# Sedentary Time in Older Adults: A Critical Review of Measurement, Associations with Health, and Interventions.

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***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, socializing – 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.

**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 organization or environment level changes. Research is specifically needed to inform evidence-based interventions that help maintain functional autonomy among older adults.

## INTRODUCTION

Sedentary behaviour is defined as any waking behaviour in a seated or reclining posture, with a low energy expenditure (≤ 1.5 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 summarize 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, and depressive symptoms.(12-15) These geriatric syndromes have a major impact on quality of life, independence, and longevity.(12, 13, 16) Bowling et al. (16) conducted a longitudinal examination of nondisease-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 self-reported health and 2-year mortality than the presence of chronic conditions such as diabetes or heart disease.(14) Thus, these nondisease 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 on 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 November 9th, 2015 and the search was repeated on August 27th, 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 organized 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 categorized into physical function, cognitive function, mental health, incontinence, quality of life/wellbeing, 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 to 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 USA, (26) 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 sedentary time (defined as ≤1.5 METs), only weak correlations (men: 0.17; women: 0.18) were observed with sedentary time in hours per day.(19) This tool underestimated ST more in women (34%) than in men (26%) when compared to 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 to an accelerometer (ActiGraph); however, it overestimated ST among those who accumulated 640 minutes/day.(20) Of note, test-retest reliability was acceptable for TV viewing, computer use, driving, and total sitting time. Further, 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 to 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 to an activPAL3™ inclinometer.(24) Furthermore, validity was found to be lower for adults aged 75 and older compared to 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 (MARCA), 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 to 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 Sedentary Time with Geriatric-Relevant Health Outcomes

### *Physical Function*

Mobility limitations have a significant impact on quality of life 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, 46) For the assessment of ST, five studies used self-reported ST,(30, 36, 41,

45) several 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 performance (28, 30-33, 37) or muscle strength.(37, 38) One study found no relationship between ST and grip strength (34) while others found that the observed relationship between ST and function was not significant after adjustment for moderate-vigorous intensity physical activity.(29, 38) In contrast to the majority of findings, one study reported a positive association between ST and lower leg extensor power;(35) 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 tests(28, 32) and lower odds of limitations in instrumental activities of daily living (IADL).(43)

In terms of ADL, four cross-sectional studies found that greater ST was associated with greater limitations in ADL(39, 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, provides 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 falling (33)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 interaction (34, 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 to do ADLs 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 moderate to vigorous intensity physical activity 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 activity(49) and engaging cognitive activities(50) 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 (51, 54, 57) or performance on neurocognitive tests such as the mini mental state exam or memory tests.(33, 52, 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, handcrafts, 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 years (52) 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 mild cognitive impairment (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*

Urinary incontinence (UI) is a common geriatric syndrome that has a significant impact on quality of life 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 is a common geriatric syndrome that negatively impacts both functional abilities and quality of life.(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 study(71) 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 evident (63) 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) analyzed 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.

*Quality of Life and Wellbeing*

Seven studies were identified that examined the relationship between ST and quality of life (QOL) or wellbeing; only one(72) 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 wellbeing.(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 wellbeing,(76) although it is worth noting that those participants had very high ST with an average of more than 11 hours/day of ST. Meneguci 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 minutes of sitting time/day with activity is associated with improved QOL(72) and psychosocial wellbeing.(77)

Dogra and Stathokostas (75) found that sedentary behaviours were more likely to be associated with social wellbeing 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 8 older adults, and had them restrict their TV time to only 0.5 hours/day, for one 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 quality of life 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 moderate to vigorous intensity physical activity (MVPA), although other approaches were used, including examining ST as a mediator(47) or using isotemporal substitution (77). Many studies simply analyzed 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 Sedentary Time**

The evidence summarized 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 organization level policies that tend to inadvertently promote ST.

