

Sedentary time in older adults: a critical review of measurement, associations with health, and interventions

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ABSTRACT

Sedentary time (ST) is an important risk factor for a variety of health outcomes in older adults. Consensus is needed on future research directions so that collaborative and timely efforts can be made globally to address this modifiable risk factor. In this review, we examined current literature to identify gaps and inform future research priorities on ST and healthy ageing. We reviewed three primary topics: (1) the validity/reliability of self-report measurement tools, (2) the consequences of prolonged ST on geriatric-relevant health outcomes (physical function, cognitive function, mental health, incontinence and quality of life) and (3) the effectiveness of interventions to reduce ST in older adults.

Methods A trained librarian created a search strategy that was peer reviewed for completeness.

Results Self-report assessment of the context and type of ST is important but the tools tend to underestimate total ST. There appears to be an association between ST and geriatric-relevant health outcomes, although there is insufficient longitudinal evidence to determine a dose–response relationship or a threshold for clinically relevant risk. The type of ST may also affect health; some cognitively engaging sedentary behaviours appear to benefit health, while time spent in more passive activities may be detrimental. Short-term feasibility studies of individual-level ST interventions have been conducted; however, few studies have appropriately assessed the impact of these interventions on geriatric-relevant health outcomes, nor have they addressed organisation or environment level changes. Research is specifically needed to inform evidence-based interventions that help maintain functional autonomy among older adults. This consensus statement has been endorsed by the following societies: Academy of Geriatric Physical Therapy, Exercise & Sports Science Australia, Canadian Centre for Activity and Aging, Society of Behavioral Medicine, and the National Centre for Sport and Exercise Medicine.

INTRODUCTION

Sedentary behaviour is defined as any waking behaviour in a seated or reclining posture, with a low energy expenditure (≤ 1.5 metabolic equivalent of task (METs)).¹ The time spent in these behaviours, that is, sedentary time (ST), has emerged as an important determinant of health in the last decade.² Among older adults ST is high, with the majority accumulating 8 or more hours/

day.^{3–4} A systematic review of studies from 10 countries found that older adults accumulate an average of 9.4 hours/day of ST.⁵ Based on current evidence, older adults are the most sedentary of any other age group.^{6,7} While a considerable amount of research has been done to identify the determinants of ST among older adults,⁸ more work is needed to understand the effect of ST on healthy ageing. We sought to develop an international consensus statement to summarise the current state of the evidence and guide future research in the area of ST and healthy ageing. As part of this process, a review of the literature was conducted to help inform the consensus statement.⁹

Several longitudinal studies of older adults have demonstrated that all-cause mortality has a graded, inverse relationship with self-reported total ST and TV time.¹⁰ Keadle *et al*¹¹ found that older adults who watched 5 or more hours/day of TV had a 28% higher risk of mortality over 6.6 years than those who watched less than 3 hours/day. There is also a growing body of cross-sectional evidence that indicates an association between ST and cardiometabolic risk factors such as metabolic syndrome and obesity; these associations have been previously reviewed.¹⁰ While these outcomes are important, the major categories of impairment in older adults are not cardiometabolic in nature.

The term ‘geriatric syndromes’ refers to multifactorial conditions that are common among older adults but do not fit clearly into specific categories of disease. These include instability and falls, mobility impairment, frailty, cognitive impairment, dizziness, urinary incontinence (UI) and depressive symptoms.^{12–15} These geriatric syndromes have a major impact on quality of life (QOL), independence and longevity.^{12–15} Bowling *et al*¹⁶ conducted a longitudinal examination of non-disease-specific geriatric syndromes including cognitive impairment, depressive symptoms, falls and impaired mobility. They found a graded increase in hazard ratios for all-cause mortality with each additional condition that was present.¹⁶ Recently, Koroukian *et al*¹⁴ examined the combinations of chronic conditions, functional limitations and geriatric syndromes that predict poor health in older adults. Using a representative sample of more than 16 000 older adults, they showed that functional limitations and geriatric syndromes were stronger predictors of poor



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self-reported health and 2-year mortality than the presence of chronic conditions such as diabetes or heart disease.¹⁴ Thus, these non-disease outcomes are just as relevant to an older population.

