Linear and non-linear associations of device-measured sedentary time with older adults’ skeletal muscle mass

Ai Shibata a,b,*, Kaori Ishii b, Mohammad Javad Koohsari b, Takemi Sugiyama c,d, David W. Dunstan d,e, Neville Owen f,g, Koichiro Oka b

a Faculty Health and Sport Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8575, Japan
b Faculty of Sport Sciences, Waseda University, 2-579-15 Mikajima, Tokorozawa, Saitama 359-1192, Japan
c Centre for Urban Transitions, Swinburne University of Technology, John Street, Hawthorn, Victoria 3122, Australia
d Baker Heart & Diabetes Institute, 75 Commercial Road, Melbourne, Victoria 3004, Australia
e Faculty of Sport Sciences, Waseda University, 2-579-15 Mikajima, Tokorozawa, Saitama 359-1192, Japan
f Mary MacKillop Institute for Health Research, Australian Catholic University, 215 Spring Street, Melbourne, Victoria 3000, Australia
g Faculty of Sport Sciences, Waseda University, 2-579-15 Mikajima, Tokorozawa, Saitama 359-1192, Japan

* Corresponding author at: 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8575, Japan.
E-mail addresses: shibata.ai.ga@u.tsukuba.ac.jp (A. Shibata), ishikoa@waseda.jp (K. Ishii), javadkoohsari@aoni.waseda.jp (M.J. Koohsari), tsugiyama@swin.edu.au (T. Sugiyama), David.Dunstan@baker.edu.au (D.W. Dunstan), Neville.Owen@baker.edu.au (N. Owen), koka@waseda.jp (K. Oka).

https://doi.org/10.1016/j.exger.2022.111870
Received 30 March 2022; Received in revised form 24 May 2022; Accepted 10 June 2022
Available online 15 June 2022

Objectives: To examine the linear and non-linear associations of device-measured sedentary time with appendicular skeletal muscle mass (ASM) in older Japanese adults.

Methods: Participants (n = 281, 74.3 ± 5.2 yr) wore a tri-axial accelerometer for seven days. Body mass index-adjusted ASM (kg/BMI) was derived from bioimpedance measures. Multivariate linear and quadratic regression models examined the associations of ASM with total sedentary time, stratified by sex. Restricted cubic spline models were fitted to estimate non-linear associations. Isotemporal substitution (IS) models were used to estimate the impacts of replacing 30-minute of sedentary time with light physical activity (LPA) and moderate-to-vigorous physical activity (MVPA).

Results: After adjustment, total sedentary time had a significant linear and negative association with ASM among community-dwelling older Japanese males and females. For males, only very high volumes of sedentary time appeared to be detrimental. These adverse relationships may in part be offset by more time spent in either LPA or MVPA.

Conclusions: In older Japanese adults, higher volumes of time spent sedentary were associated with lower ASM. For males, only very high volumes of sedentary time appeared to be detrimental. These adverse relationships may in part be offset by more time spent in either LPA or MVPA.

1. Introduction

In older adults, age-related loss of skeletal muscle mass has been reported to have deleterious associations with functional and health outcomes, including a decline in muscle strength (Goodpaster et al., 2006), frailty (Hirani et al., 2017), disability (Tyrerolas et al., 2015), loss of activities of daily living (Wang et al., 2020), and mortality (Srikanthan and Karlamangla, 2014). Also, such muscle atrophy is a key component of sarcopenia, the progressive and generalized loss of skeletal muscle mass and strength (Cruz-Jentoft et al., 2014). Sarcopenia is a highly prevalent geriatric syndrome worldwide (Cruz-Jentoft et al., 2014). For example, a Japanese cross-sectional study reported a 22% prevalence of sarcopenia among community-dwelling older adults (Yamada et al., 2013). Sarcopenia contributes to increasing numerous health risks and health care costs (Cruz-Jentoft et al., 2019). In light of rapidly growing ageing populations in many countries, it is a global public health priority to prevent loss of skeletal muscle mass and the development of sarcopenia.

