Interventions targeting sedentary behavior in non-working older adults

Aunger, Justin Avery; Doody, Paul; Greig, Carolyn Anne

DOI:
10.1016/j.maturitas.2018.08.002

Maturitas 116 (2018) 89–99

Contents lists available at ScienceDirect

Maturitas

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

Interventions targeting sedentary behavior in non-working older adults: a systematic review

Justin Avery Aunger*, Paul Doody, Carolyn Anne Greig

School of Sport, Exercise, and Rehabilitation Sciences, University of Birmingham, B15 2TT, United Kingdom

ARTICLE INFO

Keywords:
Sitting
Elderly
Behavior change
Aging
Sedentary
Older adults

ABSTRACT

Sedentary behavior has been found to be associated with negative health outcomes independently of physical activity in older adults. This systematic review collates interventions to reduce sedentary behavior in non-working older adults, assessing whether they are effective, feasible, and safe. A systematic search identified 2560 studies across five databases. Studies were included where participants were ≥60 years on average with none younger than 45, and participants did not work > 2 days per week. A total of six studies were identified, three of which included control groups, while the other three were repeated-measures pre-post designs. Only one study randomised participants. The overall level of quality of included studies was poor. A narrative synthesis was conducted, as the level of heterogeneity in outcomes and outcome reporting were too high for a meta-analysis to be performed. The narrative synthesis suggested that interventions have the potential to reduce sitting time in non-working older adults. Included studies reported feasible and safe implementations of their interventions in most samples, except for one subsample from a study of people in sheltered housing. Objectively measured reductions in sitting time were between 3.2% and 5.3% of waking time, or up to 53.9 min per day. Future studies should employ more rigorous designs to assess the effects of reducing sedentary behavior on health and physical function, and should include follow-ups to measure the duration of behavior change.

1. Introduction

1.1. Rationale

Sedentary behavior is defined by the Sedentary Behavior Research Network [1] as any activity performed in a sitting or reclining posture with an energy expenditure equivalent to ≤1.5 Metabolic Equivalent of Tasks (METs). Interventions to reduce sedentary behavior are important, as sedentary behavior has been found to be a risk factor for multiple metabolic diseases, independent of the degree of moderate-to-vigorous physical activity a person performs (MVPA) [2,3]. Specific populations are at greater risk than others for the negative consequences of sedentary behavior, particularly because these populations have low cardiorespiratory fitness and activity levels, both of which have been found to be independently related to risk for cardiovascular disease [4]. A demographic fitting these criteria is older adults aged > 60 years.

Older adults are growing significantly both as a segment of the UK and global population [5]. Globally, the number of people over 60 is expected to increase by 56% by 2030, and, is expected to double by 2050 [6]. This means that in the UK, in 2050, older adults are expected to constitute approximately 25% of the total population [7]. In older people, objectively-measured sedentary behavior manifests its negative health effects in terms of reduced physical function, greater risk for cardiovascular disease and type 2 diabetes, and increased mortality, independent of performance of MVPA [8–10]. Additionally, sedentary behavior is related to disease risk in a multitude of ways. For example, the manner in which sitting time is accumulated, such as in longer or shorter bouts, is differentially associated with cardiovascular disease risk in adults > 45 years [11]. In this sample, interrupting bouts of sitting time every 20 min had a significant enough effect on systolic blood pressure to lower all-cause mortality risk by 3–4% [11]. The morbidities of this population combined with the ongoing relative growth makes this segment of the population highly burdensome to healthcare facilities of their respective countries [5,12]. For example, in the UK, healthcare for older adults over-65 s account for 2/5ths of the total National Health Service's budget [13]. Thus, designing, testing, and implementing interventions in older adults that target sedentary behavior specifically is important, has been found to have beneficial impacts on physical function, and is associated with improvements to cardiometabolic health [10,14]. Although there are many published studies focusing on reducing sedentary behavior, not many have

* Corresponding author.
E-mail addresses: j.aunger@bham.ac.uk (J.A. Aunger), p.d.doody@bham.ac.uk (P. Doody), c.a.greig@bham.ac.uk (C.A. Greig).

https://doi.org/10.1016/j.maturitas.2018.08.002
Received 19 February 2018; Received in revised form 10 July 2018; Accepted 3 August 2018

specifically targeted older adults, and no systematic reviews of sedentary behavior interventions exclusively in older adults have yet been published [15]. Therefore, the aim of this review is to assess the feasibility, safety and efficacy of interventions targeting sedentary behavior in older adults .

1.2. Objectives

The objectives of the review are as follows:

1 To assess the efficacy of interventions to reduce sedentary behavior in older adults.
2 To investigate how sitting time is displaced to other behaviors in older adults.
3 To identify design methodologies and theoretical frameworks used in interventions to reduce sedentary behavior in older adults.
4 To assess the feasibility and safety of interventions to reduce sedentary behavior in older adults.
5 To analyse the current state of the research and propose future directions.

2. Methods

2.1. Prospero registration

The review was registered on PROSPERO (https://www.crd.york.ac.uk/PROSPERO/) on 20/01/2017 with registration number CRD42017054932.

2.2. Search

Systematic searches were run on the following databases: EMBASE including Epub, Ovid MEDLINE®, CINAHL Plus SportDiscus, and PsychInfo. The searches were run on the 13th of January 2017 and included papers from 1946 onwards.

A systematic search strategy was primarily developed for the OVID platform with EMBASE in mind, was checked by a senior librarian at the University of Birmingham, and then adapted for the other databases. The search strategy for Ovid is supplied in supplementary file 1. Additional articles were sought by reference-list and primary author searching of identified articles. After running the searches, articles were retrieved and imported into a citation manager and duplicates were removed. Two reviewers, JA and PD, screened all titles and abstracts for relevance and resulting articles were compared. Any disagreement was resolved through discussion. Full-text articles were then independently screened against inclusion criteria and any ineligible were removed.

2.2.1. Inclusion criteria

1 All participants aged 45 years or older with a mean age of all participants equalling 60 years or older.
2 In voluntary or paid employment ≤2 days per week (e.g. a typical retirement lifestyle).
3 Interventions specifically designed to reduce sedentary behavior.
4 Randomised controlled trials (RCTs), quasi-experimental study, controlled before-and-after studies, interrupted time series designs, and feasibility or pilot studies (pre-post) designs.
5 Papers must measure sitting time (mins/day, mins/week, mins/weekday, mins/weekend-day, percentage change), standing time (mins/day), stepping time (mins/day), number of breaks in sitting time and sitting time in bouts > 30 min measured using either self-report or objective tools.

2.2.2. Exclusion criteria

1 Articles not written in English.

2.3. Data extraction

Data extraction was performed on a custom-designed, piloted form tested by one reviewer. Data extracted included: (1) study, participant, and intervention characteristics (such as theoretical framework, intervention components, and which device was used to measure sedentary behavior); (2) outcome measures including sitting time, number of breaks in sedentary time, lengths of sedentary bouts, time spent in sitting bouts ≥30 or < 30 min, and data relating to physical activity, such as walking, stepping, standing time, and time spent in light, moderate, and vigorous physical activity; data for outcome measures were extracted for any type of measurement tool used (e.g. ActivPal or IPAQ), and the measurement tool used was recorded. Feasibility and safety data were also extracted where possible.

