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# Moderate-to-vigorous physical activity modifies the relationship between sedentary time and sarcopenia: the Tromsø Study 2015–2016

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## Abstract

**Background** Sarcopenia is an age-related muscle disease primarily characterized by reductions in muscle strength that increases the risk of falls, fractures, cognitive impairment, and mortality. Exercise is currently preferred in prevention and treatment, but it is unknown how different habitual physical activity and sedentary behaviour patterns associate with sarcopenia status. The purpose of the present study was to compare associations of these patterns with probable sarcopenia in older adults.

**Methods** In 3653 community-dwelling participants (51% women) aged 60–84 years from the seventh survey of the Tromsø Study, we assessed objective physical activity and sedentary behaviour collected over 8 days (ActiGraph wGT3X-BT Accelerometer), grip strength (Jamar+ Digital Dynamometer), five-repetition chair stands, and self-reported disease. We combined tertiles of sedentary (SED) time and moderate-to-vigorous physical activity (MVPA) to create nine different activity profiles ($SED_{HIGH}$, $SED_{MOD}$, and $SED_{LOW}$ combined with $MVPA_{HIGH}$, $MVPA_{MOD}$, or $MVPA_{LOW}$). Multiple logistic regression models were used to examine how these profiles associated with probable sarcopenia, defined by low handgrip strength and/or slow chair stands time according to the revised European Working Group on Sarcopenia in Older People criteria.

**Results** Probable sarcopenia was present in 227 (6.2%) participants. Men with probable sarcopenia had on average 35.3 min more SED time and 20 min less MVPA compared with participants without sarcopenia ($P < 0.01$ for all), while women with probable sarcopenia only had 18 min less MVPA ($P < 0.001$). Compared with the $SED_{HIGH}$–$MVPA_{LOW}$ reference activity profile (714.2 min SED/day and 10.4 min MVPA/day), the $SED_{HIGH}$–$MVPA_{MOD}$ profile (697.1 min SED/day and 31.5 min MVPA/day) had significantly lower odds ratio (OR) for probable sarcopenia (OR 0.17, 95% confidence interval [CI] 0.08–0.35), while the $SED_{LOW}$–$MVPA_{LOW}$ profile (482.9 min SED/day and 11.0 min MVPA/day) did not (OR 0.72, 95% CI 0.47–1.11). These findings were not influenced by age, sex, smoking, or self-reported diseases, and higher levels of MVPA did not further decrease ORs for probable sarcopenia.

**Conclusions** Older adults who achieve moderate amounts of MVPA have reduced odds for probable sarcopenia, even when they have high sedentary time. Those with low sedentary time did not have reduced odds for probable sarcopenia when they also had low amounts of MVPA. These findings need confirmation in longitudinal studies but suggest that interventions for preventing sarcopenia should prioritize increasing MVPA over reducing sedentary behaviour.

**Keywords** Sarcopenia; Physical activity; Sedentary behaviour; Accelerometers; The Tromsø Study

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# Introduction

Sarcopenia is an ICD-10-CM-categorized muscle disease that predisposes mainly older people to falls, fractures, cognitive impairment, and mortality.[1–3] According to the revised European Working Group on Sarcopenia in Older People (EWGSOP2) guidelines, sarcopenia can be characterized as probable (and interventions recommended) when an individual has reduced upper-body or lower-body muscle strength.[4] This represents a shift from the earliest operational definitions where sarcopenia was characterized as low muscle mass alone.[5] Similarly, the recent Sarcopenia Diagnosis and Outcomes Consortium definition also emphasizes muscle strength and does not recommend muscle mass assessments.[6] Regardless of the ongoing controversy over operational definitions, the disease burden of sarcopenia is expected to increase given ageing populations globally,[7] making it a priority for researchers and policymakers to understand how to best prevent this muscle disease.

Current evidence supports using resistance exercise as the primary treatment to counteract sarcopenia in older adults, as it increases both muscle strength and muscle mass.[8–10] However, older adults are more likely to meet the World Health Organization (WHO) recommendations of 150 min of moderate-intensity aerobic physical activity per week, or 75 min of vigorous intensity per week, than to meet the muscle-strengthening exercise recommendations of two times per week.[11] Incidental and intentional episodes of aerobic physical activities such as brisk walking, cycling, stair climbing, dancing, or light running are likely common throughout the day and could reduce the risk of incident sarcopenia, as indicated by the AGES-Reykjavik Study using self-reported data.[12] Likewise, sedentary behaviour constitutes the largest proportion of an older adult's daily life and has been associated with increased sarcopenia risk, indicating that reduction of sedentary behaviour could be an important intervention target for sarcopenia prevention.[13–15]