While the association of ST with mortality and chronic disease has been reviewed elsewhere,¹⁰ the association between ST and geriatric-relevant health outcomes is relatively unexplored. Furthermore, the evidence of ST interventions has not been previously reviewed. Thus, the goal of this review was to explore the consequences of prolonged ST on geriatric-relevant health outcomes and the effectiveness of interventions to reduce ST among older adults. In this context, accurate measurement of ST is critical; thus, we also reviewed the evidence of the accuracy of self-report ST measures among older adults.

METHODS

Although this is a narrative review, the literature was searched systematically. An experienced librarian created a search strategy that was reviewed for completeness and accuracy by an independent librarian using Peer Review of Electronic Search Strategies. A search was conducted in Sport Discus, CINAHL, Medline, Embase and PsycINFO on 9 November 2015, and the search was repeated on 27 August 2016. Studies were excluded if they were a conference proceeding, abstract, thesis, report, systematic review or qualitative study design. Studies were included if the study population was ≥ 60 years which is consistent with previously published reviews in this area.^{10 17} The United Nations defines an older person as 60+ years of age.¹⁸

A two-phase screening process was used. In phase I, titles and abstracts were screened and classified as relevant, possibly relevant or irrelevant. In phase II, full text articles of possibly relevant articles were reviewed to determine whether they were relevant or irrelevant. All screening was done by the first (JLC) and last author (SD). All relevant articles were organised according to the three areas: validity and reliability of self-report measures, geriatric-relevant health outcomes and ST interventions. Within the geriatric-relevant health outcomes, articles were categorised into physical function, cognitive function, mental health, incontinence, QOL/well-being and sleep. We also investigated age, sex and gender differences in the associations between ST and health in older adults.

It is important to note that ST is distinct from physical inactivity, which refers to a lack of moderate-to-vigorous physical activity.¹ Thus, studies were included if they specifically measured ST or participation in specific sedentary behaviours; they were excluded if they only assessed physical activity, even if they defined the lack of activity as 'sedentary'. Studies of short-term bed rest were also excluded.

Validity and reliability of self-report measures of ST in older adults

To assess the effectiveness of interventions and the longitudinal associations between ST and health outcomes, valid measurement tools that are sensitive enough to capture changes in ST, and to measure ST duration and type accurately, are needed. While device-based measures of ST such as accelerometers or inclinometers have many advantages, such as being more objective and less prone to bias, self-report tools are more practical for population-based studies. Self-report is also valuable for providing context to the ST that is accumulated, and to identify specific sedentary behaviours. This is important as time spent in cognitively engaging sedentary behaviours, such as reading, socialising or computer use, could have different effects on health

outcomes compared with more passive sedentary behaviours, such as watching television.

Nine studies that directly compared self-reported ST to device-based measures were identified through the search. Four of the studies were conducted in Europe,^{19–22} three in Australia,^{23–25} one in the USA²⁶ and one in Brazil.²⁷ Cultural norms could influence perceptions of 'sedentary behaviour' and should be considered in research using self-report.

Six studies used an ActiGraph accelerometer^{20–22 25–27} and one used an Actiheart accelerometer.¹⁹ It should be noted that accelerometers cannot provide information about posture, which is an important part of the definition of ST. Thus, accelerometers also only provide an estimate of ST by quantifying lack of movement, and may not be an ideal criterion measure. An inclinometer can measure time spent sitting, lying and standing, and was used by two studies.^{23 24} In most studies, lying time associated with sleep was excluded; this is important as the definition of ST refers specifically to waking activity.