2.4. Risk of bias in individual studies

Preliminary searching identified a very heterogeneous pool of potentially eligible studies; therefore, two assessment tools of methodological quality were selected. For RCTs and non-randomised CTs, the Delphi Quality Assessment [16] tool was employed, but was modified by removing items 5 and 6 due to the inability to blind the participant and researcher in these studies. For simple pre-post style feasibility or pilot studies, the National Heart, Lung and Blood Institute's Quality Assessment of Before-After Studies With No Control Group (QABAS) tool was used, with the caveat that even high quality studies of this type are likely to be highly biased [17]. Quality assessment was performed by two independent reviewers, JA and PD, and discrepancies were resolved with discussion. A third reviewer (CAG) was available to resolve issues of contention, but all issues were resolved through discussion.

2.5. Method of synthesis

A quantitative synthesis was not possible due to an insufficiency of eligible studies, and heterogeneity of outcome measure reporting and assessment tools. A narrative synthesis was performed according to guidance distributed by Popay et al. [17] and the Centre for Reviews and Dissemination [18]. All aspects of narrative synthesis were performed: developing a theory of why the interventions work, a preliminary synthesis of included studies, an exploration of relationships within and between studies, and an assessment of the robustness of the synthesis. No additional analyses were performed.

3. Results

3.1. Study selection

Only six studies were eligible for inclusion in the data analysis including n = 222 total completing participants [20–25]. Most studies were screened out in the title and abstract stage as they evidently did not focus on older adults or were not an intervention study (Fig. 1). Of 12 items identified by the title and abstract screening, a further six items were removed at the full-text stage, five due to including adults in employment > 2 days/week, and one as the study was an exercise, not sedentary behavior, intervention. No additional studies were identified via additional web-searching outside of the main systematic search, or through examination of authors' publications and reference lists.

3.2. Preliminary synthesis of findings of included studies

The primary mode of preliminary synthesis adopted in this review was a tabulation of study characteristics (Table 2) and the following textual description.

3.3. Study characteristics

3.3.1. Study design

One study was quasi-experimental in design, meaning a control group was included, but randomisation was not performed [20]. Only one 'true' RCT was identified [22], with the four remaining studies all feasibility or pilot studies [21,23–25], of which only one utilised a comparison group [23].

3.3.2. Risk of bias within studies

Overall quality of the identified studies was poor. Three studies were assessed with the modified Delphi tool as they included control groups [20,22,23], and the other three were before-after designs and were thus assessed with the QABAS tool [21,24,25]. Of the modified Delphi-assessed studies (Table 1), one scored a 6/7 [22], and the other two scored 3/7 [20,23]. Regarding the QABAS-assessed studies, the scores were all determined as fair for pre-post designs. Independent quality assessment agreement was 100% for Delphi-assessed studies, and agreement was 97.2% for the QABAS-assessed items.

3.3.3. Samples

Sample sizes were small, ranging from 30 [24] to 59 [25]. Recruitment sources of older adults varied; one study recruited from a Public Health Centre in Korea [20], another from outpatient clinics and previous trials due to the focus on hypertensive patients [22], one from senior centres [23], two were convenience samples of community-dwelling older adults [24,25], and one compared two samples from among both sheltered housing and community-dwelling older adults [21]. Five studies included participants that were at least 60 years and older [20,21,23–25]. Only one study included participants younger than 60 years, however it should be noted that for this study, the mean age was 66.9 years with a SD = 12.7 years [21].

3.3.4. Duration

Duration of interventions varied from 2 to a maximum of 8 weeks, with a mean of 5.5 weeks.

3.4. Exploring relationships within and between studies

Methods adopted for this section of the narrative synthesis included the vote counting of study features (Table 3), tabulation of differences in study outcomes for sedentary behavior variables, standing, and stepping, (Table 4) and the following textual analysis outlining the variations in methodologies and effects within and between included studies.

3.4.1. Intervention components

All included interventions focused on decreasing sedentary behavior. Common intervention components included goal-setting, which all

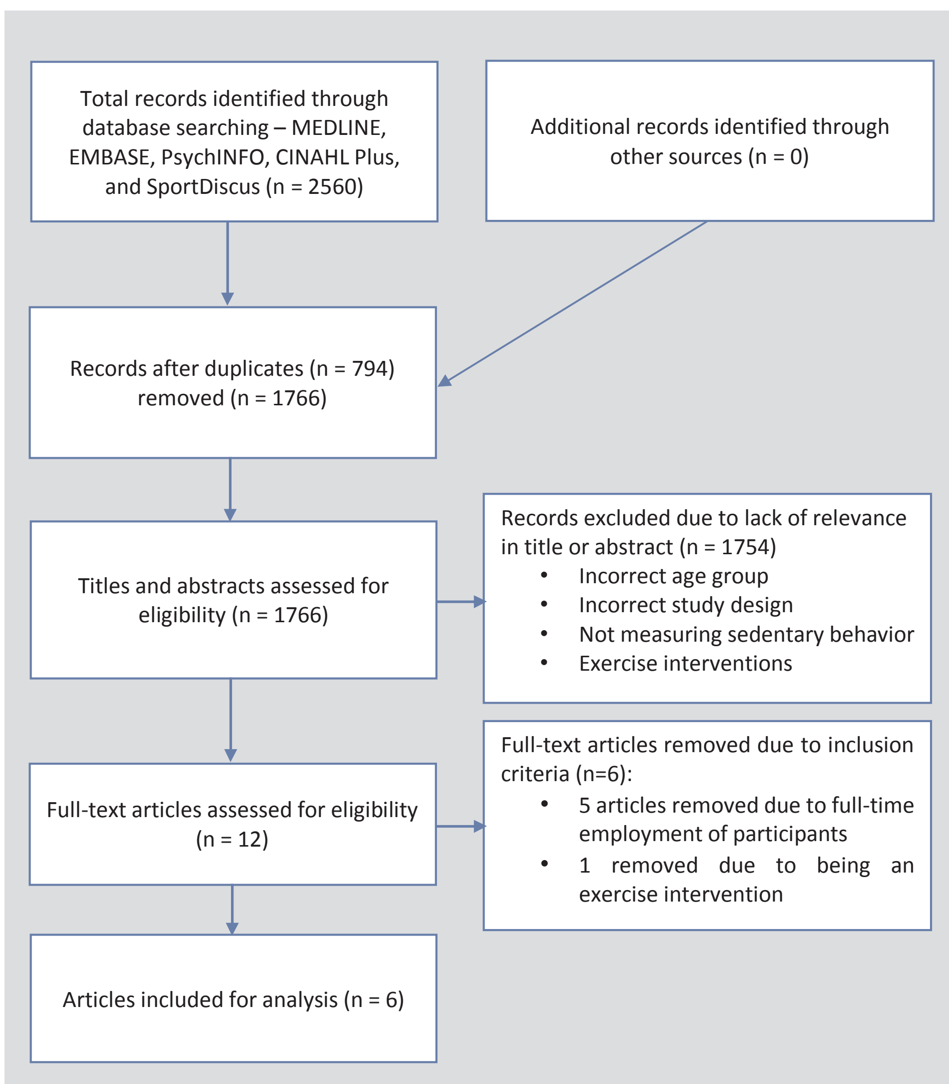

Fig. 1. PRISMA flow diagram of the study selection process.

Table 1
Delphi quality assessment of included study with control groups.