Objective measures of daily physical activity and sedentary behaviour patterns are becoming more readily available, minimizing the recall and response bias associated with self-reported data, and allowing greater understanding of their relationships with sarcopenia.[16] Recent studies using accelerometers have shown that moderate-to-vigorous physical activity (MVPA) is associated with lower odds of prevalent sarcopenia independent of sedentary time.[13,17] However, both these behaviours are part of a daily continuum, where individuals may have relatively high and low amounts of both MVPA and sedentary behaviour simultaneously. Better presentation and understanding of habitual activity and sedentary patterns can help shape recommendations for sarcopenia prevention and treatment. Furthermore, few studies have investigated how objective physical activity and sedentary behaviour are associated with both the upper-body and lower-body strength measures that define probable sarcopenia in the EWGSOP2 guidelines. The aim of this study was to investigate how different activity profiles are associated with sarcopenia status based on grip strength and/or five-repetition chair stands in a population-based sample of older adults.

# Methods

## *Study description and ethical approval*

This cross-sectional study analysed data from the seventh survey (Tromsø 7, 2015–2016) of the ongoing population-based Tromsø Study in Northern Norway.[18] Recruitment and data collection procedures for Tromsø 7 have been described previously.[19,20] In short, all Tromsø inhabitants aged 40 and above ($n$ = 32 591) were invited to a basic examination including physical examination and collection of questionnaire data, of which 21 083 participated (65%). A subsample ($n$ = 9253) of these participants were also invited to extended clinical examinations, of which 8346 (90%) attended (Supporting Information, *Figure* S1). The study was approved by the Regional Committee for Medical and Health Research Ethics North (Ref. 2019/1136), and all participants gave written informed consent.

## *Muscle strength testing*

Grip strength was tested using a newly calibrated Jamar+ Digital Dynamometer (Patterson Medical, Warrenville, IL, USA) following procedures outlined in the Southampton protocol.[21] Participants held the dynamometer in a 90° elbow joint angle and squeezed with maximal effort. They performed three attempts per arm, and we analysed the highest value in kilograms from all six tries.

Lower-body muscle strength was tested using the five-repetition chair stand test from the Short Physical Performance Battery,[22] where participants were instructed to rise up completely five times from a chair, unaided and as fast as possible, without stopping and keeping their arms folded across the chest. Each participant practised one chair rise before the main test. A stopwatch was used to measure the time in seconds between the initial seated position until the participant stood up after the last rise. The test was aborted if more than 60 s passed, if participants used their hands for aid, or if there were doubts regarding the participant's safety.

## *Objective physical activity data collection and processing*

Objective data on physical activity were collected using small (4.6 × 3.3 × 1.5 cm), non-intrusive ActiGraph wGT3X-BT


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accelerometers (ActiGraph LLC, Pensacola, FL, USA) with a sampling frequency of 100 Hz. The procedures for data collection and processing in Tromsø 7 have been previously described in detail.[19] In short, participants wore the accelerometer at their right hip for 24 h during eight consecutive days and only removed it temporarily during water-based activities such as showering and swimming. The accelerometer was returned in a prepaid envelope after the measurement period.

Raw accelerometer data were downloaded and transformed into counts per minute (CPM) units by the ActiLife software (ActiGraph LLC), whereas the custom-written Quality Control & Analysis Tool (QCAT) software was used for wear time validation and variable generation.[19] Non-wear time protocols flagged recordings as invalid if there were <4 days with a minimum of 10 h/day of collected data and excluded those recordings from further analysis.[23,24] The present study used triaxial accelerometer data to capture activity and sedentary behaviour in the three-dimensional spectrum, using established vector magnitude cut-points for sedentary behaviour (<150 CPM), light physical activity (LPA; 150–2689 CPM), and MVPA (≥2690 CPM).[25,26]

### Covariates and sarcopenia definition

Participants answered comprehensive questionnaires including smoking status and diseases listed as frequent underlying causes of sarcopenia: cardiovascular disease (CVD), arthrosis, rheumatoid arthritis, respiratory disease, diabetes, kidney disease, and cancer.[10] We used cut-points from the EWGSOP2 definition to detect sarcopenia status.[4] Participants were defined as having probable sarcopenia if they had low grip strength (<16 kg for women and <27 kg for men) and/or slow chair stands time (>15 s to perform five chair stand repetitions for both women and men).

