacy of motivational counselling and text message reminders on daily sitting time in patients with rheumatoid arthritis? Long-term follow-up of a randomized, parallel-group trial. Arthritis Care Res. https://doi.org/10.1002/acr.24060. Article in press.
Tremblay, M.S., Aubert, S., Barnes, J.D., et al., 2017. Sedentary behavior research network (SBRN) – terminology consensus project process and outcome. Int. J. Behav. Nutr. Phys. Act. 14, 75. https://doi.org/10.1186/s12966-017-0525-8.
van Sloten, T.T., Savelberg, H.H., Duimel-Peeters, I.G., et al., 2011. Peripheral neuropathy, decreased muscle strength and obesity are strongly associated with walking in persons with type 2 diabetes without manifest mobility limitations. Diabetes Res. Clin. Pract. 91, 32–39, 2010/10/23. https://doi.org/10.1016/j.diabres.2010.09.030.
Veldhuijzen van Zanten, J.J., Rouse, P.C., Hale, E.D., et al., 2015. Perceived barriers, facilitators and benefits for regular physical activity and exercise in patients with rheumatoid arthritis: a review of the literature. Sports Med. (Auckland, NZ) 45, 1401–1412, 2015/07/30. https://doi.org/10.1007/s40279-015-0363-2.
Way, K.L., Sultana, R.N., Sabag, A., et al., 2019. The effect of high intensity interval training versus moderate intensity continuous training on arterial stiffness and 24h blood pressure responses: a systematic review and meta-analysis. J. Sci. Med. Sport 22, 385–391. https://doi.org/10.1016/j.jsams.2018.09.228.
WHO, 2018. Global Action Plan on Physical Activity 2018–2030: More Active People for a Healthier World. More Active People for a Healthier World. World Health Organization, Geneva.
Williams, J., Stubbs, B., Richardson, S., et al., 2019. 'Walk this way': results from a pilot randomised controlled trial of a health coaching intervention to reduce sedentary behaviour and increase physical activity in people with serious mental illness. Bmc Psychiatry 19. https://doi.org/10.1186/s12888-019-2274-5.
Wilmot, E.G., Edwardson, C.L., Achana, F.A., et al., 2012. Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis. Diabetologia 55, 2895–2905, 2012/08/15. https://doi.org/10.1007/s00125-012-2677-z.
Yang, Y.P., Wang, C.J., Wang, J.J., et al., 2017. The effects of an activity promotion system on active living in overweight subjects with metabolic abnormalities. Obes. Res. Clin. Pract. 11, 718–727. https://doi.org/10.1016/j.orcp.2017.06.007.
Yogaratnam, J., Biswas, N., Vadivel, R., et al., 2013. Metabolic complications of schizophrenia and antipsychotic medications–an updated review. East Asian Arch. Psychiatr. 23, 21–28 (2013/03/29).
Zhang, P., Engelgau, M.M., Valdez, R., et al., 2005. Efficient cutoff points for three screening tests for detecting undiagnosed diabetes and pre-diabetes. Diabetes Care 28, 1321. https://doi.org/10.2337/diacare.28.6.1321.