Of the available intervention studies in older adults, five were randomized 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 organization level. Some studies assessed the impact of their intervention on ST within 1-8 weeks (81, 95-100) while other interventions lasted six 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) and mailed written information.(98) More details on the interventions can be seen in supplemental Table 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 minutes per day (99)in studies using an inclinometer to as much as 120 minutes/day(94) 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 minutes/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 minutes/day.(99) In another study where older adults were specifically told to restrict TV time to 30 minutes/day, TV time decreased from 322 minutes/day to 16 minutes/day.(81) Finally, three studies reported an increase in the number of breaks in

ST(95, 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 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-second 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 quality of life 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 sedentary time 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. RCT studies 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 is important to health outcomes, as some sedentary behaviours, such as reading or use of computers, could benfit 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 quality of life. These categories of impairment better speak to the multi-morbidity 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 organizational 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.

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**SUMMARY BOXES FOR EACH SECTION OF THE REVIEW**

| **Summary Box 1: Measurement of Sedentary Time** |
|---|
| Available self-reported sedentary time measurement tools underestimate total sedentary time. |
| Self-report is needed to provide context to sedentary behaviour; however, self-report of some sedentary behaviours is more accurate than others. |

| **Summary Box 2: Sedentary Time and Geriatric-Relevant Health Outcomes** |
|---|
| ***Physical Function**** <br> Sedentary time is inversely associated with physical function and fall risk. Older women may be particularly susceptible to losses in physical function related to sedentary time. |
| ***Cognitive Function**** <br> Total sedentary time is inversely associated with cognitive function; however, the association depends on the specific type of sedentary behaviour. Some cognitively engaging sedentary behaviours may have benefits, while more passive behaviours may be detrimental to cognitive function. Studies of sedentary time and cognitive function in older adults used inconsistent measures of sedentary time. |
| ***Urinary Incontinence*** <br> There is no evidence of a significant association between sedentary time and urinary incontinence at this time. However, the potential impact of sedentary time on the strength of pelvic floor muscles provides biological plausibility for an association. |
| ***Depressive Symptoms and Overall Mental Health**** <br> There is minimal evidence of a significant association between sedentary time and depression or other mental health outcomes at this time. Studies of sedentary time and mental health in older adults used inconsistent measures of sedentary time. |
| ***Well-Being and Quality of Life**** <br> Sedentary time is inversely associated with quality of life and psychosocial well-being. This association may be stronger in women than in men. |

*These statements are based primarily on cross-sectional evidence.

| **Summary Box 3: Interventions to Reduce Sedentary Time** |
|---|
| Interventions to reduce sedentary time by targeting individual level behaviour change appear to be feasible. Most of the studies to date have been short-term. |
| There is limited evidence on the effectiveness of reducing sedentary time on geriatric-relevant health outcomes. |

| **So What?** |
|---|
| Sedentary time may be associated with physical and cognitive function among older adults, both of which could affect functional autonomy. |
| Short-term reduction in sedentary time is feasible among older adults. |
| *Conclusion:* There is limited evidence of a relationship between prolonged sedentary time and geriatric-relevant health outcomes; the dose of sedentary time associated with clinically relevant risk is not known at this time. More longitudinal research is needed to determine if |

sustained changes in sedentary behaviour among older adults are feasible, and if reducing sedentary time will positively impact mobility, quality of life, and healthy ageing.