Older adults tend to spend a higher proportion of their waking hours in sedentary behaviors (Healy et al., 2011). Extensive epidemiological
evidence shows that sedentary behavior is adversely associated with multiple health outcomes such as all-cause and cardiovascular mortality, the incidence of type 2 diabetes and cancer, including in older adult populations (Patterson et al., 2018; de Rezende et al., 2014a). The associations of sedentary behavior with physical function and/or muscle strength have also been explored in a small but growing number of cross-sectional studies, with deleterious associations reported (Copeland et al., 2017). However, evidence on sedentary behavior and skeletal muscle mass is limited and mixed. Total sedentary time has been reported to have a negative association with absolute total and percent lean tissue mass in older adults (Gianoudis et al., 2014; Reid et al., 2018). However, findings on appendicular skeletal muscle mass (ASM), which is a diagnostic index of sarcopenia (Cruz-Jentoft et al., 2019; Cruz-Jentoft and Sayer, 2019) and a better proxy measure of whole-body skeletal muscle mass (Walowski et al., 2020), have been inconsistent (Gianoudis et al., 2014; Reid et al., 2018; Foong et al., 2016), possibly due to differences in standardization of the ASM measures used, or the stratifications employed.

Most studies on sedentary behavior and health outcomes have focused on examination of linear relationships. However, recent evidence on associations of sedentary behavior with mortality suggests that they can be related in a non-linear manner (Matthews et al., 2016). Examining the shape of the association and whether there is an inflection in the slope of the relationship is relevant to better understand the nature of relationships and to identify a threshold that might be useful to inform future prevention initiatives. It is also possible that previous studies focusing on linear associations may have reported non-significant results due to the presence of non-linear, but meaningful relationships. However, no previous study has examined the shape of the relationship of sedentary behavior with skeletal muscle mass. Little is also known to what extent replacing time spent sedentary with physical activity can be beneficial for musculoskeletal health; such evidence would be valuable for informing public health guidelines and programs (Grgic et al., 2018).

Thus, we first examined linear and non-linear associations of total sedentary time with skeletal muscle mass among community-dwelling older Japanese adults. Thereafter, we used an isotemporal substitution (IS) approach to examine whether replacing sedentary behavior with light-intensity or moderate-to-vigorous intensity physical activity (LPA; MVPA) is associated with skeletal muscle mass.

2. Methods

2.1. Participants

The present study was conducted in 2013 in Matsudo, a suburban city east of Tokyo (population: approx. 0.5 million). Of the 107,928 community-dwelling older adults aged 65–84 years living in this city (as of April 2013), 3000 were randomly selected from the registry of residential addresses, stratified by sex and age (65–74 years, 75–84 years). Details of this data collection process have been published elsewhere (Shibata et al., 2019). Briefly, the postal surveys were mailed to 3000 potential participants. The response rate for the survey was 42% (n = 1250). Those who agreed to take part in additional data collection of this study (n = 951) were invited to participate in on-site examinations via postal mail. At the testing site, participants’ height and body composition were measured. They were also asked to wear an accelerometer except when sleeping or during water-based activities (i.e., bathing, showering, and swimming) for at least seven consecutive days. They also recorded their daily life activities (i.e. waking time, bedtime, and exercising time) during the seven-day period to confirm the date and time of their accelerometer wear.

The analytical sample of this study consisted of those who completed the postal survey and the on-site examinations (n = 330). After excluding those who had insufficient accelerometer data (n = 30) and missing data for relevant variables (n = 25) (numbers not mutually exclusive), the final sample size was 281. Written informed consent was obtained from all participants. The study was approved by the Waseda University Ethics Committee (2013-265).