### Statistical analyses

Descriptive data for continuous variables are presented with means and standard deviations, with categorical variables presented as percentages. We used the Student's *t*-test to examine differences in the continuous variables between participants with or without probable sarcopenia and reported mean differences with 95% confidence intervals (CIs). For categorical variables, the $\chi^2$ test was used. We fitted fractional polynomials and reported age-adjusted standardized beta coefficients ($\beta$) separately for men and women when exploring associations between physical function and accelerometer measures.

We created tertiles of sedentary (SED) time and MVPA that were combined into nine different activity profiles ($SED_{HIGH}$, $SED_{MOD}$, or $SED_{LOW}$ combined with $MVPA_{HIGH}$, $MVPA_{MOD}$, or $MVPA_{LOW}$). Details regarding time in each behaviour for each profile are outlined in *Table* 1. These profiles were analysed in multiple logistic regression models with presentation of odds ratios (ORs) and 95% CIs. For each model, $SED_{HIGH}$–$MVPA_{LOW}$ was used as the reference category with probable sarcopenia as the dependent variable. Model 1 was adjusted for age and sex. Model 2 was additionally adjusted for smoking status and self-reported disease. We inspected the models for multicollinearity (variance inflation factor) and goodness of fit (Hosmer–Lemeshow), and all statistical analyses were performed using Stata software Version 16.1 (StataCorp, College Station, TX, USA).

## Results

From the total sample attending extended examinations (*n* = 8346), we were able to include 3653 community-dwelling older adults aged 60–84 years with complete data on objective physical activity and sedentary behaviour, upper-body and lower-body muscle strength, self-reported smoking, and current/previous non-communicable diseases (*Figure* S1). Sensitivity analyses showed that these participants had a slightly lower mean age, higher grip strength, and slower chair stand times compared with a larger sample (*n* = 5341) with completed physical function measures as the only criteria (*Table* S1). *Table* 2 shows that probable sarcopenia was prevalent in 227 out of 3653 (6.2%) participants, who were older and more prone to be female compared with

**Table 1** Description of accelerometer-based activity profiles (the Tromsø Study 2015–2016)

| Activity profile | *N* | SED time/day (min) | LPA/day (min) | MVPA/day (min) |
|---|---|---|---|---|
| $SED_{HIGH}$–$MVPA_{LOW}$ (ref group) | 483 | 714.2 ± 66.4 | 343.0 ± 74.7 | 10.4 ± 6.1 |
| $SED_{MOD}$–$MVPA_{LOW}$ | 417 | 588.6 ± 24.7 | 374.6 ± 85.6 | 10.6 ± 6.0 |
| $SED_{LOW}$–$MVPA_{LOW}$ | 329 | 482.9 ± 43.4 | 408.0 ± 104.0 | 11.0 ± 5.9 |
| $SED_{HIGH}$–$MVPA_{MOD}$ | 428 | 697.1 ± 55.1 | 373.2 ± 68.5 | 31.5 ± 6.9 |
| $SED_{MOD}$–$MVPA_{MOD}$ | 391 | 587.9 ± 24.8 | 406.6 ± 78.9 | 31.3 ± 6.5 |
| $SED_{LOW}$–$MVPA_{MOD}$ | 390 | 484.6 ± 47.3 | 436.3 ± 90.5 | 31.9 ± 6.4 |
| $SED_{HIGH}$–$MVPA_{HIGH}$ | 306 | 687.4 ± 45.6 | 381.5 ± 66.5 | 67.2 ± 22.2 |
| $SED_{MOD}$–$MVPA_{HIGH}$ | 408 | 585.4 ± 24.3 | 405.8 ± 76.2 | 69.0 ± 22.2 |
| $SED_{LOW}$–$MVPA_{HIGH}$ | 501 | 477.4 ± 53.6 | 456.6 ± 90.5 | 76.7 ± 29.0 |

LPA, light physical activity; MOD, moderate; MVPA, moderate-to-vigorous physical activity; SED, sedentary.