Each study assessed a different questionnaire. For the Epic Physical Activity Questionnaire (men $n=813$; women $n=876$), which assesses physical activity in four domains to estimate physical activity energy expenditure and ST (defined as ≤ 1.5 METs), only weak correlations (men: 0.17; women: 0.18) were observed with ST in hours per day.¹⁹ This tool underestimated ST more in women (34%) than in men (26%) when compared with a heart rate and movement sensor (Actiheart). A questionnaire using self-reported frequency and duration of sedentary behaviours in the past 7 days ($n=442$) was found to underestimate ST when compared with an accelerometer (ActiGraph); however, it overestimated ST among those who accumulated 640 min/day.²⁰ Of note, test–retest reliability was acceptable for TV viewing, computer use, driving and total sitting time. Furthermore, the correlations between the questionnaire and accelerometer data were stronger in older men than older women.²⁰ For a similar questionnaire on time spent in 10 sedentary behaviours on a regular weekday and regular weekend ($n=83$), total self-reported ST was underestimated, and correlated moderately (0.35) with accelerometer (ActiGraph) measured ST.²² The reliability of six individual activities ranged from 0.31 (talking) to 0.85 (napping) in this study. For the Measuring Older Adults' Sedentary Time questionnaire ($n=48$), validity was acceptable (0.30) and test–retest reliability ranged from 0.90 for computer use to 0.45 for transport.²⁵ Self-reported ST underestimated accelerometer (ActiGraph) measured ST by 3.6 hours/day among those with average ST.²⁵ The Physical Activity Survey for Older Adults and the Community Health Activities Model Program for Seniors (CHAMPS) are widely used tools but both questionnaires were found to underestimate ST when compared with accelerometer data (ActiGraph). The CHAMPS questionnaire ($n=58$) underestimated ST by 5.21 hours/day.²⁶ The Human Activity Profile Questionnaire includes 94 activities that have variable energy requirements (low to high); it had a strong correlation (-0.47) with accelerometer (ActiGraph) measured ST ($n=120$).²⁷ For a questionnaire on hours/week spent in specific sedentary behaviours ($n=1377$), correlations with accelerometer (ActiGraph) measured ST were weak; this was particularly true for men over the age of 80 years. Here again, the questionnaire underestimated daily ST (by 5.38 hours/day).²¹

Only two studies compared self-report to measured sitting time from an inclinometer. A 7-day recall questionnaire on sedentary behaviours in five contexts was found to underestimate ST in older adults (65–89 years) by approximately 3 hours/day when compared with an activPAL3 inclinometer.²⁴ Furthermore, validity was found to be lower for adults aged 75 and

older compared with those aged 65 to 74 years.²⁴ Aguilar-Farias *et al*²³ assessed two different self-report tools in a small sample of older adults. They found that a single-item question on total sitting time had a weak association ($r=0.13-0.33$) with ST measured from an activPAL3 inclinometer, and it underestimated ST. They also examined a 24-hour recall computer-delivered Multimedia Activity Recall for Children and Adolescents, and found that in older adults it overestimated ST, and had a moderate correlation ($r=0.49-0.67$) with measured ST from the activPAL3 inclinometer.²³

Conclusions: self-report measures of ST for older adults

Generally, self-reported measures of ST underestimated total ST when compared with measured ST. Validity and reliability for some sedentary behaviours (eg, TV time and napping) was better than others, and data suggest that there may be age and sex differences in accuracy of self-reported ST. It is important to note that questionnaires do not specifically ask about posture when engaging in certain behaviours and it is therefore simply assumed that when one is watching TV or reading that they are in a seated or reclined position. Furthermore, all of these studies only assessed the validity of self-report as measured against total ST, and none assessed movement throughout the 24 hours, that is, no measures obtained information on sleep, ST and light-to-vigorous intensity physical activity, despite all these behaviours being interrelated and having implications for health outcomes. Thus, self-report tools should be validated for different movement behaviours across the 24 hours. Furthermore, the context of ST is crucial, as different types of sedentary behaviours may have different associations with geriatric-relevant health outcomes; some could even be beneficial to outcomes such as cognitive function. It is unknown how accurate self-report tools are for identifying participation in different types of behaviours; unfortunately, currently available tools such as accelerometers cannot assess specific behaviours for validation. However, some combination of device-based and self-report measures might be able to address this limitation. Advances in technology are allowing the development of novel approaches to assessing the context of ST (ie, wearable cameras), but more research is needed to assess feasibility in larger studies.