2.2. Measures

2.2.1. Objectively measured sedentary behavior and moderate-to-vigorous intensity of physical activity

Participants were asked to wear a tri-axial accelerometer (Active style Pro HJA 350-IT, Omron Healthcare Co. Ltd., Kyoto, Japan) on their left hip during waking hours for at least seven consecutive days. Data were recorded in one-minute epochs. Non-wear time was defined as intervals of at least 60 consecutive minutes of no activity, which was estimated to be 0.9 or less metabolic equivalents (METs) based on a validity study (Ohkawara et al., 2011), with allowance for up to two minutes of some limited movement (≤1.0 METs). Days with at least 10 h of wear time were considered valid. Participants with at least four valid days, including at least one weekend day, were included in the analyses. Total sedentary time, LPA, and MVPA time were defined as all wear time for any activity with an estimated intensity of ≤1.5 METs, >1.5 to <3.0 METs, and 3.0 or more METs, respectively. MET values were determined by the built-in algorithms of the accelerometer. They have been reported to be closely correlated with METs calculated by the indirect calorimetry (Ohkawara et al., 2011). Mean weekday and weekend values for total sedentary, LPA, and MVPA time were first calculated on each valid weekday and weekend day. Then, the mean daily total value was computed by weighting five times for weekdays and two times for weekend days for each behavior.

2.2.2. Body composition

Skeletal muscle mass measures including total lean tissue mass (kg), percentage of lean tissue mass (%), and ASM (kg/BMI) and percentage body fat (%) were estimated using multi-frequency bioelectrical impedance analyzer (BIA; MC-980A, TANITA, Tokyo, Japan). This BIA instrument used six electrical frequencies (1, 5, 50, 250, 500, and 1000 kHz) and eight-point tactile electrodes with four in contact with the palm and thumb of both hands and the other four in contact with the anterior and posterior aspects of the sole of both feet. The accuracy of this whole-body BIA on estimating ASM has been validated against dual X-ray absorptiometry in the previous study (Heysmfield et al., 2015). The participants were asked to arrive at the measurement site with hydrated and rested state. Then, they were asked to stand barefoot on the analyzer platform and grasp the two handgrips. The analyzer was operated by trained staff and completed within 30 s. Data provided included weight, BMI, total and regional (arm, leg, trunk) lean tissue mass (kg), fat mass (kg), percentages of body fat (%) and total lean tissue mass (%). All skeletal muscle mass measures were estimated using the manufacturer’s algorithm. Height was objectively measured and entered into the device prior to body composition assessment. ASM was calculated using the sum of arm and leg lean tissue mass. In this study, ASM (kg/BMI) was utilized as a skeletal muscle mass index because previous studies have reported that standardization by BMI may be more appropriate for discriminating clinically-related weakness and for predicting future mortality or disability than is the use of a measure of height (Hirani et al., 2017; Cawthon et al., 2014; Otsuka et al., 2018). The height-adjusted ASM, where skeletal muscle mass was divided by squared height (kg/m²), was also examined as an alternative outcome, since this is another common and widely used measure (Chen et al., 2020; Cruz-Jentoft et al., 2019).

2.2.3. Covariates

The postal survey asked participants to report sex, age, educational attainment (university or further education; high school or less), marital status (married; single), living status (living alone; living others), employment status (employed; not employed), current smoking status, and the presence of chronic conditions (stroke, cardiovascular diseases,
diabetes, dyslipidemia, hyperuricemia, peripheral vascular disease, osteoporosis, knee osteoarthritis, hip osteoarthritis, spondylosis, spinal canal stenosis, rheumatoid arthritis, collagenases, cancer). The total number of chronic conditions was used as a covariate.