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**Table 2** Study sample characteristics based on sarcopenia status (the Tromsø Study 2015–2016)

| Characteristic | All ($n$ = 3653) | No sarcopenia ($n$ = 3426) | Probable sarcopenia ($n$ = 227) | $P$ |
|---|---|---|---|---|
| Age (years) | 68.5 ± 5.9 | 68.2 ± 5.8 | 72.8 ± 6.3 | <0.001 |
| Women, $n$ (%) | 1863 (51.0) | 1716 (50.1) | 147 (64.8) | <0.001 |
| Smoking status, $n$ (%) | | | | 0.576 |
| Current smoker | 409 (11.2) | 379 (11.1) | 30 (13.2) | |
| Previous smoker | 1914 (52.4) | 1800 (52.5) | 114 (50.2) | |
| CVD, previous, $n$ (%) | 365 (10.0) | 337 (9.8) | 28 (12.3) | 0.216 |
| Arthrosis, $n$ (%) | | | | <0.001 |
| Current | 937 (25.7) | 820 (24.0) | 117 (51.5) | |
| Previous | 59 (1.6) | 53 (1.6) | 6 (1.6) | |
| Rheumatoid arthritis, $n$ (%) | | | | <0.001 |
| Current | 163 (4.5) | 140 (4.1) | 23 (10.1) | |
| Previous | 13 (0.4) | 13 (0.4) | 0 (0.0) | |
| Respiratory disease, $n$ (%) | | | | 0.058 |
| Current | 131 (3.6) | 118 (3.4) | 13 (5.7) | |
| Previous | 31 (0.9) | 27 (0.8) | 4 (1.8) | |
| Diabetes, $n$ (%) | | | | <0.001 |
| Current | 242 (6.6) | 212 (6.2) | 30 (13.2) | |
| Previous | 19 (0.5) | 19 (0.6) | 0 (0.0) | |
| Kidney disease, $n$ (%) | | | | 0.018 |
| Current | 62 (1.7) | 53 (1.6) | 9 (4.0) | |
| Previous | 95 (2.6) | 91 (2.7) | 4 (1.8) | |
| Cancer, $n$ (%) | | | | 0.148 |
| Current | 120 (3.3) | 109 (3.2) | 11 (4.9) | |
| Previous | 344 (9.4) | 317 (9.3) | 27 (11.9) | |
| Men ($n$ = 1790) | | | | |
| SED/day (min) | 606.1 ± 104.3 | 604.5 ± 103.3 | 639.7 ± 119.4 | 0.003 |
| LPA/day (min) | 380.8 ± 87.9 | 382.1 ± 87.2 | 354.2 ± 97.7 | 0.006 |
| MVPA/day (min) | 41.1 ± 32.5 | 42.0 ± 32.5 | 22.0 ± 26.0 | <0.001 |
| WHO 2020 criteria, $n$ (%)[a] | 1227 (68.6) | 1202 (70.3) | 25 (31.3) | <0.001 |
| Wear time, total (h) | 116.9 ± 17.1 | 117.0 ± 16.9 | 114.4 ± 20.0 | 0.259 |
| Women ($n$ = 1863) | | | | |
| SED/day (min) | 574.4 ± 95.7 | 573.6 ± 95.4 | 583.4 ± 99.1 | 0.234 |
| LPA/day (min) | 415.6 ± 87.3 | 417.5 ± 86.3 | 393.7 ± 96.0 | 0.002 |
| MVPA/day (min) | 34.8 ± 26.6 | 36.2 ± 26.6 | 18.2 ± 20.0 | <0.001 |
| WHO 2020 criteria, $n$ (%)[a] | 1165 (62.5) | 1123 (65.4) | 42 (28.6) | <0.001 |
| Wear time, total (h) | 116.6 ± 15.6 | 116.9 ± 15.5 | 113.2 ± 16.5 | 0.006 |

CVD, cardiovascular disease (myocardial infarction or stroke); LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; Respiratory disease, chronic bronchitis, emphysema, or chronic obstructive pulmonary disease; SED, sedentary; WHO, World Health Organization.

Numbers are mean ± standard deviation or $n$ (%). $P$-values indicate potential differences between no sarcopenia and probable sarcopenia groups.

[a]Proportions of participants achieving 150 min MVPA (non-bouted) based on the recently updated WHO 2020 physical activity recommendations for older adults.

non-sarcopenic participants (both $P < 0.001$). There were no significant differences in smoking status, CVD, respiratory disease, or cancer between participants with or without probable sarcopenia. Sarcopenic participants were more likely to have arthrosis (51.5% vs. 24.0%), rheumatoid arthritis (10.1% vs. 4.1%), diabetes (13.2% vs. 6.2%), and kidney disease (4.0% vs. 1.6%), compared with non-sarcopenic participants (all $P < 0.05$).