Criteria ID	Question	Chang et al. [20]	English et al. [22]	Maher et al. [23]
1a	Was a method of randomisation performed?	No	Yes	Yes
1b	Was the treatment allocation concealed?	No	Yes	No
2	Were the groups similar at baseline?	Yes	Don't Know	No
3	Were the eligibility criteria specified?	Yes	Yes	Yes
4	Was the outcome assessor blinded?	No	Yes	No
5*	Was the care provider/interventionist blinded?			
6*	Was the patient/participant blinded?			
7	Were the point estimates and measures of variability presented for the primary outcome measures?	Yes	Yes	Yes
8	Did the analysis include an intention-to-treat analysis?	Don't Know	Yes	Don't Know
Total score		3	6	3
Other comments				90% female sample

These asterixis were used to designate that items 5 and 6 of the Delphi quality assessment tool were not utilised, as, for example, it is not possible to blind participants in exercise/sedentary behavior interventions from their group allocation.

interventions incorporated to some degree, and individualised feedback [24,25]. Motivational sessions were also employed, designed to inspire behavior change [20,22] and phone calls to achieve the same aim [22,24].

3.4.2. Theoretical frameworks

Theoretical frameworks employed included empowerment theory [20], social cognitive and behavioral choice theories [25], self-determination theory [24], the health action process approach and a habit dual-process framework [23], and a habit-formation model [21]. Only one study did not mention a theoretical foundation [22].

3.4.3. Sedentary behavior reduction targets

Of the included studies, one mentioned a 30 min/day reduction in sitting time as their minimum target that they would consider clinically significant, but did not support this with references [22] and another cited 60 min/day [24]. A further study cited a 5.6% reduction in sitting as a target, but gave no rationale [25], and another targeted keeping sedentary behavior to an 8 h/day maximum with standing or moving for at least 10 min per hour [23]. The remaining two studies did not set specific targets [20,21].

3.4.4. Sedentary behavior measurement

Three of the included studies used self-report methods alone for assessing sedentary behavior, with the International Physical Activity Questionnaire (IPAQ) being most common [20,21]. However, the IPAQ has not been well validated for sedentary behavior measurement as it was originally designed to assess physical activity [26]. Other studies used the Measure of Older Adults' Sedentary Time (MOST) [21,23,27], and the Multimedia Activity Recall for Children and Adults (MARCA) [22,24]. Three studies used accelerometers to measure sedentary time, such as the ActiGraph GT1M [25], or an inclinometer such as the ActivPal3 [22,24].

3.4.5. Sedentary behavior outcomes

There was large heterogeneity in outcome measures and how they were reported in the studies (Table 4). All studies reported total sitting time, but some did so in minutes/week [20,21,23], average minutes/day [22,24], and a percentage of waking time reduction [24,25]. Only one study standardised measures for accelerometer wear time [21] and for another it was unclear whether they did so or not [20]. However, those studies which used the ActivPal3 inclinometer [21,23] have accounted for sleeping behavior in their analyses, and one used the Actigraph GT1M, accounting for waking time [25]. Most included studies were powered to detect significant differences in sitting time [20,22,24,25], thus, five studies detected a significant positive reduction in sitting time [20,21,23–25]. However, Lewis et al. [23] report that their large number of secondary outcomes may have inflated the significance of their results. Additionally, in the study by Matei et al. [20], a significant difference was found only in the sample of community-dwelling older adults and not in the sheltered housing residents. In the studies using accelerometery to assess sitting time where a significant difference occurred, reductions were M = 3.20% ($p < .001$) of waking time [25] and M = 5.3% ($p = .004$) [23]. English et al. [21] also reported a M = 30 (SD = 50.6) minute average reduction in daily sitting time, but these results were not statistically significant. Both English et al. [21] and Lewis et al. [23] reported a larger displacement of sedentary behavior to standing time rather than walking time post-intervention.

Other sedentary behavior variables were also included in more than one study. Both English et al. [21] and Lewis et al. [23] included the variable 'sitting time accumulated in bouts of ≥30 min per day'. For English et al. [21], there was a non-significant reduction of M = 36.1 (SD = 65.0) mins, and for Lewis et al. [23] a significant reduction of M = 53.9 min. ($p = .003$) for this variable.

In studies utilising self-report measures, both Chang et al. [19] and Matei et al. [20] used the IPAQ to measure sitting time. Chang et al. [19] reported a M = 534.33 (SD = 494.79) minute reduction in weekly sitting time ($p = .004$), and Matei et al. [20] reported a post-intervention reduction of M = 1055.86 min per week ($p < .001$) in their sample of community-dwelling older adults, but a non-significant increase in sitting time of M = 340.5 min per week ($p = .76$) in sheltered housing participants. Maher et al. [22] reported a significant reduction of weekday sedentary time of M = 132.6 min (SD = 28.5, $p < .01$) using the MOST, which is more suited to measuring change in sedentary time than the IPAQ [31]. Matei et al. [20] also used the MOST tool, and reported a reduction from M = 3534.13 (SD = 1895.25) minutes/week to M = 2530.43 (SD = 1416.67) minutes/week in their sample of community-dwelling older adults.

Effect sizes for sitting time were reported only by Chang et al. [19], English et al. [21], and Lewis et al. [23], and these were 0.83, 0.62, and 0.53 respectively, which are considered a moderate-to-large effect.

3.4.6. Feasibility and safety outcomes

Five out of six included studies assessed either feasibility or safety, except for the study by Chang et al. [19]. Common methods of assessing feasibility included adherence to intervention components [21–23], attendance [23], completion of measurements [22,23], retention [24,25], reach (defined as amount of participants recruited of those screened and eligible) [25], satisfaction [20,24,25], burden [21,22,24], completion of questionnaires relating to acceptability [21,23], and semi-structured interviews [21]. Most of these measures were qualitative in nature and thus were difficult to synthesise.

Safety was assessed by English et al. [21], and Maher et al. [22]. In both, safety was measured by reporting of adverse events and, by English et al. [21] with assessment of self-reported pain, spasticity, and fatigue using the Checklist Individual Strength Questionnaire [32].

All included interventions reported a high degree of feasibility based on their qualitative assessments. Only Matei et al. [20] reported low feasibility in their sample of older adults from sheltered housing

Table 2
Characteristics of included studies.