2.3. Statistical analyses

Descriptive statistics (mean, standard deviation [SD]) were computed for all body composition variables, accelerometer-related variables, sociodemographic covariates in total and by sex. Multivariate linear (\(y = a + b_1 x + b_2 x^2\)) and quadratic (curvilinear) regression models (\(y = a + b_1 x + b_2 x^2 + b_3 x^3\)) were then utilized to examine the linear and non-linear associations between each skeletal muscle mass measure (total lean tissue mass, percentage of lean tissue mass, ASM) and total sedentary time for each sex. All models were adjusted for age, marital status, educational status, living status, working status, number of chronic diseases, current smoking, accelerometer-wearing time, and MVPA time. If a significant quadratic association was found between ASM and total sedentary time, restricted cubic spline models were fitted to describe the shape of the dose-response curves of total sedentary time with ASM. Knots corresponding to the 10th, 50th, and 90th percentiles of total sedentary time were utilized, given the distribution of the ASM values (Harrell, 2015).

If a significant linear association was found between ASM and total sedentary time, further three multiple linear regression models were fitted: a single-activity model, partition model, and IS models. The single-activity model assessed each activity component separately, only adjusting for accelerometer-wearing time and all covariates. The partition model examined all behaviors (sedentary behavior, LPA, MVPA) simultaneously, without adjusting for accelerometer-wearing time. The IS model was applied to estimate the “substitutional association” by statistically reallocating time from target behavior to an equal duration of another behavior with the outcome variable. This was accomplished by omitting the target behavior from the model and entering accelerometer-wearing time in the model. In this study, the effect of replacing a 30-minute of sedentary behavior with the same amount of LPA or MVPA with ASM was examined. Analyses were conducted with Stata 15.0 (Stata Corp, College Station, Texas, USA) and the level of statistical significance was set at \(p < 0.05\).

3. Results

3.1. Descriptive characteristics of the sample

Table 1 and Supplementary Table 1 show the characteristics of the study sample including sociodemographic attributes, accelerometer-based sedentary behavior and physical activity, and body composition. They had a mean age of 74.4 (SD: 5.2) years, with three-fifths of them being male (61.5 %). The proportion of those who completed a tertiary or higher education was 40 %. More than four-fifths were married and lived with others. More than 70 % were not employed. Current smokers accounted for 7 % of all participants. The mean number of chronic diseases present was 1.2. Males were significantly older and more likely to be highly educated, married, and be current smokers than females.

Participants wore the accelerometer on average for 15.0 h/d, over a mean of 7.2 valid wearings days. Overall, they spent a mean of 8.8 h/d sedentary. The mean of total MVPA time was 49.6 min/d. Males had significantly less accelerometer-wearing time and wear days but longer sedentary time per day than females. There was no significant difference in total MVPA between males and females. For skeletal muscle measures, males had significantly higher total lean tissue mass, percentage of lean tissue mass and ASM than females.

3.2. Associations between skeletal muscle mass measures and sedentary behavior

The results for linear and quadratic associations of total sedentary time with the skeletal muscle mass measures in males and females are presented in Table 2. The total lean mass was not associated with sedentary time in males and females. In the linear models, total sedentary time was significantly negatively associated with percentage lean tissue mass (%) in both males and females. A negative association between total sedentary time and ASM was only observed in females \((p = 0.023)\). In the quadratic models, a significant quadratic trend \((p = 0.020)\) for the association of total sedentary time with ASM was observed among males. For them, spline models indicated a reverse U-shaped association of total sedentary time with ASM \((p < 0.001, \text{Fig. 1})\) with the peak point at total sedentary time per day of 8.8–9.3 h. The results for the height-adjusted ASM (kg/m²) are shown in Table 2.