Men with probable sarcopenia had less LPA (−27.9 min/day, 95% CI −47.6 to −8.2) and MVPA (−20.0 min/day, 95% CI −27.3 to −12.8) and higher SED time (35.3 min/day, 95% CI 11.9–58.6) compared with non-sarcopenic men (*Table* 2). For women with probable sarcopenia, only physical activity parameters differed compared with those without sarcopenia, by −23.8 min LPA/day (95% CI −38.5 to −9.1) and −18.0 min MVPA/day (95% CI −22.4 to −13.6). A total of 31.3% of men and 28.6% of women with probable sarcopenia were sufficiently physically active according to newly proposed WHO 2020 guidelines,[27] compared with 70.3% and 65.4% among non-sarcopenic men and women, respectively (all $P < 0.001$). There was no difference in accelerometer wear time according to sarcopenia status among men, but women with probable sarcopenia had significantly lower wear time (−3.7 h, 95% CI −6.2 to −1.1) compared with non-sarcopenic women.

MVPA was significantly associated with grip strength in women ($\beta$ = 0.08, $P$ = 0.001, *Figure* 1A) and in men ($\beta$ = −0.09, $P < 0.001$, *Figure* 1B), with a potential threshold discernible at 15–20 min MVPA/day for both. Compared with grip strength, the association between MVPA and chair stand performance was stronger in both women ($\beta$ = −0.26, $P < 0.001$, *Figure* 1C) and men ($\beta$ = 0.31, $P < 0.001$, *Figure* 1D), with a threshold noticeable at 20–30 min MVPA/day. There were no significant associations between SED time and grip


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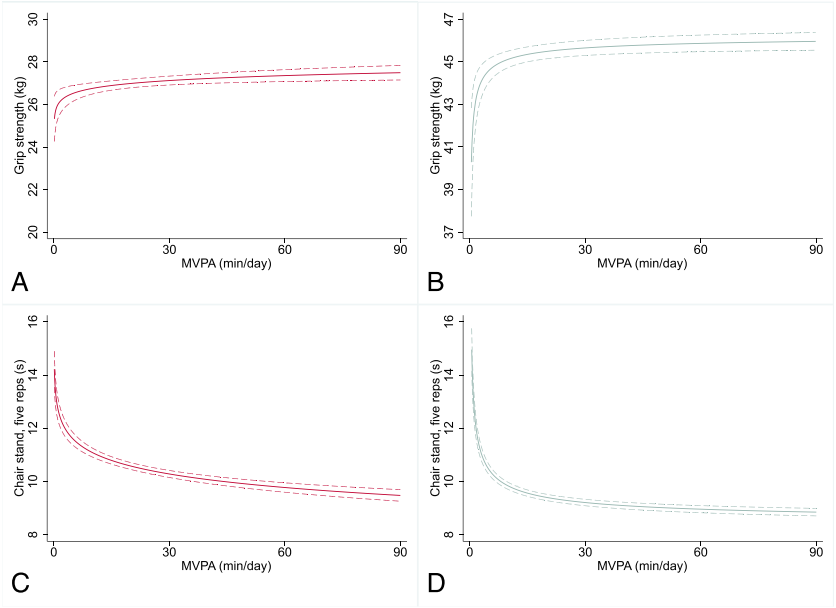


**Figure 1** Associations between upper/lower-body muscle strength and moderate-to-vigorous physical activity (MVPA). The Tromsø Study 2015–2016. Data are age-adjusted fractional polynomial regression lines with 95% confidence intervals, shown for (A, C) women (red) and (B, D) men (green) separately.

strength in either women (*Figure* 2A) or men (*Figure* 2B), or between SED time and chair stand performance in women (*Figure* 2C). However, SED time was significantly associated with chair stand performance in men ($\beta$ = 0.08, $P < 0.001$, *Figure* 2D).

*Figure* 3A shows the age-adjusted and sex-adjusted logistic regression model examining associations between sarcopenia status and the different activity profiles (*Table* 1) compared with the $SED_{HIGH}$–$MVPA_{LOW}$ reference (714.2 ± 66.4 min SED/day and 10.4 ± 6.1 min MVPA/day). In this model, the lower SED time in the $SED_{MOD}$–$MVPA_{LOW}$ (588.6 ± 24.7 min SED/day) and $SED_{LOW}$–$MVPA_{LOW}$ (482.9 ± 43.4 min SED/day) profiles did not translate to reduced odds for probable sarcopenia (OR 0.75, 95% CI 0.50–1.13 and OR 0.72, 95% CI