Study	Design	Intervention	Study Duration (weeks)	Comparator	Participant characteristics	Mean age of participants	Outcome Measures (efficacy)	Outcome Measures (feasibility)	Study was powered	Study used objective measurement and specific device
Chang et al. [20]	Quasi-experimental	One 110-minute empowerment session per week & normal care	8	Standard hypertension education & normal care	Older adults > 60 years with hypertension	66.3	Sitting (total min.week^{-1}), Total physical activity (MET min.week^{-1}), Perceived health, Depression, Self-efficacy for physical activity	N/A	Yes	No
English et al. [22]	Randomised Controlled Trial	Four counselling sessions	7	Calcium supplement & attention-matching	Stroke survivors	66.9	Total sitting time (min.day^{-1}), Sitting time accumulated in bouts ≥30 min (min.day^{-1}), Standing time (min.day^{-1}), Stepping time (min.day^{-1}), MVPA, ≥1952 cpm (min.day^{-1})	Pain, spasticity, fatigue, no. of falls, no. valid wear days activPAL3, waking wear hours activPAL3 (hr.day^{-1}), no. of valid wear days Actigraph, waking wear hours Actigraph (hr.day^{-1})	Yes	Yes (Actigraph GT3+ and ActivPal3)
Gardiner, Eaken et al. [25]	Feasibility or pilot study	One session of individual and normative feedback, goal setting, and formulation of an action plan	2	None	Older adults > 60 years	74.3	Sedentary time, breaks, and physically active time	Reach, retention, and participant satisfaction	Yes	Yes (ActiGraph GT1M)
Lewis et al. [24]	Feasibility or pilot study	"Small Steps" - individual goal-setting, normative feedback, phone calls	6	None	Older adults > 60 years	71.7	Total sitting time (min.day^{-1}), Sitting < 30 (min/day), Sitting ≥30 (min.day^{-1}), % of waking time sitting, No. of bouts sitting ≥30 min (n), Standing (min.day^{-1}), Stepping (min/day), TST1.5a (sitting time accrued with activities at less than 1.5 METs) (min.day^{-1}), TV (min.day^{-1}), Computer (min.day^{-1}), Reading (min.day^{-1}), Passive transport (min.day^{-1}), Light physical activity (min.day^{-1}), moderate-to-vigorous physical activity (min.day^{-1}), Total Daily Energy Expenditure (TDEE) (MET minutes)	Satisfaction, burden, feasibility (uptake and retention)	Yes	Yes (ActivPal3)
Maher et al. [23]	Feasibility or pilot study	Focus group, video segment about risks, enhancement of outcome expectancies, action plan formulation	2	Social isolation intervention	Older adults > 60 years in senior centres	76.9	Sedentary behavior (separated into weekday and weekend for each sub-item) made up of following domains: total sedentary behavior, TV time, computer time, reading time, socialising time, transportation time, hobbies time, paperwork time, eating time, and 'other'	Feasibility (participation, adherence, and measurement completion), participation (no. of centres with meaningful recruitment), acceptability, and safety.	No	No
Matei et al. [21]	Feasibility or pilot study	Booklet with tips & goals	8	None	Sample 1 from sheltered housing, sample 2 from community-dwelling older adults. Over 55 years of age.	66.42 (sample 1); 66.91 (sample 2)	Sitting time (IPAQ; min.week^{-1}), sitting time (MOST; min.week^{-1}), sitting habit (1-7 scale), walking (min.week^{-1}), moderate PA (min.week^{-1}), vigorous PA (min.week^{-1}), PA habit (1-7 scale)	Adherence to tips (tick-sheets). Qualitative semi-structured covering experiences using leaflets, barriers to adherence, habit-formation, whether further support was required, and suggestions for improvement.	No	No

Table 3
Vote counting of intervention components, measurements, and whether studies included comparison groups.

Studies	Intervention components					Measurement			Study had a comparator group
	Goal setting	Individualised Feedback on Sedentary Time	Motivational Sessions	Phone Calls	Sedentary behavior education	Study used objective measurement of sedentary behavior	Study assessed feasibility	Study assessed safety	
Chang et al. [20]	✓		✓		✓				✓
English et al. [22]	✓		✓	✓		✓	✓	✓	✓
Gardiner, Eaken et al. [25]	✓	✓				✓	✓		
Lewis et al. [24]	✓	✓		✓	✓	✓	✓	✓	
Maher et al. [23]	✓				✓		✓	✓	✓
Matei et al. [21]	✓				✓		✓		

due to the unique circumstances of their lifestyles. However, these individuals still reported benefits to wellbeing due to the intervention. For other aspects of feasibility, the quantitative measure of satisfaction was reported between 8.2 [24] to 9 [25] out of 10. Compliance (or adherence) was also assessed by Lewis et al. [23], who achieved 90% adherence to goals. Likewise, Matei et al. [20] achieved 40% adherence to goals as assessed using tick-sheets in their sample from sheltered housing. In the sample of community-dwelling older adults, adherence was 58%, in line with the greater efficacy achieved in this group [20]. However, in comparison with Lewis et al. [23], the goals were pre-specified (not individualised), and some were reported to have lacked social desirability, which could explain the poorer outcome. Maher et al. [22] achieved 98% adherence to session attendance, and data completion was 98%. English et al. [21] reported 100% compliance to counselling sessions. These data suggest that overall compliance with the interventions was high.

Few safety concerns were reported. Maher et al. [22] reported that the most severe effect of the intervention was mild soreness from increasing standing and walking, and English et al. [21] reported that four non-injurious falls occurred, but that they were unrelated to the intervention. Participant ratings of pain improved in the intervention group, but this study was not powered to detect significant differences in safety measures [22]. Gardiner et al. [25] reported no adverse events, and Matei et al. [20] reported one death, and three illnesses, unrelated to study participation.

4. Discussion

The aim of this review was to assess the feasibility, safety, and efficacy of interventions targeting sedentary behavior in older adults living a typical retirement lifestyle. As evidenced by this review, most of the included studies were of low methodological quality with respect to assessing efficacy. Thus, the overall evidence pool is limited. Additionally, the discrepancy in reporting style, methodology, and subpopulations of included studies mean it is difficult to be conclusive about efficacy, feasibility, and safety. Nevertheless, since significant reductions in sitting time were attained by a few studies with good effect sizes, there is some indication that sedentary behavior interventions may be effective in older adults. It seems theoretically and ecologically possible to achieve reductions in sitting time of approximately one hour per day in older adults, as a 51.5 min reduction was reached by one of the included studies [24]. This is similar to a previous review in adults of all ages, which found a mean of 42 min./day reduction in studies that focused on reducing sedentary behavior [15]. Although feasibility was largely qualitatively-assessed, evidence suggests these interventions are feasible, at least in samples of community-dwelling individuals. The same is found in relation to safety, as reducing sedentary behavior should not expose individuals to more substantial risk than any other day-to-day activity.

4.1. A theory of interventions to reduce sedentary behavior in older adults

All the included studies had primary aims of reducing sedentary behavior. The most common technique used was goal-setting to reduce contextual sedentary behavior. Accomplishing this involves the displacement of time spent sitting to other slightly more active behaviors, such as light physical activity or standing. Sitting time, light physical activity, and standing were measured in the included studies, and therefore are placed in Fig. 2 as intermediate outcomes.

However, the ultimate purpose of interventions to reduce sedentary behavior relates to the assumed detrimental impact of sedentary behavior upon disease risk and physical function. All included studies mentioned the distinct effects of sedentary behavior on an aspect of health, most typically cardiovascular health, and that the effects of sedentary behavior are more severe in older adults. All included studies stated a mitigation of the negative health effects of sedentary behavior on disease risk as a main purpose of their interventions, either in the

Table 4
Tabulation of outcomes in included studies.

Outcome	Reporting Method	Measurement Tool	Study	Value (SD)	Significance
Change in sitting time	Minutes/week	International Physical Activity Questionnaire	Chang et al. [20]	−534.33 (494.79)	0.004
			Matei et al. [21] Sample 1	+340.5 (NR)	0.76
			Matei et al. [21] Sample 2	−1055.86 (NR)	< 0.001
		Measure of Older Adults' Sedentary Time	Matei et al. [21] Sample 1	+565.59 (NR)	0.33
			Matei et al. [21] Sample 2	−1003.7 (NR)	0.047
	Minutes/day	ActivPal3 Inclinometer	Lewis et al. [24]	−51.5 (NR)	0.006
			English et al. [22]	−30.2 (50.6)[a]	0.018
	Minutes/weekday	Measure of Older Adults' Sedentary Time	Maher et al. [23]	−132.6 (NR)	< 0.001
	Minutes/weekend-day	Measure of Older Adults' Sedentary Time	Maher et al. [23]	−87.4 (NR)	0.65
	Percentage change	ActiGraph GT1M Accelerometer	Gardiner, Eaken et al. [25]	−3.2%	< 0.001
Change in sitting time (mins/day) – effect size (Cohen's *d*)			Chang et al. [20]	−0.83	N/A.
			English et al. [22]	−0.62	N/A.
			Lewis et al. [24]	−0.58	N/A.
Change in sitting time (mins/weekday) – effect size (Cohen's *d*)			Maher et al. [23]	−0.83	N/A.
Change in sitting time (total mins) – effect size (Cohen's *d*)			Maher et al. [23]	−1.02	N/A
Change in sitting time in bouts ≥30 minutes (mins/day)			English et al. [22]	−36.1 (65.0)[a]	0.026
			Lewis et al. [24]	−53.9 (NR)	0.003
Change in number of breaks in sedentary time			Gardiner, Eaken et al. [25]	+4.0 (NR)	0.003
Change in standing time (mins/day)		ActivPal3 Inclinometer	English et al. [22]	+22.4 (35.5)[a]	0.013
			Lewis et al. [24]	+38.5 (NR)	0.006
Change in stepping time (mins/day)		ActivPal3 Inclinometer	English et al. [22]	+7.8 (19.2)[a]	0.096
			Lewis et al. [24]	+9.3 (NR)	0.148