Associations of ST with geriatric-relevant health outcomes

Physical function

Mobility limitations have a significant impact on QOL and independence, and can also result in functional limitations, and ultimately, disability.¹³ Impaired mobility is highly prevalent and is associated with more than double the risk of mortality among older adults.¹⁶ In fact, functional limitations have been shown to be a stronger predictor of mortality than chronic conditions.¹⁴ Nineteen studies were identified that examined the relationship between ST and function, with a variety of outcomes used to represent 'function'. Most of these were cross-sectional studies of performance on functional tests (such as the timed up-and-go or chair rise test),²⁸⁻³³ laboratory-based strength assessments (such as grip strength or leg power)³⁴⁻³⁵ or a combination of both.³⁶⁻³⁸ Other outcomes were self-reported limitations within activities of daily living (ADL)³⁹⁻⁴⁴ or falls.⁴⁵⁻⁴⁶ Only three of the studies were longitudinal.⁴¹⁻⁴⁴ For the assessment of ST, five studies used self-reported ST,³⁰⁻³⁶ four used measured ST using accelerometers or similar devices,²⁸⁻²⁹⁻³¹⁻³²⁻³⁵⁻³⁷⁻⁴⁰⁻⁴²⁻⁴⁴⁻⁴⁶ and two used both.³³⁻³⁴

The majority of cross-sectional studies that used functional testing found that ST was inversely related to

performance²⁸⁻³⁰⁻³³⁻³⁷ or muscle strength.³⁷⁻³⁸ One study found no relationship between ST and grip strength³⁴ while others found that the observed relationship between ST and function was not significant after adjustment for moderate-to-vigorous intensity physical activity (MVPA).²⁹⁻³⁸ In contrast to the majority of findings, one study reported a positive association between ST and lower leg extensor power³⁵; it was suggested that this was due to the potential training stimulus provided by the higher body mass index observed in more sedentary participants. The pattern of ST accumulation may also be important; more breaks in ST are associated with better performance on functional fitness tests²⁸⁻³² and lower odds of limitations in instrumental ADL.⁴³

In terms of ADL, four cross-sectional studies found that greater ST was associated with greater limitations in ADL³⁹⁻⁴⁰⁻⁴³⁻⁴⁴ while one found that measured ST was not a predictor of risk of losing independence.⁴² The only longitudinal study unexpectedly found that watching TV was protective against functional loss over 8 years, which is not consistent with the majority of literature on TV viewing.⁴¹ Perhaps some types of TV, such as educational programming, provide stimulation that is beneficial to functional outcomes, although this question has not been addressed in any studies to date. This discrepant finding may also simply reflect a measurement issue, as TV time was not assessed with a validated measure, nor was total time spent watching TV assessed.⁴¹

A cross-sectional analysis of falls found that self-reported prolonged sitting (>8 hours/day) was independently associated with falls in the past 12 months and also mediated the positive association between obesity and fall risk.⁴⁷ Accelerometer-measured ST was associated with fear of falling³³ and with risk of falls.⁴⁶ Jefferis *et al*⁴⁶ conducted a 1-year prospective study of falls in older men and found that greater ST was related to higher risk of falls in a dose-dependent manner. This relationship was observed among men with mobility limitations but was not significant among men without mobility limitations.⁴⁶

Women live longer than men on average, and have lower absolute strength/fitness than men. Thus, older women are more likely to live with functional impairments; this interaction between age and sex with physical function was confirmed by several studies.³²⁻⁴¹⁻⁴² To account for this, most studies of the relationship between ST and physical function adjusted their analyses for age and/or sex,²⁸⁻³¹⁻³²⁻³⁶⁻³⁸⁻⁴⁰⁻⁴³ while others examined men and women separately or tested for a sex interaction³⁴⁻³⁵ or examined only one sex.³⁷⁻⁴⁴⁻⁴⁶ Several studies noted some important differences. Dunlop *et al*³⁹ found a stronger relationship between ST and disability in ADL in older individuals and women. Chastin *et al*³⁵ found an association of ST and breaks in ST with muscle function that was significant in older men but not older women. Marques *et al*⁴² found that based on self-reported ability for ADL and advanced activities (eg, vigorous sports/exercise activities), the risk of losing independence increased with age and was higher in women, but ST was not a significant predictor. They did find a significant interaction of both age and sex with MVPA to predict loss of independence, such that physically active men have better odds of living independently than physically active women. In general, the relationship between ST and physical function may be greater in women and the oldest old. However, sex and age may not be the main modifiers, it may be that individuals with the greatest mobility limitations are more susceptible to the detrimental effects of ST.