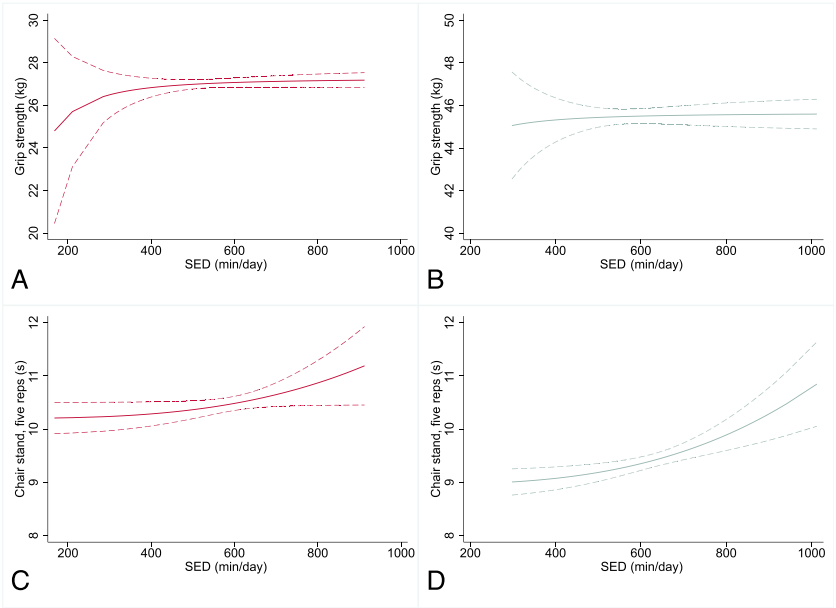


**Figure 2** Associations between upper/lower-body muscle strength and sedentary (SED) time. The Tromsø Study 2015–2016. Data are age-adjusted fractional polynomial regression lines with 95% confidence intervals, shown for (A, C) women (red) and (B, D) men (green) separately.


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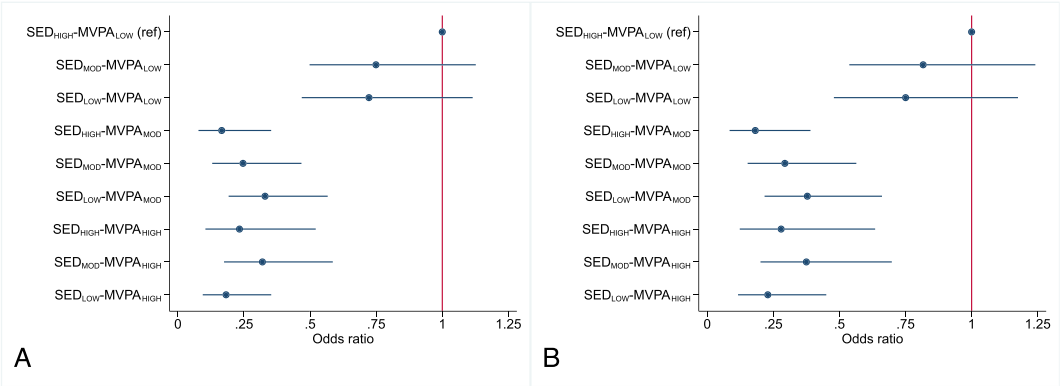


**Figure 3** Multiple logistic regression models and associations between probable sarcopenia and different activity profiles. The Tromsø Study 2015–2016. Data are odds ratios with 95% confidence intervals. Odds for probable sarcopenia are compared with the different activity profiles and the $SED_{HIGH}$–$MVPA_{LOW}$ profile representing the reference category. (A) Model 1 is adjusted for age and sex. (B) Model 2 is further adjusted for smoking status and self-reported diseases. MOD, moderate; MVPA, moderate-to-vigorous physical activity; SED, sedentary.

0.47–1.11, respectively). The $SED_{HIGH}$–$MVPA_{MOD}$ profile (697.1 ± 55.1 min SED/day and 31.5 ± 6.9 min MVPA/day) had significantly reduced odds for probable sarcopenia (OR 0.17, 95% CI 0.08–0.35) compared with the reference profile. Higher levels of MVPA combined with lower SED time did not further decrease ORs for probable sarcopenia, and these findings were not attenuated in the fully adjusted model (*Figure* 3B). ORs and 95% CIs for each activity profile are further described in *Table* 3.