Outcomes for experimental groups only.
NR = not reported.
Note: P-values here must be interpreted with caution due to small sample sizes and feasibility nature of the studies.
[a] Data standardised to accelerometer wear time.

discussions or conclusions of their studies. Additionally, Maher et al. [22] mentioned that benefits for physical function could be attained due to a decrease in sedentary behavior. Therefore, these aspects can be included in a theory of change as ultimate outcomes as depicted in Fig. 2. However, longer-term ultimate outcomes which result from improved health and function, namely a healthier ageing process and a reduction in the burden of older adults on healthcare services, were not mentioned in the included studies. These ultimate outcomes rely on the assumption that the achieved reductions in sitting time and/or subsequent increases in light physical activity are clinically meaningful (i.e. provide a detectable improvement to health or physical function) (Fig. 2). However, intermediate outcomes such as health and physical function, despite being repeatedly mentioned as key assumptions, have not yet been investigated as outcomes in sedentary behavior interventions in older adults. Therefore, the field is left in an intermediate stage in which the effectiveness of interventions on sitting time is being investigated, but the intended effect on ultimate outcomes, such as effects on disease risk, healthy ageing, healthy lifespan, and quality of life, remains unassessed (Fig. 2).

4.2. Robustness of the narrative synthesis

Overall robustness of this narrative synthesis is low, due to both the low methodological quality of included studies and the lack of quantitative synthesis in this review. Certain elements of the narrative synthesis were subjective, such as which information was chosen for inclusion in Table 2. Additionally, heterogeneity of study designs was very high, precluding the use of quantitative techniques, increasing risk of bias. Therefore, the results cannot be considered conclusive and must be interpreted with caution (Box 1).

Box 1
Definitions.

Concept	Definition
Metabolic Equivalent of Task (MET)	A measure of the energy cost of physical activities, defined as the ratio of metabolic rate during a specific activity to the resting metabolic rate (1 MET).
Sedentary behavior	Any activity performed in a sitting or lying posture, with an energy expenditure of 1.5 METs or less.
Light physical activity (LPA)	Physical activity, such as walking at a slow pace, where the energy expenditure is between 1.5 to 3.0 METs.
Moderate physical activity (MPA)	Physical activity that is likely to increase your heart rate, such as bicycling or walking briskly, equivalent to between 3 and 6 METs.
Vigorous physical activity	Activities such as jogging that have an MET value of 6 or above.
Moderate-to-vigorous physical activity (MVPA)	Physical activity guidelines usually target performance of MVPA, and this includes any activities above 3.0 METs.
Accelerometer	A device that can measure movement, typically in counts per minute (CPM), where a higher CPM indicates a greater intensity of movement.
Inclinometer	A device that can measure both movement and posture of the wearer.

4.3. Future directions and recommendations

Since five out of six of the included studies were published between 2013 and 2016, there is clearly a spotlight moving within the research community towards sedentary behavior, particularly in the demographic of older adults. However, this review identified a lack of studies with RCT designs of sufficient sample size and ecological validity. Although the included studies were powered to detect significant differences in sedentary behavior variables, sample sizes were limited to between 30 and 59 participants. Larger sample sizes are needed in future clinical trials to increase rigour, and detect smaller differences, as individual variation in magnitude of behavior change can be substantial [22]. Increasing sample sizes would also increase the sensitivity of analyses within studies, enabling the individual components of interventions to be assessed proportionally for their role in the degree of behavior change achieved. Adequate sensitivity of intervention subcomponents was lacking in the included studies, as it was not clear which part of the multicomponent interventions contributed most to the observed effects. Where possible, such an analysis should be incorporated, so that ineffective aspects of interventions can be discarded and overall efficiency of design can be improved moving forward.

Despite efforts from organisations such as the Sedentary Behavior Research Network (2013), there is still large heterogeneity in reporting and assessment of outcomes within the field of sedentary behavior research. Half of the included studies used only self-report methods of sedentary behavior: either the IPAQ or MOST [20,21,23]. In these studies, there were substantially greater effects reported on sitting time; for one, a 28% reduction was reported [21], which far exceeds the maximum of 5.3% reported in the objectively-measured studies [24]. The sizeable reductions reported by these studies are likely due to response bias and information bias (bias resulting from measurement error), which are common in self-report methods compared with objective ones [33,34]. Half of the studies used at least one objective measurement tool, such as an accelerometer or inclinometer. However, there are also problems with heterogeneity of objective measures: an accelerometer such as the ActiGraph GT1M or an inclinometer such as the ActivPal3 do not have complete cross-comparability. For example, in direct observation of sitting, the ActiGraph GT3X+ has been found to have a correlation of $r^2 = 0.39$, whereas the ActivPal3 achieved a correlation of $r^2 = 0.94$ [35,36]. Likewise, the GT3X+ can misclassify standing activity as sitting or lying [37]. Although any kind of objective measurement device is considered more valid and reliable than self-report methods for measuring sedentary behavior, inclinometers such as the ActivPal3 are considered superior as they can detect and record the posture of the individual wearing them [28,29]. A recent critical review of sedentary behavior in older adults, that also covered measurement techniques, found that self-report methods significantly underestimate sedentary time in comparison to objective measures, whereas inclinometers are the current gold standard [30]. Inclinometers allow for more accurate measurement of sedentary behavior, as it includes the postural component of the definition. A recent review of interventions to reduce sedentary behavior in adults of all ages found that a combination of ActivPal3 to capture objective postural information, as well as at least one self-report measure to assess context, provides the optimal detection of a beneficial intervention effect [15]. Thus, pooling the data could lead to substantial problems if the assumption is that the data are based on a comparable measurement, since the tools have substantially different validity. This heterogeneity extends to how outcomes are reported, meaning that performance of any kind of statistical analysis when systematically reviewing such articles is obfuscated. For example, one study reported in minutes of sitting time per week [20], while another reported a reduction in