### Table 1

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total N = 281</th>
<th>Males n = 173</th>
<th>Females n = 108</th>
<th>p*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr), mean (SD)</td>
<td>74.4 (5.2)</td>
<td>75.1 (5.4)</td>
<td>73.3 (4.8)</td>
<td>0.005</td>
</tr>
<tr>
<td>Educational attainment (≥ university), n (%)</td>
<td>108 (38.4)</td>
<td>82 (47.4)</td>
<td>26 (24.1)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Marital status (married), n (%)</td>
<td>234 (83.3)</td>
<td>153 (88.4)</td>
<td>81 (75.0)</td>
<td>0.003</td>
</tr>
<tr>
<td>Living status (with others), n (%)</td>
<td>249 (88.6)</td>
<td>157 (90.8)</td>
<td>92 (85.2)</td>
<td>0.153</td>
</tr>
<tr>
<td>Current employment status (not employed), n (%)</td>
<td>206 (73.3)</td>
<td>122 (70.5)</td>
<td>84 (77.8)</td>
<td>0.181</td>
</tr>
<tr>
<td>Current smoking, n (%)</td>
<td>20 (7.1)</td>
<td>19 (11.0)</td>
<td>1 (0.9)</td>
<td>0.001</td>
</tr>
<tr>
<td>Number of chronic diseases, mean (SD)</td>
<td>1.3 (1.2)</td>
<td>1.3 (1.2)</td>
<td>1.4 (1.1)</td>
<td>0.085</td>
</tr>
<tr>
<td>Accelerometer-based SB and PA, mean (SD)</td>
<td>15.0 (1.5)</td>
<td>14.9 (1.6)</td>
<td>15.4 (1.0)</td>
<td>0.004</td>
</tr>
<tr>
<td>Total accelerometer wearing time (h/d)</td>
<td>7.2 (0.9)</td>
<td>7.1 (1.0)</td>
<td>7.3 (0.7)</td>
<td>0.000</td>
</tr>
<tr>
<td>Total sedentary time (h/d)</td>
<td>8.9 (1.4)</td>
<td>9.2 (1.9)</td>
<td>8.1 (1.6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total LPA time (h/d)</td>
<td>5.5 (1.7)</td>
<td>4.8 (1.5)</td>
<td>6.5 (1.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total MVPA time (min/d)</td>
<td>49.6 (32.4)</td>
<td>50.1 (35.5)</td>
<td>48.9 (27.0)</td>
<td>0.762</td>
</tr>
<tr>
<td>Body composition, mean (SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.4 (3.2)</td>
<td>23.6 (3.0)</td>
<td>23.1 (3.4)</td>
<td>0.173</td>
</tr>
<tr>
<td>Percentage body fat (%)</td>
<td>26.6 (7.5)</td>
<td>23.3 (5.7)</td>
<td>32.0 (7.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total lean tissue mass (kg)</td>
<td>41.3 (7.5)</td>
<td>46.2 (4.9)</td>
<td>33.5 (2.7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Percentage lean tissue mass (%)</td>
<td>69.5 (7.2)</td>
<td>72.7 (5.4)</td>
<td>64.3 (6.7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ASM (kg/m²)</td>
<td>7.32 (1.00)</td>
<td>8.01 (0.55)</td>
<td>6.22 (0.39)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ASM (kg/BMI)</td>
<td>0.78 (0.15)</td>
<td>0.88 (0.09)</td>
<td>0.62 (0.08)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

ASM = appendicular skeletal muscle mass; BMI = body mass index; LPA = light intensity of physical activity; MVPA = moderate-to vigorous intensity of physical activity; SB = sedentary behavior; SD = standard deviation.

Data are presented as mean (SD) for continuous data and as n (%) for categorical data.

* Statistical significance of sex differences.
Non-linear manner in males. It was found that the gradient of ASM was among both older males and females. Furthermore, longer total sedentary time was associated adversely with ASM linearly in females but in a non-linear or quadratic models. Replacing SB with LPA was significantly and favorably associated with ASM in the IS model.

### 4. Discussion

We examined linear and non-linear associations of total sedentary time with skeletal muscle mass measures.