## Discussion

In this population-based study of community-dwelling older Norwegian adults, we found that moderate amounts of MVPA (~30 min/day) were associated with reduced odds for probable sarcopenia even if participants also had high SED time. Participants with low SED time and simultaneously low amounts of MVPA (~10 min/day) did not have reduced odds for probable sarcopenia. Furthermore, our data suggest that achieving high amounts of MVPA (~60 min/day) may not provide any additional benefit on upper-body and lower-body muscle strength in older adults. These findings provide a better understanding of how different SED and MVPA patterns interact and associate with sarcopenia status, which could help shape habitual activity recommendations for prevention and treatment.

In a previous study, Sanchez-Sanchez *et al*. reported 15% lower odds of sarcopenia when 15 min of SED time was replaced with an equal amount of MVPA and indicated a dose–response relationship up to replacements of 60 min/day.[17] We recently also published findings on 70-year-old Swedish adults, showing that odds for probable and confirmed sarcopenia were reduced by 20% per 1 h increase in MVPA per week even after adjusting for SED time.[13] The present study expands these findings by showing that moderate amounts of MVPA and high SED time can coexist during a day while still reducing odds for probable sarcopenia. The activity profiles included in our analyses provide a simple and clinically interpretable overview over possible healthy and non-healthy behaviour for sarcopenia prevention. Furthermore, these profiles lend support to previous findings based on self-report, suggesting that MVPA may be able to

**Table 3** Multiple logistic regression models and associations between probable sarcopenia and different activity profiles (the Tromsø Study 2015–2016)

| Activity profile | Model 1 | Model 2 |
|---|---|---|
| $SED_{HIGH}$–$MVPA_{LOW}$ (ref) | — | — |
| $SED_{MOD}$–$MVPA_{LOW}$ | 0.75 (0.50–1.13) | 0.81 (0.53–1.23) |
| $SED_{LOW}$–$MVPA_{LOW}$ | 0.72 (0.49–1.11) | 0.75 (0.48–1.18) |
| $SED_{HIGH}$–$MVPA_{MOD}$ | 0.17 (0.08–0.35) | 0.18 (0.08–0.39) |
| $SED_{MOD}$–$MVPA_{MOD}$ | 0.25 (0.13–0.47) | 0.28 (0.15–0.54) |
| $SED_{LOW}$–$MVPA_{MOD}$ | 0.33 (0.19–0.57) | 0.37 (0.21–0.64) |
| $SED_{HIGH}$–$MVPA_{HIGH}$ | 0.23 (0.10–0.52) | 0.27 (0.12–0.60) |
| $SED_{MOD}$–$MVPA_{HIGH}$ | 0.32 (0.17–0.59) | 0.36 (0.20–0.68) |
| $SED_{LOW}$–$MVPA_{HIGH}$ | 0.18 (0.09–0.35) | 0.21 (0.11–0.41) |

MOD, moderate; MVPA, moderate-to-vigorous physical activity; SED, sedentary.
Data are odds ratios with 95% confidence intervals. Odds for probable sarcopenia are compared with the different activity profiles and the $SED_{HIGH}$–$MVPA_{LOW}$ profile representing the reference category. Model 1 is adjusted for age and sex. Model 2 is further adjusted for smoking status and self-reported diseases.


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'compensate' for the detrimental effects of sitting.[28] However, the thresholds in our activity profiles are somewhat arbitrary and should be interpreted as general estimates. Dissimilar to the findings of Sanchez-Sanchez *et al*., we did not see any additional benefit of higher activity or lower SED time after participants achieved roughly 30 min of MVPA per day. There could be several explanations for this, such as their inclusion of older participants (mean 78 years), implementation of different accelerometer cut-offs, and use of different sarcopenia criteria. A recent meta-analysis on physical activity and mortality, with similar accelerometer cut-offs and study sample age, reported a clear saturation in the associations at 24 min MVPA/day.[29] While that study investigated a sarcopenia-related outcome and not sarcopenia directly, and also analysed physical activity and sedentary behaviour separately, it provides support for the potential MVPA threshold found in the current study.

Similar thresholds were also discernible in the present study when analysing how MVPA was associated with either grip strength or chair stand performance separately. Interestingly, MVPA associated more strongly with chair stand performance compared with grip strength, potentially driving the association between physical activity and EWGSOP2-determined probable sarcopenia in our study. Previous work supports these findings, showing that accelerometer-determined physical activity associates positively with lower-limb strength but less so with grip strength.[30,31] It is plausible that hip-worn accelerometers are able to more accurately capture activities that strengthen the lower extremities, compared with actions that enhance upper extremities and potentially influence grip strength more. This emphasizes the importance of assessing lower-body muscle strength when evaluating sarcopenia prevention efforts involving habitual physical activity.