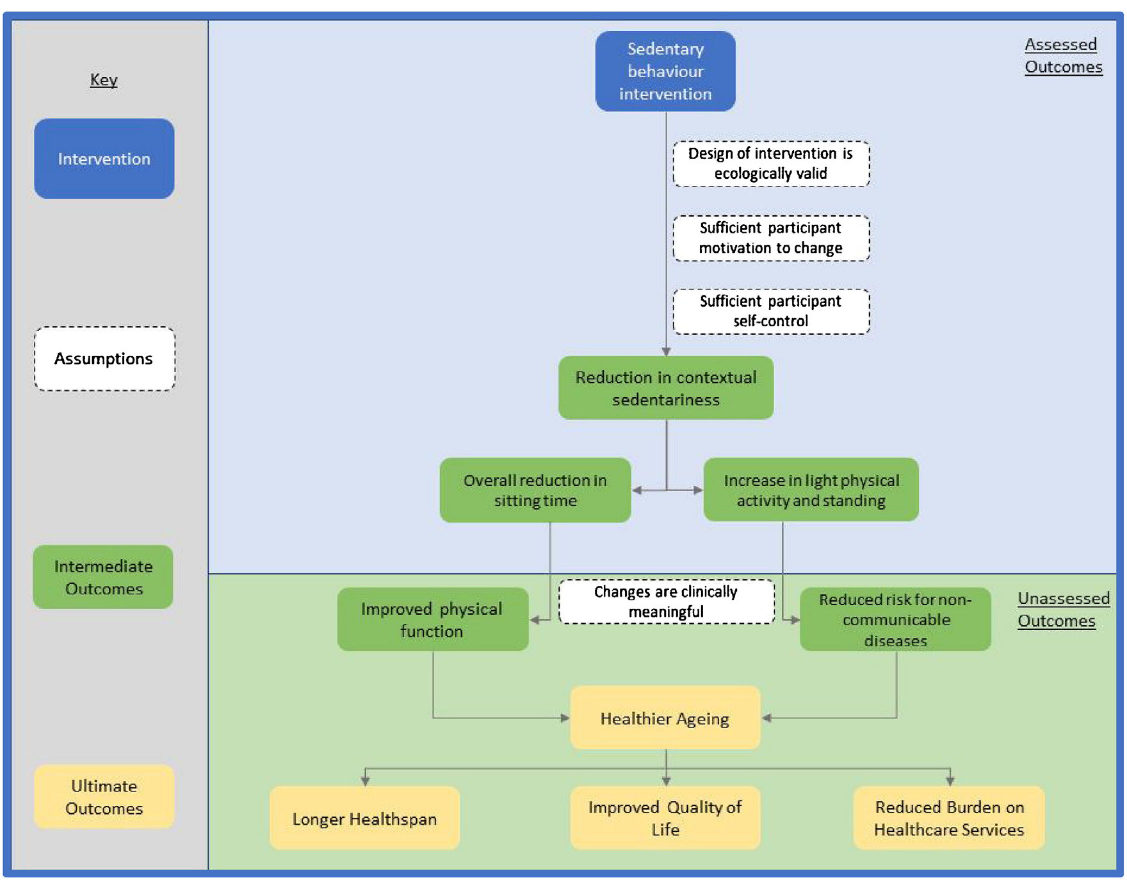

Fig. 2. Interventions to reduce sedentary behavior in older adults: an implicit theory of change model. Assessed outcomes are those investigated in the included studies of this review; unassessed outcomes represent the implicit purpose of the interventions and the future direction of the field.

average minutes per day [23] (Table 4). Future studies should endeavor to gravitate towards better-suited measurement tools that are directly applicable to sedentary behavior as the primary outcome, such as inclinometers which assess posture as well as detect movement, and not be satisfied with the use of self-report measures alone. Additionally, greater consensus within the field as to reporting of outcome measures is desirable; for example, reporting sedentary time in average minutes/day is more useful than minutes/week as it is more sensitive. This would allow for better synthesis of results within the field.

Older adults have varied lives – some are retired, some working, looking after grandchildren, or living in care homes. These lifestyle factors will have large effects on sedentary time and how it is accumulated. This means that differences in participant lifestyle are key considerations that should be addressed when designing interventions in these groups. For this reason, the decision was made not to include older adults in full-time employment in this review, as other studies have mixed working and non-working participants in their analyses despite their very different lifestyles [14,38]. If half of the participant base spends eight hours a day in the office whereas the rest are retired, and participants with both lifestyles are included, then there is significant heterogeneity in lifestyle within the same study. This presents a problem because the behavior change strategies used will have to be quite different, as one group will likely be sitting out of necessity at work, and the other for leisure purposes. If it is still necessary to include participants with different lifestyles in a single study, then subgroup analyses are suggested based on these lifestyle types (e.g., working and non-working). Likewise, motivations and lifestyle may change substantially within the week, as weekday versus weekend behavior patterns are very different in older adults, causing substantial changes in sedentariness within a single 7-day period [36]. Therefore, given this substantial difference, researchers suggest that sedentary behavior outcomes should be reported for weekends and week-days separately [39].

Since the overall trend of the included studies suggests that interventions have the potential to be safe, effective, and feasible in non-working older adults, it is now time for studies to assess physical function and cardiometabolic health following a reduction in sedentary time. The assumption is that interventions will improve these health factors. However, currently, the estimated magnitude of improvement to health and function is based largely on epidemiological studies that employ statistical techniques such as isotemporal modelling, a statistical technique that allows the effect of displacing time spent in one activity to another, to estimate improvements from hypothetical reductions in sedentary behaviour, or is from associational data [40]. Two studies (identified in the search, but not eligible due to including working participants) assessed a measure of function using the Short Physical Performance Battery [14,41]. One did not detect a significant difference pre-to-post intervention [14], and another found a significant improvement [41]. No study, thus far, has experimentally assessed the impact of a sedentary behavior reduction in older adults on blood markers such as cholesterol, fasting insulin, triglycerides, or low-density lipoproteins, all of which are associated with disease factors influenced by sedentary behavior [42]. Thus, it is not yet clear from the interventional data what the required magnitude of change in sedentary behavior would be to confer clinically meaningful health benefits. However, studies utilising isotemporal substitution modelling suggest that replacing 30 min./day of sedentary behavior with MVPA, or even light physical activity in individuals with co-morbidities, could have positive effects on frailty in older adults [43]. Another isotemporal substitution study suggests that replacing 30 min/day of sedentary behavior with light physical activity could reduce all-cause mortality by 11% and cardiovascular disease risk by 24% [44]. Based on interventional data alone, however, it is currently undetermined whether reducing sedentary behavior is a powerful enough stimulus to confer a definite improvement in health and physical function in older adults.

Furthermore, follow-up measurements were not included within the included studies, which makes it impossible to assess whether lasting behavioral change could be accomplished by the interventions. To be able to inform policy design and clinical practice accurately and properly, sedentary behavior research must reliably demonstrate that interventions arising from the field have the potential to confer lasting positive behavioral change with a resultant impact on health and function.

5. Limitations

This review has several limitations. Firstly, due to the infancy of this specific field, there were too few studies with too high a degree of measurement heterogeneity to undertake meta-analysis, which means the efficacy of sedentary behavior interventions in older adults can only be estimated. Secondly, the review was of studies published only in the English language, thus, other potentially eligible studies may have been missed. Thirdly, although every effort was made to distinguish between studies relying solely on self-report and those involving objective measurement of sedentary behavior according to the definition, this review nonetheless relies partially on studies utilising self-report methodologies, as well as accelerometers, rather than inclinometers, for objective measurement (which could not provide postural information). Finally, even in the included studies which used objective measures, some were of feasibility design or included small sample sizes, making them unsuitable for estimating efficacy.

6. Conclusion

This systematic review is the first to assess sedentary behavior interventions in older adults, who are simultaneously one of the most sedentary demographics and most at-risk for its negative health effects. Although the evidence is both limited in quantity and quality, sedentary behavior interventions in non-working older adults have the potential to lead to meaningful reductions in sedentary time. However, there is not yet experimental evidence for any impact of sedentariness on clinical outcomes such as physical function and cardiometabolic health. Additionally, a lack of follow-up in these studies means there is no evidence of the duration of behavior change elicited by the intervention. As multiple pilot studies of sedentary behavior interventions indicate that sedentary behavior can be reduced by up to 1 h/day in this demographic, future studies should be of RCT design, and should endeavor to assess changes in function and health as primary outcomes, with adequate follow-up assessment. In this manner, the underlying assumptions of the field can be tested, and it can be established what dose of sedentary behavior reduction is required to improve health and physical function in older adults.