Cognitive function

Cognitive impairment is a prevalent geriatric syndrome; it is estimated that globally, 5%–7% of people ≥ 60 years suffer from

dementia.⁴⁸ There is great interest in identifying preventative strategies and both physical activity⁴⁹ and engaging cognitive activities⁵⁰ may help prevent cognitive decline. The role of ST in cognitive impairment is unclear, and studying the effect of ST on cognitive function is complicated by the fact that many cognitively engaging activities are sedentary in nature.

Fourteen studies of ST and cognitive function were identified; five were longitudinal or prospective study designs.^{51–56} The cognitive outcome variables that were assessed included dementia or mild cognitive impairment (MCI)^{51 54 57} or performance on neurocognitive tests such as the mini mental state examination or memory tests.^{33 32 56 58–64} There were also three studies that measured brain structure or brain activity.^{55 65 66} ST was assessed with an accelerometer in four of the studies,^{33 55 65 66} while the others used self-report. However, not all reported total ST as an independent variable; four studies examined self-reported time spent watching TV^{33 56 57 63} while five simply asked about participation in a variety of sedentary pastimes, including reading, handicrafts and visiting with friends.^{51 54 58 60 62} While most studies controlled for age and sex in the analyses, none commented on whether interactions of ST with age or sex were significant.

Greater total ST was associated with cognitive decline over 8 years⁵² and with 5-year decline in white matter volume.⁵⁵ Cross-sectional data also show an inverse association between ST and white matter integrity.⁶⁶ In contrast, two studies found that more self-reported total ST was associated with *better* cognitive function.^{33 61} However, Rosenberg *et al*³³ noted the size of the effect was small and only present in one of two cognitive tests. Furthermore, Vance *et al*⁶¹ included sleep time in their measure of ST and sleep has a positive association with cognitive function.⁶⁷ This highlights the importance of separating sleep time in studies of sedentary behaviour. One study found that total ST was unrelated to brain activity.⁶⁵

Time spent watching TV was negatively associated with cognitive function in most studies.^{54 58 63} One study found that higher TV time was associated with lower odds of MCI, although this finding was based on self-reported TV time from individuals with MCI, which may present issues with validity.⁵⁷ More cognitively engaging sedentary pastimes such as reading, using computers or doing puzzles may be associated with better cognitive performance^{56 60} and lower risk of dementia,^{51 54} although it is important to note that in most of these studies the dose of the activities was not defined. It is not known if the association between cognitive leisure activities and cognitive function is causal; it could be that higher socioeconomic status (SES) is associated with these activities and confounding the relationship. However, a longitudinal study showed that participation in leisure activities was associated with lower risk of developing dementia over 5 years independent of education level.⁵¹ They suggested that participation in engaging leisure activities could increase cognitive reserve, thus delaying loss of cognitive function.⁵¹ Conversely, one study found that greater frequency of socially or cognitively engaging pastimes was associated with lower executive function,⁶² although TV time was included as one of the sedentary pastimes which may be influencing those results. Clearly, more research is needed to determine if different sedentary behaviours have differential effects on cognitive function.

Incontinence

UI is a common geriatric syndrome that has a significant impact on QOL and disability.¹³ Obesity and poor physical function are

known risk factors for UI.⁶⁸ One study has examined the relationship between self-reported total ST and UI in older women and found no association.⁶⁸ This is an area that requires future research.

Mental health

Moderate-to-severe depressive symptoms are a common geriatric syndrome that negatively impacts both functional abilities and QOL.¹⁴ Five studies examined the relationship between ST and various aspects of mental health in older adults: four were cross-sectional^{33 63 69 70} and one was a longitudinal analysis with a 2-year follow-up.⁷¹ Four of these studies used a self-report measure of ST and one used both an accelerometer and self-report.³³ The longitudinal study⁷¹ found that total ST was not a significant predictor of depression diagnosis or increased depressive symptoms at 2-year follow-up.