## REFERENCES


1. Sedentary Behaviour Research N. Letter to the editor: standardized use of the terms "sedentary" and "sedentary behaviours". Appl Physiol Nutr Metab. 2012;37(3):540-2.
2. Owen N, Healy GN, Matthews CE, Dunstan DW. Too much sitting: the population health science of sedentary behavior. Exerc Sport Sci Rev. 2010;38(3):105-13.
3. Harvey JA, Chastin SF, Skelton DA. Prevalence of sedentary behavior in older adults: a systematic review. Int J Environ Res Public Health. 2013;10(12):6645-61.
4. Copeland JL, Clarke J, Dogra S. Objectively measured and self-reported sedentary time in older Canadians. Prev Med Rep. 2015;2:90-5.
5. Harvey JA, Chastin SF, Skelton DA. How Sedentary are Older People? A Systematic Review of the Amount of Sedentary Behavior. J Aging Phys Act. 2015;23(3):471-87.
6. Colley RC, Garriguet D, Janssen I, Craig CL, Clarke J, Tremblay MS. Physical activity of Canadian adults: Accelerometer results from the 2007 to 2009 Canadian Health Measures Survey. Health Rep. 2011;22(1).
7. Matthews CE, George SM, Moore SC, Bowles HR, Blair A, Park Y, et al. Amount of time spent in sedentary behaviors and cause-specific mortality in US adults. Am J Clin Nutr. 2012;95(2):437-45.
8. Chastin SF, Buck C, Freiberger E, Murphy M, Brug J, Cardon G, et al. Systematic literature review of determinants of sedentary behaviour in older adults: A DEDIPAC study. Int J Behav Nutr Phys Act. 2015;12(133).
9. Dogra S, Ashe M, Biddle S, Brown W, Buman M, Chastin S, Gardiner P, Inoue S, Jeffries B, Oka K, Owen N, Sardinha L, Skelton D, Sugiyama T, Copeland, J.L. . Sedentary time in older men and women: a consensus statement on measurement, health, interventions, and research priorities. Br J Sports Med. 2017.
10. de Rezende LF, Rey-Lopez JP, Matsudo VK, do Carmo Luiz O. Sedentary behavior and health outcomes among older adults: a systematic review. BMC Public Health. 2014;14:333.
11. Keadle SK, Arem H, Moore SC, Sampson JN, Matthews CE. Impact of changes in television viewing time and physical activity on longevity: a prospective cohort study. Int J Behav Nutr Phys Act. 2015;12(1):156.
12. Flacker JM. What is a geriatric syndrome anyway? J Am Geriatr Soc. 2003;51(4):574-6.
13. Inouye SK, Studenski S, Tinetti ME, Kuchel GA. Geriatric syndromes: Clinical, research, and policy implications of a core geriatric concept. J Am Geriatr Soc. 2007;55(5):780-91.
14. Koroukian SM, Schiltz N, Warner DF, Sun JY, Bakaki PM, Smyth KA, et al. Combinations of Chronic Conditions, Functional Limitations, and Geriatric Syndromes that Predict Health Outcomes. J Gen Intern Med. 2016;31(6):630-7.
15. Rockwood K, Mitnitski A. Frailty in relation to the accumulation of deficits. J Gerontol Ser A-Biol Sci Med Sci. 2007;62(7):722-7.