Contributors

Justin Avery Aunger was the main author, and thus developed the search strategy, ran the searches, screened the results, assessed titles and abstracts for eligibility, performed full-text screening, data extraction, quality assessment, the narrative analysis, and prepared the manuscript.

Paul Doody performed independent screening of titles, abstracts, and full texts, and completed independent quality assessment.

Carolyn Anne Greig edited the manuscript and was in place as a third independent reviewer if needed.

Conflict of interest

The authors declare that they have no conflicts of interest.

Funding

This review was supported by a European Commission Horizon

2020 Marie Curie-Skłodowska Innovative Training Network [grant number 657003].

Provenance and peer review

This article has undergone peer review.

Acknowledgement

We thank Lynne Harris (University of Birmingham library services) for her advice and review of the search strategy.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.maturitas.2018.08.002.

References

[1] Sedentary Behaviour Research Network, Letter to the Editor: standardized use of the terms "sedentary" and "sedentary behaviours", Ment. Health Phys. Act. 6 (2013) 55–56, https://doi.org/10.1016/j.mhpa.2012.06.001.
[2] M.T. Hamilton, D.G. Hamilton, T.W. Zderic, Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease, Diabetes 56 (2007) 2655–2667, https://doi.org/10.2337/db07-0882.CVD.
[3] P.T. Katzmarzyk, T.S. Church, C.L. Craig, C. Bouchard, Sitting time and mortality from all causes, cardiovascular disease, and cancer, Med. Sci. Sports Exerc. 41 (2009) 998–1005, https://doi.org/10.1249/MSS.0b013e3181930355.
[4] C. Bouchard, S.N. Blair, P.T. Katzmarzyk, Less sitting, more physical activity, or higher fitness? Mayo Clin. Proc. 90 (2015) 1533–1540, https://doi.org/10.1016/j.mayocp.2015.08.005.
[5] Office of National Statistics, Ageing of the UK Population, (2015) http://webarchive.nationalarchives.gov.uk/20160105160709/http://www.ons.gov.uk/ons/rel/pop-estimate/population-estimates-for-uk–england-and-wales–scotland-and-northern-ireland/mid-2014/sty-ageing-of-the-uk-population.html.
[6] United Nations, Department of Economic and Social Affairs, Population Division, World Population Ageing, (2015) doi:ST/ESA/SER.A/390 http://www.un.org/en/development/desa/population/publications/pdf/ageing/WPA2015_Report.pdf.
[7] R. Cracknell, The ageing population, Key Issues New Parliam. (2010), p. 44.
[8] L.F.M. Rezende, J.P. Rey-López, V.K.R. Matsudo, O. do C. Luiz, Sedentary behavior and health outcomes among older adults: a systematic review, BMC Public Health 14 (2014) 333–341, https://doi.org/10.1186/1471-2458-14-333.
[9] D.E. Rosenberg, J. Bellettiere, P.A. Gardiner, V.N. Villarreal, K. Crist, J. Kerr, Independent associations between sedentary behaviors and mental, cognitive, physical, and functional health among older adults in retirement communities, J. Gerontol. A Biol. Sci. Med. Sci. 71 (2015), https://doi.org/10.1093/gerona/glv103 glv103-.
[10] E. Stamatakis, M. Davis, A. Stathi, M. Hamer, Associations between multiple indicators of objectively-measured and self-reported sedentary behaviour and cardiometabolic risk in older adults, Prev. Med. (Baltim). 54 (2012) 82–87, https://doi.org/10.1016/j.ypmed.2011.10.009.
[11] R.N. Larsen, B.A. Kingwell, P. Sethi, E. Cerin, N. Owen, D.W. Dunstan, Breaking up prolonged sitting reduces resting blood pressure in overweight/obese adults, Nutr. Metab. Cardiovasc. Dis. 24 (2014) 976–982, https://doi.org/10.1016/j.numecd.2014.04.011.
[12] M.J. Prince, F. Wu, Y. Guo, L.M. Gutierrez Robledo, M. O'Donnell, R. Sullivan, S. Yusuf, The burden of disease in older people and implications for health policy and practice, Lancet. 385 (2015) 549–562, https://doi.org/10.1016/S0140-6736(14)61347-7.
[13] H.M. Treasury, Country and Regional Analysis: 2015, (2015) https://www.gov.uk/government/statistics/country-and-regional-analysis-2015.
[14] D.E. Rosenberg, N.M. Gell, S.M.W. Jones, A. Renz, J. Kerr, P.A. Gardiner, D. Arterburn, The feasibility of reducing sitting time in overweight and obese older adults, Health Educ. Behav. 42 (2015) 669–676, https://doi.org/10.1177/1090198115577378.
[15] A. Martin, C. Fitzsimons, R. Jepson, D.H. Saunders, H.P. van der Ploeg, P.J. Teixeira, C.M. Gray, N. Mutrie, Interventions with potential to reduce sedentary time in adults: systematic review and meta-analysis, Br. J. Sports Med. 49 (2015) 1056–1063, https://doi.org/10.1136/bjsports-2014-094524.
[16] A.P. Verhagen, H.C.W. De Vet, R.A. De Bie, A.G.H. Kessels, M. Boers, L.M. Bouter, P.G. Knipschild, The Delphi list: a criteria list for quality assessment of randomized clinical trials for conducting systematic reviews developed by Delphi consensus, J. Clin. Epidemiol. 51 (1998) 1235–1241, https://doi.org/10.1016/S0895-4356(98)00131-0.
[17] NHLBI, Quality Assessment Tool for Before-After (Pre-Post) Studies with No Control Group, NHLBI Study Qual. Assess. Tools, (2014) https://www.nhlbi.nih.gov/health-pro/guidelines/in-develop/cardiovascular-risk-reduction/tools/before-after.
[18] J. Popay, H. Roberts, A. Sowden, M. Petticrew, L. Arai, M. Rodgers, N. Britten, K. Roen, S. Duffy, Guidance on the conduct of narrative synthesis in systematic reviews (2006).
[19] Centre for Reviews and Dissemination, Systematic Reviews: CRD's Guidance for Undertaking Reviews in Health Care, (2009), https://doi.org/10.1016/S1473-3099(10)70065-7.
[20] A.K. Chang, C. Fritschi, M.J. Kim, Sedentary behavior, physical activity, and psychological health of Korean older adults with hypertension: effect of an empowerment intervention, Res. Gerontol. Nurs. 6 (2013) 81–88, https://doi.org/10.3928/19404921-20121219-01.
[21] R. Matei, I. Thune-Boyle, M. Hamer, S. Iliffe, K.R. Fox, B.J. Jefferis, B. Gardner, Acceptability of a theory-based sedentary behaviour reduction intervention for older adults ('On Your Feet to Earn Your Seat'), BMC Public Health 15 (2015) 606 http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=medl&NEWS=N&AN=26135402.
[22] C. English, G.N. Healy, T. Olds, G. Parfitt, E. Borkoles, A. Coates, S. Kramer, J. Bernhardt, Reducing sitting time after stroke: a phase II safety and feasibility randomized controlled trial, Arch. Phys. Med. Rehabil. 97 (2016) 273–280, https://doi.org/10.1016/j.apmr.2015.10.094.
[23] J.P. Maher, M.J. Sliwinski, D.E. Conroy, Feasibility and preliminary efficacy of an intervention to reduce older adults' sedentary behavior, Transl. Behav. Med. (2016) 1–10, https://doi.org/10.1007/s13142-016-0394-8.
[24] L.K. Lewis, A.V. Rowlands, P.A. Gardiner, M. Standage, C. English, T. Olds, Small Steps: preliminary effectiveness and feasibility of an incremental goal-setting intervention to reduce sitting time in older adults, Maturitas 85 (2016) 64–70, https://doi.org/10.1016/j.maturitas.2015.12.014.
[25] P.A. Gardiner, E.G. Eakin, G.N. Healy, N. Owen, Feasibility of reducing older adults' sedentary time, Am. J. Prev. Med. 41 (2011) 174–177, https://doi.org/10.1016/j.amepre.2011.03.020.
[26] S.F.M. Chastin, B. Culhane, P.M. Dall, Comparison of self-reported measure of sitting time (IPAQ) with objective measurement (activPAL), Physiol. Meas. 35 (2014) 2319–2328 http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=medl&NEWS=N&AN=25341050.
[27] P.A. Gardiner, B.K. Clark, G.N. Healy, E.G. Eakin, E.A.H. Winkler, N. Owen, Measuring older adults' sedentary time: reliability, validity, and responsiveness, Med. Sci. Sport. Exerc. 43 (2011) 2127–2133, https://doi.org/10.1249/MSS.0b013e31821b94f7.
[28] F. van Nassau, J.Y. Chau, J. Lakerveld, A.E. Bauman, H.P. van der Ploeg, Validity and responsiveness of four measures of occupational sitting and standing, Int. J. Behav. Nutr. Phys. Act. 12 (2015) 1–9, https://doi.org/10.1186/s12966-015-0306-1.
[29] C. Busschaert, I. De Bourdeaudhuij, V. Van Holle, S.F.M. Chastin, G. Cardon, K. De Cocker, Reliability and validity of three questionnaires measuring context-specific sedentary behaviour and associated correlates in adolescents, adults and older adults, Int. J. Behav. Nutr. Phys. Act. 12 (2015) 117 http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=medl&NEWS=N&AN=26381488.
[30] J.L. Copeland, M.C. Ashe, S.J. Biddle, W.J. Brown, M.P. Buman, S. Chastin, P.A. Gardiner, S. Inoue, B.J. Jefferis, K. Oka, N. Owen, L.B. Sardinha, D.A. Skelton, T. Sugiyama, S. Dogra, Sedentary time in older adults: a critical review of measurement, associations with health, and interventions, Br. J. Sports Med. 51 (2017) 1539, https://doi.org/10.1136/bjsports-2016-097210.
[31] K.C. Heesch, J.G. van Uffelen, R.L. Hill, W.J. Brown, What do IPAQ questions mean to older adults? Lessons from cognitive interviews, Int. J. Behav. Nutr. Phys. Act. 7 (35) (2010), https://doi.org/10.1186/1479-5868-7-35.
[32] J.H. Vercoulen, C.M. Swanink, J.F. Fennis, J.M. Galama, J.W. van der Meer, G. Bleijenberg, Dimensional assessment of chronic fatigue syndrome, J. Psychosom. Res. 38 (1994) 383–392, https://doi.org/10.1016/0022-3999(94)90099-X.
[33] N. Aguilar-Farías, W.J. Brown, T.S. Olds, G.M.E.E. (Geeske) Peeters, Validity of self-report methods for measuring sedentary behaviour in older adults, J. Sci. Med. Sport 18 (2015) 662–666, https://doi.org/10.1016/j.jsams.2014.08.004.
[34] C.E. Matthews, S.C. Moore, S.M. George, J. Sampson, H.R. Bowles, Improving self-reports of active and sedentary behaviors in large epidemiologic studies, Exerc. Sport Sci. Rev. 40 (2012) 118–126, https://doi.org/10.1097/JES.0b013e31825b34a0.
[35] N. Aguilar-Farías, W.J. Brown, G.M.E.E. (Geeske) Peeters, ActiGraph GT3X+ cut-points for identifying sedentary behaviour in older adults in free-living environments, J. Sci. Med. Sport 17 (2014) 293–299, https://doi.org/10.1016/j.jsams.2013.07.002.
[36] S. Kozey-Keadle, A. Libertine, K. Lyden, J. Staudenmayer, P.S. Freedson, Validation of wearable monitors for assessing sedentary behavior, Med Sci Sport. Exerc. 43 (2011) 1561–1567.
[37] J.A. Steeves, H.R. Bowles, J.J. McClain, K.W. Dodd, R.J. Brychta, J. Wang, K.Y. Chen, Ability of thigh-worn actigraph and activpal monitors to classify posture and motion, Med. Sci. Sports Exerc. 47 (2015) 952–959, https://doi.org/10.1249/MSS.0000000000000497.
[38] J. Kerr, M. Takemoto, K. Bolling, A. Atkin, J. Carlson, D. Rosenberg, K. Crist, S. Godbole, B. Lewars, C. Pena, G. Merchant, Two-arm randomized pilot intervention trial to decrease sitting time and increase sit-to-stand transitions in working and non-working older adults, PLoS One 11 (2016) e0145427http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=medc&NEWS=N&AN=26735919.
[39] S. Marshall, J. Kerr, J. Carlson, L. Cadmus-Bertram, R. Patterson, K. Wasilenko, K. Crist, D. Rosenberg, L. Natarajan, Patterns of weekday and weekend sedentary behavior among older adults, J. Aging Phys. Act. 23 (2015) 534–541, https://doi.org/10.1123/japa.2013-0208.
[40] C.E. Matthews, S.C. Moore, J. Sampson, A. Blair, Q. Xiao, S.K. Keadle, A. Hollenbeck, Y. Park, Mortality benefits for replacing sitting time with different physical activities, Med. Sci. Sport. Exerc. 47 (2015) 1833–1840, https://doi.org/