A cross-sectional analysis found that some sedentary behaviours, such as watching television, were associated with higher risk of adverse mental health outcomes while more cognitively engaging sedentary behaviours, such as using the Internet or reading, were not.⁶⁹ However, even cognitively engaging sedentary behaviours were associated with higher odds of psychological distress if they exceeded 3 hours/day.⁶⁹ Two studies found no relationship between weekly TV time or total ST and either depression or anxiety.⁶³ Finally, one study found that sedentary behaviours such as watching TV and listening to the radio were associated with lower depression in older men and women;^{33 70} however, it is important to note they did not assess the amount of time spent in these activities, only the types of leisure activities in which people participated. A dose–response relationship between ST and mental health outcomes was either not evident⁶³ or the analysis strategy did not allow examination of that question.^{33 69–71}

All the studies adjusted for age and sex. Gautam *et al*⁷⁰ analysed Nepalese men and women and found that while TV viewing was associated with lower risk of depression in both men and women, other behaviours, such as saying prayers, were only significant in men. They concluded that social and cultural norms about social behaviour are distinctly different and thus examining genders separately is important.

QOL and well-being

Seven studies were identified that examined the relationship between ST and QOL or well-being; only one⁷² was longitudinal. Five studies used self-reported sitting time or sedentary leisure behaviour as a predictor of QOL,^{72 73} satisfaction with life^{70 74} and successful ageing.⁷⁵ Two studies used device-based measures of ST and examined the relationship with both physical and psychosocial well-being.^{76 77}

In cross-sectional analyses, more ST was associated with lower QOL and lower satisfaction with life^{73 74} as well as less successful ageing.⁷⁵ Conversely, Gautam *et al*⁷⁰ found that watching TV as a leisure activity was associated with greater life satisfaction in women, but not in men, although there was no dose of TV time established or analysed. There was one study that found no significant relationship between measured ST and subjective well-being,⁷⁶ although it is worth noting that those participants had very high ST with an average of more than 11 hours/day of ST. Meneguçi *et al*⁷³ found individuals who sat more than 5 hours/day had lower scores in both physical and social domains of QOL.

A longitudinal study found that self-reported sitting time at baseline was inversely related with health-related QOL at 6-year

follow-up, in a dose–response fashion.⁷² Isotemporal substitution analysis was used to show that replacing 30–60 min of sitting time/day with activity is associated with improved QOL⁷² and psychosocial well-being.⁷⁷

Dogra and Stathokostas⁷⁵ found that sedentary behaviours were more likely to be associated with social well-being outcomes in women than in men. No other age or sex differences were noted and all studies adjusted for age and sex.

Sleep

Sleep complaints are highly prevalent in older adults and associated with depression, and cardiovascular disease, as well as cognitive and functional impairment.⁷⁸ One intervention and three cross-sectional studies have examined the relationship between sleep and ST. Madden *et al*⁷⁹ found a significant inverse relationship between ST and sleep efficiency, but the effect was small, and likely of little clinical importance. Others found no relationship between either accelerometer-measured or self-reported ST and insomnia, sleep disturbances, daytime drowsiness or poor sleep quality.^{33 80} Asaoka *et al*⁸¹ conducted an intervention with eight older adults, and had them restrict their TV time to only 0.5 hours/day, for 1 week. While weekly TV time was 95% lower during the intervention week, there was no change in sleep-wake patterns or total sleep time during the intervention. No sex or age differences were examined in any study.

Conclusions: ST and geriatric-relevant health outcomes

Overall, there is sufficient evidence on relationships of ST with geriatric-relevant health outcomes to guide further research. It is apparent that there is an association between ST and physical function among older adults; however, our understanding of this association is hampered by the fact that the data are almost exclusively cross-sectional. The pattern of ST may also be important, with some cross-sectional studies showing that a more fragmented accumulation of ST is positively associated with physical function; this is consistent with what has been shown in cross-sectional studies of disease risk factors and outcomes.^{82 83}

Conclusions about relationships of ST with cognitive impairment and depressive symptoms are limited by the inconsistent measurement of ST in those studies and reliance on self-report methods that did not always quantify the volume of ST. Studies of well-being and QOL have also been almost exclusively cross-sectional. Furthermore, the type of ST may be an important factor in these relationships, with time spent in cognitively engaging behaviours appearing to be beneficial and more passive activities being detrimental to all outcomes. More research is needed to determine if this is a causal relationship or whether extraneous variables, such as SES, are confounding the association.