16. Bowling CB, Booth JN, Safford M, Whitson HE, Ritchie C, Wadley VG, et al. Nondisease-Specific Problems and All-Cause Mortality in the REasons for Geographic and Racial Differences in Stroke (REGARDS) Study. J Am Geriatr Soc. 2013;61(5):739-46.
17. Harvey JA, Chastin SFM, Skelton DA. Prevalence of sedentary behavior in older adults: a systematic review. Int J Environ Res Public Health. 2013;10.
18. United Nations DoEaSA, Population Division. World Population Ageing 2015. 2015.
19. Espana-Romero V, Golubic R, Martin KR, Hardy R, Ekelund U, Kuh D, et al. Comparison of the EPIC Physical Activity Questionnaire with combined heart rate and movement sensing in a nationally representative sample of older British adults. PLoS ONE. 2014;9(2):e87085.
20. Van Cauwenberg J, Van Holle V, De Bourdeaudhuij I, Owen N, Deforche B. Older adults' reporting of specific sedentary behaviors: validity and reliability. BMC Public Health. 2014;14:734.
21. Jefferis BJ, Sartini C, Ash S, Lennon LT, Wannamethee SG, Whincup PH. Validity of questionnaire-based assessment of sedentary behaviour and physical activity in a population-based cohort of older men; comparisons with objectively measured physical activity data. Int J Behav Nutr Phys Act. 2016;13:14.
22. Visser M, Koster A. Development of a questionnaire to assess sedentary time in older persons--a comparative study using accelerometry. BMC Geriatr. 2013;13:80.
23. Aguilar-Farias N, Brown WJ, Olds TS, Geeske Peeters GM. Validity of self-report methods for measuring sedentary behaviour in older adults. J Sci Med Sport. 2015;18(6):662-6.
24. Clark BK, Lynch BM, Winkler EA, Gardiner PA, Healy GN, Dunstan DW, et al. Validity of a multi-context sitting questionnaire across demographically diverse population groups: AusDiab3. Int J Behav Nutr Phys Act. 2015;12:148.
25. Gardiner PA, Clark BK, Healy GN, Eakin EG, Winkler EA, Owen N. Measuring older adults' sedentary time: reliability, validity, and responsiveness. Med Sci Sports Exerc. 2011;43(11):2127-33.
26. Gennuso KP, Matthews CE, Colbert LH. Reliability and Validity of 2 Self-Report Measures to Assess Sedentary Behavior in Older Adults. J Phys Act Health. 2015;12(5):727-32.
27. de Carvalho Bastone A, de Souza Moreira B, Alvarenga Vieira R, Noce Kirkwood R, Domingues Dias JM, Corrêa Dias R. Validation of the Human Activity Profile Questionnaire as a measure of physical activity levels in older community-dwelling women. J Aging Phys Act. 2008;22(3):348-56 9p.
28. Sardinha LB, Santos DA, Silva AM, Baptista F, Owen N. Breaking-up sedentary time is associated with physical function in older adults. J Gerontol A Biol Sci Med Sci. 2015;70(1):119-24.
29. Ortlieb S, Dias A, Gorzelniak L, Nowak D, Karrasch S, Peters A, et al. Exploring patterns of accelerometry-assessed physical activity in elderly people. Int J Behav Nutr Phys Act. 2014;11(1):28.
30. Martinho KO, Dantas EH, Longo GZ, Ribeiro AQ, Pereira ET, Franco FS, et al. Comparison of functional autonomy with associated sociodemographic factors, lifestyle, chronic diseases (CD) and neuropsychiatric factors in elderly patients with or without the metabolic syndrome (MS). Arch Gerontol Geriatr. 2013;57(2):151-5.
31. Santos DA, Silva AM, Baptista F, Santos R, Vale S, Mota J, et al. Sedentary behavior and physical activity are independently related to functional fitness in older adults. Exp Gerontol. 2012;47(12):908-12.

32. Davis MG, Fox KR, Stathi A, Trayers T, Thompson JL, Cooper AR. Objectively measured sedentary time and its association with physical function in older adults. J Aging Phys Act. 2014;22(4):474-81.

33. Rosenberg DE, Bellettiere J, Gardiner PA, Villarreal VN, Crist K, Kerr J. 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. 2016;71(1):78-83.

34. Bann D, Hire D, Manini T, Cooper R, Botoseneanu A, McDermott MM, et al. Light Intensity physical activity and sedentary behavior in relation to body mass index and grip strength in older adults: cross-sectional findings from the Lifestyle Interventions and Independence for Elders (LIFE) study. PLoS ONE. 2015;10(2):e0116058.

35. Chastin SF, Ferriolli E, Stephens NA, Fearon KC, Greig C. Relationship between sedentary behaviour, physical activity, muscle quality and body composition in healthy older adults. Age Ageing. 2012;41(1):111-4.

36. Gianoudis J, Bailey CA, Daly RM. Associations between sedentary behaviour and body composition, muscle function and sarcopenia in community-dwelling older adults. Osteoporos Int. 2015;26(2):571-9.

37. Ikezoe T, Asakawa Y, Shima H, Kishibuchi K, Ichihashi N. Daytime physical activity patterns and physical fitness in institutionalized elderly women: an exploratory study. Arch Gerontol Geriatr. 2013;57(2):221-5.