10.1249/MSS.0000000000000621.
[41] B.B. Gibbs, J.S. Brach, T. Byard, S. Creasy, K.K. Davis, S. McCoy, A. Peluso, R.J. Rogers, K. Rupp, J.M. Jakicic, Reducing sedentary behavior versus increasing moderate-to-vigorous intensity physical activity in older adults: a 12-week randomized, clinical trial, J. Aging Health (2016), https://doi.org/10.1177/0898264316635564.
[42] A. Thorp, G.N.G. Healy, N. Owen, J. Salmon, K. Ball, J.E. Shaw, P.Z. Zimmet, D.W. Dunstan, Deleterious associations of sitting time and television viewing time with cardio-metabolic risk biomarkers: AusDiab 2004–2005, Diabetes Care 33 (2009) 327–334, https://doi.org/10.2337/dc09-0493.
[43] A. Mañas, B. del Pozo-Cruz, A. Guadalupe-Grau, J. Marín-Puyalto, A. Alfaro-Acha, L. Rodríguez-Mañas, F.J. García-García, I. Ara, Reallocating accelerometer-assessed sedentary time to light or moderate- to vigorous-intensity physical activity reduces frailty levels in older adults: an isotemporal substitution approach in the TSHA study, J. Am. Med. Dir. Assoc. 19 (2018), https://doi.org/10.1016/j.jamda.2017.11.003 185.e1-185.e6.
[44] I.-M. Dohrn, L. Kwak, P. Oja, M. Sjostrom, M. Hagstromer, Replacing sedentary time with physical activity: a 15-year follow-up of mortality in a national cohort, Clin. Epidemiol. Volume 10 (2018) 179–186, https://doi.org/10.2147/CLEP.S151613.