The predominance of cross-sectional evidence also makes it difficult to rule out reverse causality; it is possible that poor cognitive function, impaired mobility or poor mental health lead to an increase in ST, and not the other way around. There are only a limited number of prospective studies that suggest ST precedes poor health.^{44 46 52 72} In light of these limitations, there is insufficient evidence to identify a dose–response relationship between ST and geriatric-relevant health outcomes.

Another issue that should be considered is the interaction between ST and physical activity. Both ST and physical activity are often simultaneously included in statistical models to determine if ST has an independent effect on health. Many of the studies presented here (~65%) adjusted their models for MVPA, although other approaches were used, including examining ST as a mediator⁴⁷ or using isotemporal substitution.⁷⁷ Many studies

simply analysed ST and/or MVPA separately. Older adults spend a significant proportion of a 24-hour period in behaviours other than ST and MVPA, such as sleep and light intensity physical activity, which may also have independent effects on health.⁷⁷ Maher *et al*⁸⁴ posit that models should account for total physical activity instead of only MVPA. The type of adjustment that should be made, or whether an adjustment should be made at all, depends on a number of factors and assumptions, such as study design, collinearity between independent variables, the temporal and/or causal relationship between ST and physical activity, and whether there are independent biological mechanisms by which ST and physical activity influence the health outcomes being studied.⁸⁵ There is limited research in older adults that has addressed these issues, although some studies have examined the interaction of ST and physical activity. For example, Pavey *et al*⁸⁶ showed that the association between ST and mortality in older women was only significant in those who were not physically active. More work is needed that considers all movement behaviours and intensities in a day, and the balance between them.^{87 88}

Effectiveness of interventions on older adults ST

The evidence summarised in the previous section suggests that reducing ST could have beneficial effects on health in older adults. One could speculate that replacing ST with standing and light activity is a more feasible goal than increasing MVPA. However, intervention research in this population is limited. There are a variety of possible approaches to reducing ST in older adults. Some focus specifically on reducing ST while others focus on increasing physical activity, on the assumption that people will reallocate leisure time they normally spend sedentary to physical activity. Interventions may target individual behaviour or environmental and organisation level policies that tend to inadvertently promote ST.

Of the available intervention studies in older adults, five were randomised trials presented in six papers^{89–94} and seven were quasi-experimental pre–post design or feasibility studies.^{81 95–100} In four studies, the intervention was a physical activity intervention^{89 91 93 94} while the others either focused only on ST^{81 95–99} or on both ST and physical activity.^{92 100} Notably, all of the intervention studies were conducted on relatively young and healthy older adults who were able to exercise independently.

The interventions varied considerably in length, and all targeted individual behaviour change; no interventions focused on the environment or organisation level. Some studies assessed the impact of their intervention on ST within 1–8 weeks,^{81 95–100} while other interventions lasted 6 months to a year.^{89 91 93 94} The intervention strategies included one-time consultations,^{81 95 97} consultations with follow-up support in person or by telephone^{92 99} or mailed written information.⁹⁸ More details on the interventions can be seen in online supplementary file 1.

Changes in ST were reported as either changes in total ST, changes in prolonged ST or changes in time spent in specific sedentary behaviours. Three studies did not find a statistically significant reduction in total sitting time.^{89 92 93} From the studies that reported changes, the reduction in total ST ranged from approximately 51 min/day⁹⁹ in studies using an inclinometer to as much as 120 min/day⁹⁴ in studies using self-report. One study used an inclinometer to evaluate an intervention and found a decrease in sitting and lying time of 25 min/day; however, they did not exclude sleep time from their analysis which limits any potential conclusions about the benefits of the intervention.⁹⁷

Other interventions focused on specific behaviours such as television viewing; one of these reported that TV time was significantly reduced by 32 min/day.⁹⁹ In another study where older adults were specifically told to restrict TV time to 30 min/day, TV time decreased from 322 to 16 min/day.⁸¹ Finally, three studies reported an increase in the number of breaks in ST⁹⁵⁻⁹⁹ or sit to stand transitions.⁹⁶ In most of the studies, the intervention also resulted in a significant increase in physical activity, particularly when assessed by self-report. Two studies that used an inclinometer found that sitting time was primarily replaced with standing as opposed to stepping.⁹⁶⁻⁹⁹ The potential health benefits of more standing for older adults are not known.