38. Cooper AJ, Simmons RK, Kuh D, Brage S, Cooper R, scientific N, et al. Physical activity, sedentary time and physical capability in early old age: British birth cohort study. PLoS ONE. 2015;10(5):e0126465.

39. Dunlop DD, Song J, Arnston EK, Semanik PA, Lee J, Chang RW, et al. Sedentary time in US older adults associated with disability in activities of daily living independent of physical activity. J Phys Act Health. 2015;12(1):93-101.

40. Gennuso KP, Gangnon RE, Matthews CE, Thraen-Borowski KM, Colbert LH. Sedentary behavior, physical activity, and markers of health in older adults. Med Sci Sports Exerc. 2013;45(8):1493-500.

41. d'Orsi E, Xavier AJ, Ramos LR. Work, social support and leisure protect the elderly from functional loss: EPIDOSO study. Rev Saude Publica. 2011;45(4):685-92.

42. Marques EA, Baptista F, Santos DA, Silva AM, Mota J, Sardinha LB. Risk for losing physical independence in older adults: the role of sedentary time, light, and moderate to vigorous physical activity. Maturitas. 2014;79(1):91-5.

43. Chen T, Narazaki K, Haeuchi Y, Chen S, Honda T, Kumagai S. Associations of Sedentary Time and Breaks in Sedentary Time With Disability in Instrumental Activities of Daily Living in Community-Dwelling Older Adults. J Phys Act Health. 2016;13(3):303-9.

44. Cawthon PM, Blackwell TL, Cauley JA, Ensrud KE, Dam T-T, Harrison SL, et al. Objective Assessment of Activity, Energy Expenditure, and Functional Limitations in Older Men: The Osteoporotic Fractures in Men Study. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 2013;68(12):1518-24.

45. Gomes Gde C, Teixeira-Salmela LF, Fonseca BE, Freitas FA, Fonseca ML, Pacheco BD, et al. Age and education influence the performance of elderly women on the dual-task Timed Up and Go test. Arq Neuropsiquiatr. 2015;73(3):187-93.