Resistance exercise is currently the primary recommended treatment for sarcopenia, with documented effects on muscle strength and muscle mass that rightfully position it at the forefront.[8,9,32] However, a growing body of research indicates that promoting increased MVPA in older adults can provide a complementary approach to sarcopenia prevention.[12,13,17] The present study supports this and additionally suggests that high amounts of sedentary behaviour, as commonly seen in modern lifestyles, may not be deleterious as long as sufficient MVPA is achieved. Collectively, these findings might enhance sarcopenia prevention efforts, especially when older adults may experience several barriers to resistance exercise maintenance and seem reluctant to engage in specific muscle-strengthening activities.[11,33]

The relationship between LPA and sarcopenia is less clear,[13,17] and it is possible that low-intensity activities such as slow walking and light household chores generate an insufficient physiological stimuli for muscle strength maintenance among older adults. Thus, the present study primarily based the activity profiles on MVPA, and it was also evident that the higher LPA in the $SED_{LOW}$–$MVPA_{LOW}$ profile compared with the reference category did not translate to decreased odds for probable sarcopenia. Nonetheless, it should be noted that LPA has been shown to influence other health outcomes, such as CVD, cognitive health, and mortality, and contributes to the public health message 'a little is better than nothing'.[29,34,35] The potentially complex interplay between SED, LPA, and MVPA behaviours in preventing sarcopenia may require more advanced statistical methods such as compositional data analysis,[36] although the output from such analyses is more difficult to interpret and translate into recommendations.

The current study's main limitation is its cross-sectional design, rendering it vulnerable to reverse causation. Thus, it is just as likely that pre-existing muscle strength determines an individual's physical activity and sedentary behaviour in our reported associations. Our conclusions should be viewed as hypothesis generating and need confirmation in longitudinal and experimental studies. It should be noted that Ekelund *et al*. performed a similar activity profile analysis based on self-reported data and showed that physical activity regardless of sitting time prospectively predicted all-cause mortality.[28] We used accelerometer cut-points validated in a young adult population, and their applicability in older adults is uncertain.[26] However, roughly 65% of participants achieved the newly updated WHO physical activity recommendations of 150 min non-bouted MVPA per week, indicating that the current cut-points were relevant for our study sample of older adults.[27] Additionally, we did not include data to investigate the successive step of confirmed sarcopenia in the EWGSOP2 algorithm, as our previous study indicates that a low number of participants qualified for this criterion.[37] It would be of interest to explore whether similar associations as found in the current study also exist for participants who additionally express low lean mass. Nonetheless, it is clear that muscle strength is becoming more emphasized, and lean mass less so, as sarcopenia definitions continue to develop.[4,38] Further, we cannot rule out residual confounding in our study, as we were unable to adjust for nutritional, drug-related, or hospitalization-related causes of sarcopenia.[10] Lastly, our results might be influenced by selection bias, as the individuals declining to wear the accelerometer in Tromsø 7 were slightly older and frailer.[19]

Current study strengths relate to our large, population-based study sample and to the use of objective data on physical activity and sedentary behaviour that is less prone to recall and response bias as seen with self-report methods.[16] We used three-dimensional accelerometer data to capture a broad range of human movement behaviour and thus did not restrict ourselves to simply the vertical axis, as was common in many original accelerometer studies. We were also able to examine associations for activity and sedentary behaviour with both muscle strength parameters


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included in the EWGSOP2 definitions, compared with previous studies that only investigated grip strength.

To conclude, older adults achieving at least moderate amounts of MVPA have reduced odds for probable sarcopenia, even when they have high sedentary time. In addition, having low sedentary time was not associated with reduced odds for probable sarcopenia if time spent in MVPA was also low. This relationship between physical activity patterns and sarcopenia needs confirmation in longitudinal studies but suggests that interventions should prioritize increasing MVPA over reducing sedentary time for sarcopenia prevention.

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## Conflict of interest

None declared.

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## Online supplementary material

Additional supporting information may be found online in the Supporting Information section at the end of the article.

**Figure S1.** Study participation flow chart. The Tromsø Study 2015–2016. Tromsø inhabitants aged 40 and above were invited to participate in basic examinations. This included a pre-marked sub-sample (randomized sample: $n$ = 9925 + sample from selected clinical examinations from Tromsø 6: $n$ = 3103) intended for extended examinations.

**Table S1.** Comparison between the final study sample and a larger sample based on physical function measurements as the sole criteria. The Tromsø Study 2015–2016.

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