<table>
<thead>
<tr>
<th>β</th>
<th>95%CI</th>
<th>p for linear</th>
<th>p for quadratic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>Total lean mass (kg)</td>
<td>0.264</td>
<td>−0.263</td>
</tr>
<tr>
<td>Percentage lean tissue mass (%)</td>
<td>−0.807</td>
<td>−1.347</td>
<td>−0.267</td>
</tr>
<tr>
<td>ASM (kg/BMI)</td>
<td>−0.001</td>
<td>−0.010</td>
<td>0.008</td>
</tr>
<tr>
<td>Females</td>
<td>Total lean mass (kg)</td>
<td>0.312</td>
<td>−0.116</td>
</tr>
<tr>
<td>Percentage lean tissue mass (%)</td>
<td>−1.663</td>
<td>−2.674</td>
<td>−0.652</td>
</tr>
<tr>
<td>ASM (kg/BMI)</td>
<td>−0.014</td>
<td>−0.025</td>
<td>−0.002</td>
</tr>
</tbody>
</table>

ASM: appendicular skeletal muscle mass; BMI = body mass index; CI = confidence interval.

β (unadjusted coefficient) corresponds to a 1 h/d increment of sedentary time. All models adjusted for age, marital status, educational status, living status, working status, presence of chronic diseases, current smoking, accelerometer-wearing time, and moderate-to vigorous-intensity physical activity.

Supplementary Table 2. No significant associations were observed in the linear or quadratic models.

Based on the findings from the linear models, the IS model was applied only for females (Table 3). Replacing SB with LPA was significantly and favorably associated with ASM (β = −0.007; p = 0.022). On the other hand, the substitution of SB with MVPA was not significantly associated with ASM in the IS model.

Our findings on the association of total sedentary time with total lean tissue mass percentage are consistent with those of two previous Australian studies that did not stratify by sex (Reid et al., 2018; Foong et al., 2016). Advancing age is accompanied by significant alterations in body composition, with declining lean tissue mass and increase in fat mass, even in those who are relatively stable in weight and healthy (Makizako et al., 2017). Thus, the evidence implies that longer time spent in sedentary behavior may accelerate such age-related alterations in body composition in both females and males. Fat and muscle mass can be interconnected via several pathways (Kim et al., 2014; Buch et al., 2016). For example, a decline in a basal metabolic rate by a loss of muscle mass may increase the risk of obesity and various metabolic disorders. Meanwhile, chronic subclinical inflammation induced by increased adiposity may contribute to the impairment of muscle mass and quality. A growing body of evidence has also revealed that longer sedentary time can be associated adversely with adiposity among older adults (de Rezende et al., 2014b). Considering such a deleterious interaction of muscle mass loss and fat mass accumulation, there is likely to be considerable health benefits from population-based strategies to reduce sedentary behaviors among older adults.

Appendicular skeletal muscle mass is the most common proxy measure of whole-body skeletal muscle mass in the diagnosis of sarcopenia, and various methods of adjustment with height or BMI have been applied (Cruz-Jentoft et al., 2019). Previously, only a small number of studies have examined the associations of sedentary behavior with ASM (Gianoudis et al., 2014; Reid et al., 2018; Foong et al., 2016). The present findings are inconsistent with previous studies in older adults, which found no significant associations with either height- or BMI-adjusted ASM for the whole sample without sex stratification. One possible explanation for this inconsistency may be related to sex differences in muscle pathology. During periods of sedentary behavior, skeletal muscle activity, especially in lower limbs, is greatly reduced, which could eventually lead to disuse atrophy. A previous study...
reported that mechanical stimulation by physical activity and resistance training can enhance protein synthesis and skeletal muscle hypertrophy (Boppart and Mahmassani, 2019). Longer time spent in sedentary behavior without such mechanical stimulation may cause reduced skeletal muscle mass and atrophy. The findings from a recent review suggest that females may be more susceptible to disuse atrophy relative to males (Rosa-Caldwell and Greene, 2019). This may imply that females’ skeletal muscle mass could be more vulnerable to the detrimental impacts of sedentary behavior than males, even though the amount of time spent in sedentary behavior may be the same. On the other hand, muscle protein synthesis response to anabolic stimuli such as resistance exercise and dietary intake has been shown to be equivalent in females and males (Rosa-Caldwell and Greene, 2019; Smith et al., 2009). Age-related sex differences in muscle loss and weight loss (Makizako et al., 2017) due to sex-hormone changes (particularly in testosterone and estrogens) may partly contribute to the muscle-atrophy response to sedentary behavior, but the detailed mechanisms remain unclear. Thus, further evidence from prospective studies would be needed to better characterize the sex difference in the shape of the associations between sedentary behavior and ASM.