46. Jefferis BJ, Merom D, Sartini C, Wannamethee SG, Ash S, Lennon LT, et al. Physical activity and falls in older men: the critical role of mobility limitations. Med Sci Sports Exerc. 2015;47(10):2119-28.
47. Mitchell RJ, Lord SR, Harvey LA, Close JC. Obesity and falls in older people: mediating effects of disease, sedentary behavior, mood, pain and medication use. Arch Gerontol Geriatr. 2015;60(1):52-8.
48. Prince M, Bryce R, Albanese E, Wimo A, Ribeiro W, Ferri CP. The global prevalence of dementia: a systematic review and metaanalysis. Alzheimer's & dementia : the journal of the Alzheimer's Association. 2013;9(1):63-75.e2.
49. Sofi F, Valecchi D, Bacci D, Abbate R, Gensini GF, Casini A, et al. Physical activity and risk of cognitive decline: a meta-analysis of prospective studies. J Intern Med. 2011;269(1):107-17.
50. Wang H-X, Jin Y, Hendrie HC, Liang C, Yang L, Cheng Y, et al. Late life leisure activities and risk of cognitive decline. J Gerontol A Biol Sci Med Sci. 2013;68(2):205-13.
51. Verghese J, Lipton RB, Katz MJ, Hall CB, Derby CA, Kuslansky G, et al. Leisure activities and the risk of dementia in the elderly. N Engl J Med. 2003;348(25):2508-16.
52. Lee S, Yuki A, Nishita Y, Tange C, Kim H, Kozakai R, et al. Relationship between light-intensity physical activity and cognitive function in a community-dwelling elderly population-An 8-year longitudinal study. J Am Geriatr Soc. 2013;61(3):452-3.
53. Kesse-Guyo E, Charreire H, Andreeva VA, Touvier M, Hercberg S, Galan P, et al. Cross-sectional and longitudinal associations of different sedentary behaviors with cognitive performance in older adults. PLoS ONE. 2012;7(10):e47831.
54. Blasko I, Jungwirth S, Kemmler G, Weissgram S, Tragl KH, Fischer P. Leisure time activities and cognitive functioning in middle European population-based study. Eur Geriatr Med. 2014;5(3):200-7.
55. Arnardottir NY, Koster A, Domelen DR, Brychta RJ, Caserotti P, Eiriksdottir G, et al. Association of change in brain structure to objectively measured physical activity and sedentary behavior in older adults: Age, Gene/Environment Susceptibility-Reykjavik Study. Behav Brain Res. 2016;296:118-24.
56. Kaup AR, Nettiksimmons J, Harris TB, Sink KM, Satterfield S, Metti AL, et al. Cognitive resilience to apolipoprotein E epsilon4: contributing factors in black and white older adults. JAMA Neurol. 2015;72(3):340-8.
57. Zhao X, Yuan L, Feng L, Xi Y, Yu H, Ma W, et al. Association of dietary intake and lifestyle pattern with mild cognitive impairment in the elderly. J Nutr Health Aging. 2015;19(2):164-8.
58. Heisz JJ, Vandermorris S, Wu J, McIntosh AR, Ryan JD. Age differences in the association of physical activity, sociocognitive engagement, and TV viewing on face memory. Health Psychol. 2015;34(1):83-8.
59. Hamer M, Stamatakis E. Prospective study of sedentary behavior, risk of depression, and cognitive impairment. Med Sci Sports Exerc. 2014;46(4):718-23.
60. Nadel JL, Ulate D. Incidence and risk factors for cognitive impairment in rural elderly populations in Costa Rica. Rev Biol Trop. 2014;62(3):869-76.
61. Vance DE, Wadley VG, Ball KK, Roenker DL, Rizzo M. The effects of physical activity and sedentary behavior on cognitive health in older adults. J Aging Phys Act. 2005;13(3):294-313.

62. Steinberg SI, Sammel MD, Harel BT, Schembri A, Policastro C, Bogner HR, et al. Exercise, sedentary pastimes, and cognitive performance in healthy older adults. Am J Alzheimers Dis Other Demen. 2015;30(3):290-8.
63. Da Ronch C, Canuto A, Volkert J, Massarenti S, Weber K, Dehoust M, et al. Association of television viewing with mental health and mild cognitive impairment in the elderly in three European countries, data from the MentDis_ICF65+ project. Ment Health Phys Act. 2015;8:8-14.
64. Hayes SM, Alosco ML, Hayes JP, Cadden M, Peterson KM, Allsup K, et al. Physical Activity Is Positively Associated with Episodic Memory in Aging. J Int Neuropsychol Soc. 2015;21(10):780-90.
65. Burzynska AZ, Wong CN, Voss MW, Cooke GE, Gothe NP, Fanning J, et al. Physical activity is linked to greater moment-to-moment variability in spontaneous brain activity in older adults. PLoS ONE. 2015;10(8):e0134819.
66. Burzynska AZ, Chaddock-Heyman L, Voss MW, Wong CN, Gothe NP, Olson EA, et al. Physical activity and cardiorespiratory fitness are beneficial for white matter in low-fit older adults. PLoS ONE. 2014;9(9):e107413.
67. Landry GJ, Liu-Ambrose T. Buying time: a rationale for examining the use of circadian rhythm and sleep interventions to delay progression of mild cognitive impairment to Alzheimer’s disease. Front Aging Neurosci. 2014;6:325.
68. Moreno-Vecino B, Arija-Blazquez A, Pedrero-Chamizo R, Alcazar J, Gomez-Cabello A, Perez-Lopez FR, et al. Associations between obesity, physical fitness, and urinary incontinence in non-institutionalized postmenopausal women: The elderly EXERNET multi-center study. Maturitas. 2015;82(2):208-14.
69. Kikuchi H, Inoue S, Sugiyama T, Owen N, Oka K, Nakaya T, et al. Distinct associations of different sedentary behaviors with health-related attributes among older adults. Prev Med. 2014;67:335-9.
70. Gautam R, Saito T, Kai I. Leisure and religious activity participation and mental health: gender analysis of older adults in Nepal. BMC Public Health. 2007;7:299.
71. Wassink-Vossen S, Noorthoorn EO, Collard RM, Comijs HC, Oude Voshaar RC, Naarding P. Value of Physical Activity and Sedentary Behavior in Predicting Depression in Older Adults. J Am Geriatr Soc. 2016;64(3):647-9.
72. Balboa-Castillo T, Leon-Munoz LM, Graciani A, Rodriguez-Artalejo F, Guallar-Castillon P. Longitudinal association of physical activity and sedentary behavior during leisure time with health-related quality of life in community-dwelling older adults. Health Qual Life Outcomes. 2011;9:47.
73. Meneguci J, Sasaki JE, da Silva Santos A, Scatena LM, Damiao R. Socio-demographic, clinical and health behavior correlates of sitting time in older adults. BMC Public Health. 2015;15:65.
74. O'Neil C, Dogra S. Different Types of Sedentary Activities and Their Association With Perceived Health and Wellness Among Middle-Aged and Older Adults: A Cross-Sectional Analysis. Am J Health Promot. 2015.
75. Dogra S, Stathokostas L. Sedentary behavior and physical activity are independent predictors of successful aging in middle-aged and older adults. J Aging Res. 2012;2012:190654.
76. Withall J, Stathi A, Davis M, Coulson J, Thompson JL, Fox KR. Objective indicators of physical activity and sedentary time and associations with subjective well-being in adults aged 70 and over. Int J Environ Res Public Health. 2014;11(1):643-56.