Several studies found decreases in ST that could theoretically be clinically important. Based on a cross-sectional analysis, Rosenberg *et al*³³ observed that for every 1 hour increase in ST, older adults had a 21 s increase in time to complete a 400 m walk test and a 0.55 lower score in the short physical performance battery. Both of these differences would be considered clinically meaningful. While several of the intervention studies reviewed here found decreases in ST that exceeded an hour, few studies reported on changes in health outcomes as a result of the intervention. One study found that reduced sitting time was associated with telomere lengthening in blood cells.⁹⁰ Barone Gibbs *et al*⁹² found that participants in the ST reduction group had significant improvements in the physical function and the pain component of a QOL scale, despite the fact that total ST did not change. Finally, in a study assessing the impact of TV time restriction on sleep, no changes were noted in sleep-wake patterns as a result of the intervention.⁸¹ It is important to note that most of the intervention studies in older adults were short term and none were longer than a year. Thus, the available evidence does not clarify if intervening to reduce ST in older adults will be beneficial for health outcomes. Long-term follow-up studies with sustained behaviour change are needed to determine if reducing ST will have an effect on health.

Conclusions: reducing ST in older adults

It appears that reducing ST in older adults is feasible through ST and physical activity interventions. A meta-analysis of 33 studies conducted by Prince *et al*¹⁰¹ indicated that among adults, interventions that specifically target ST are more effective at reducing ST than physical activity interventions; however, there are insufficient studies to date to allow us to draw a conclusion specifically for older adults. From the studies reviewed here, all interventions that had non-significant findings were either physical activity interventions or a combination of physical activity and ST interventions. Randomised controlled trials using sufficiently large sample sizes are needed to determine how best to reduce ST and to better understand the effects of ST on changes in geriatric-relevant health outcomes. Furthermore, few intervention studies addressed sex and gender differences which could be important as differences between men and women in functional fitness and patterns of ST may impact intervention effectiveness.

OVERALL CONCLUSIONS

The available self-report tools consistently underestimated total sitting time. However, it is evident that both the dose and the type of sedentary behaviour are important to health outcomes, as some sedentary behaviours, such as reading or use of computers, could benefit older adults. Therefore, tools are needed to accurately quantify the context of ST, including both the dose and the type.

While effects of ST on chronic disease and all-cause mortality are important, more research is needed on the major categories of impairment among older adults as they significantly impact independence and QOL. These categories of impairment better speak to the multimorbidity and mobility impairment that older adults experience, and this is an issue that also needs to be addressed through ST intervention research. While several feasibility studies and RCTs have successfully reduced ST in older adults, few have assessed the impact of such changes on health outcomes and impairments. Furthermore, all intervention studies to date have focused on the individual-level change; there are no studies assessing the impact of environmental or organisational interventions on ST reduction. There is limited research on adults over the age of 80, those in assisted living facilities or those with mobility impairments. Finally, there are potential age, sex and gender differences in ST and health outcomes that have not been adequately addressed. At this critical point in time, as research on ST and healthy ageing research is just beginning, and the ageing population is growing dramatically, consensus is needed on future research priorities.

What is already known?

Sedentary time is associated with an increased risk of mortality and cardiometabolic disease in older adults.

What are the new findings?

- ▶ Self-report tools underestimate total sedentary time in older adults, but they provide context to the behaviour.
- ▶ There are specific associations of sedentary time with geriatric-relevant health outcomes such as physical function, cognitive function, mental health and quality of life, but the relevant evidence base is modest and derived primarily from cross-sectional data.
- ▶ Some cognitively engaging sedentary behaviours—reading, using the internet, socialising—may benefit geriatric-relevant health outcomes.
- ▶ Interventions that target reducing sedentary time in healthy, community-dwelling older adults appear to be feasible, but few have appropriately assessed the impact on geriatric-relevant health outcomes.

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