We observed that longer sedentary time was associated with greater ASM in males for daily sedentary time less than nine hours. Reasons or mechanisms for this unexpected relationship are unknown. However, the definition of non-wear time on the accelerometer in this study might differ from the accelerometer algorithms validated in this study. While the new WHO 2020 guidelines on physical activity and sedentary behavior removed the requirement of bouts of at least 10 min of physical activity to be counted toward the recommended levels (Bull et al., 2020), little is known whether short bouts of physical activity are related to skeletal muscle health (Jakicic et al., 2019). We found that MVPA was intermitted and accounted for only a small portion of time (approximately 5%) in a day, which may be insufficient to provide benefits for skeletal muscle mass maintenance or improvement, especially in older Japanese females. Also, the accelerometer algorithm has been validated with younger adults (Ohkawara et al., 2011), which may be another possible reason for this unexpected result. Such algorithms may underestimate older adults’ MVPA levels due to their lower resting metabolic rates (Barnett et al., 2016). Future studies ideally should use age-specific accelerometer algorithms to be more precise in examining the association between MVPA and skeletal muscle mass in older females.

Some limitations need to be considered in interpreting the present findings. First, the study design was cross-sectional, thereby precluding any determination of cause and effect. Longitudinal studies examining the contribution of sitting time to skeletal muscle loss are warranted. Further, the final sample size was reduced to <300. Even though a relatively large sample was initially recruited using random sampling, the reduced sample size may have resulted in potential selection bias. The present study utilized multi-frequency BIA to estimate muscle mass, which may be less accurate than other instruments, such as dual-energy X-ray absorptiometry, although BIA is inexpensive, easy to use, portable, and causing no radiation exposure. Furthermore, this study did not adjust for nutritional status such as protein and energy intake. Since it is
Possible that active and health-conscious older adults consume more healthy nutrients than sedentary ones (Hsueh et al., 2019), the consumption of protein may be a confounder involved in the associations observed. Another potential confounder not measured in the study was the amount of resistance exercise, which is known to influence muscle mass. Additionally, this study did not consider increased albuminuria and declined glomerular filtration rate, which have been reported to be associated with loss of muscle mass in those with more serious chronic kidney disease and type II diabetes (Chung et al., 2018; Zhou et al., 2018). Since they can be caused by prolonged sedentary behavior (Hannan et al., 2021), they may serve as potential pathways through which sedentary time can influence skeletal muscle mass. Understanding such biological mechanisms in future research can help reduce the possibility of reverse causality.

5. Conclusion

Building on existing studies that found detrimental associations of sedentary time with muscle strength (Copeland et al., 2017), this study added new evidence on how sitting time may contribute to sarcopenia. Our study found that higher volumes of sedentary time were generally associated with lower ASM in this sample of older Japanese adults, after accounting for MVPA and other potential confounding factors. We also found a sex difference in this relationship: It was linear among females but non-linear among males. For the latter, we observed an inverted U-shape of the association, in which the slope was positive for shorter total sedentary time (<9 h/d) and negative for longer sedentary time. Further studies are needed to examine male and female separately to better understand the role of sedentary time and bouts in older adults’ musculoskeletal health.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.exger.2022.111870.

References

Hsueh, J.L., Auyeung, T.W., Chou, M.Y., Assantachai, P., Chu, M.Y., Iijima, K., et al., 2020. Healthy nutrients than sedentary ones (Hsueh et al., 2019), the con...