77. Buman MP, Hekler EB, Haskell WL, Pruitt L, Conway TL, Cain KL, et al. Objective light-intensity physical activity associations with rated health in older adults. Am J Epidemiol. 2010;172(10):1155-65.
78. Vaz Fragoso CA, Gill TM. Sleep complaints in community-living older persons: a multifactorial geriatric syndrome. J Am Geriatr Soc. 2007;55(11):1853-66.
79. Madden KM, Ashe MC, Lockhart C, Chase JM. Sedentary behavior and sleep efficiency in active community-dwelling older adults. Sleep Sci. 2014;7(2):82-8.
80. Vaz Fragoso CA, Miller ME, Fielding RA, King AC, Kritchevsky SB, McDermott MM, et al. Sleep-wake disturbances in sedentary community-dwelling elderly adults with functional limitations. J Am Geriatr Soc. 2014;62(6):1064-72.
81. Asaoka S, Fukuda K, Tsutsui Y, Yamazaki K. Does television viewing cause delayed and/or irregular sleep-wake patterns? Sleep Biol Rhythms. 2007;5(1):23-7.
82. Bankoski A, Harris TB, McClain JJ, Brychta RJ, Caserotti P, Chen KY, et al. Sedentary activity associated with metabolic syndrome independent of physical activity. Diabetes Care. 2011;34(2):497-503.
83. Manns P, Ezeugwu V, Armijo-Olivo S, Vallance J, Healy GN. Accelerometer-Derived Pattern of Sedentary and Physical Activity Time in Persons with Mobility Disability: National Health and Nutrition Examination Survey 2003 to 2006. J Am Geriatr Soc. 2015;63(7):1314-23.
84. Maher C, Olds T, Mire E, Katzmarzyk PT. Reconsidering the sedentary behaviour paradigm. PLoS ONE. 2014;9(1):e86403.
85. Page A, Peeters G, Merom D. Adjustment for physical activity in studies of sedentary behaviour. Emerging Themes in Epidemiology. 2015;12(1):10.
86. Pavey TG, Peeters GG, Brown WJ. Sitting-time and 9-year all-cause mortality in older women. Br J Sports Med. 2015;49(2):95-9.
87. Chastin SFM, Palarea-Albaladejo J, Dontje ML, Skelton DA. Combined Effects of Time Spent in Physical Activity, Sedentary Behaviors and Sleep on Obesity and Cardio-Metabolic Health Markers: A Novel Compositional Data Analysis Approach. PLoS ONE. 2015;10(10):e0139984.
88. Pedišić Z. Measurement issues and poor adjustments for physical activity and sleep undermine sedentary behaviour research—the focus should shift to the balance between sleep, sedentary behaviour, standing and activity. Kinesiology. 2014;46:11.
89. Fanning J, Porter G, Awick EA, Wojcicki TR, Gothe NP, Roberts SA, et al. Effects of a DVD-delivered exercise program on patterns of sedentary behavior in older adults: a randomized controlled trial. Prev Med Rep. 2016;3:238-43.
90. Sjogren P, Fisher R, Kallings L, Svenson U, Roos G, Hellenius ML. Stand up for health--avoiding sedentary behaviour might lengthen your telomeres: secondary outcomes from a physical activity RCT in older people. Br J Sports Med. 2014;48(19):1407-9.
91. Burke L, Lee AH, Jancey J, Xiang L, Kerr DA, Howat PA, et al. Physical activity and nutrition behavioural outcomes of a home-based intervention program for seniors: a randomized controlled trial. Int J Behav Nutr Phys Act. 2013;10:14.
92. Barone Gibbs B, Brach JS, Byard T, Creasy S, Davis KK, McCoy S, et al. Reducing Sedentary Behavior Versus Increasing Moderate-to-Vigorous Intensity Physical Activity in Older Adults: A 12-Week Randomized, Clinical Trial. J Aging Health. 2016.
93. Lee RE, King AC. Discretionary time among older adults: how do physical activity promotion interventions affect sedentary and active behaviors? Ann Behav Med. 2003;25(2):112-9.

94. Kallings LV, Sierra Johnson J, Fisher RM, Faire U, Stahle A, Hemmingsson E, et al. Beneficial effects of individualized physical activity on prescription on body composition and cardiometabolic risk factors: results from a randomized controlled trial. Eur J Cardiovasc Prev Rehabil. 2009;16(1):80-4.
95. Gardiner PA, Eakin EG, Healy GN, Owen N. Feasibility of reducing older adults' sedentary time. Am J Prev Med. 2011;41(2):174-7.
96. Rosenberg DE, Gell NM, Jones SM, Renz A, Kerr J, Gardiner PA, et al. The Feasibility of Reducing Sitting Time in Overweight and Obese Older Adults. Health Educ Behav. 2015;42(5):669-76.
97. Fitzsimons CF, Kirk A, Baker G, Michie F, Kane C, Mutrie N. Using an individualised consultation and activPALTM feedback to reduce sedentary time in older Scottish adults: results of a feasibility and pilot study. Prev Med. 2013;57(5):718-20.
98. Matei R, Thune-Boyle I, Hamer M, Iliffe S, Fox KR, Jefferis BJ, et al. Acceptability of a theory-based sedentary behaviour reduction intervention for older adults ('On Your Feet to Earn Your Seat'). BMC Public Health. 2015;15:606.
99. Lewis LK, Rowlands AV, Gardiner PA, Standage M, English C, Olds T. Small Steps: Preliminary effectiveness and feasibility of an incremental goal-setting intervention to reduce sitting time in older adults. Maturitas. 2016;85:64-70.
100. Chang AK, Fritschi C, Kim MJ. Sedentary behavior, physical activity, and psychological health of Korean older adults with hypertension: effect of an empowerment intervention. Res Gerontol Nurs. 2013;6(2):81-8.
101. Prince SA, Saunders TJ, Gresty K, Reid RD. A comparison of the effectiveness of physical activity and sedentary behaviour interventions in reducing sedentary time in adults: a systematic review and meta-analysis of controlled trials. Obes Rev. 2014;15(11):905-19.