**ORIGINAL ARTICLE**

# Physical activity and sarcopenia in older adults

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## Abstract

**Background** Sarcopenia is prevalent in ever growing older adult populations.

**Aim** The aim of this study was to quantify the association between physical activity (PA), sedentary time (SED), cardiorespiratory fitness (CRF), and strength (STR) with sarcopenia in community-dwelling older adults using a standard definition of sarcopenia.

**Method** This cross-sectional study examined a large group of older adults ($n = 304$) who provided a broad range of health, lifestyle, and socioeconomic variables. PA was assessed using a pedometer worn for 7 days. SED was assessed by survey. CRF was assessed by 400-m walk test performance. Strength (STR) was assessed by one-repetition maximum chest and leg press. The European Working Group on Sarcopenia in Older People (EWGSOP) definition defined 10.9% ($n = 33$) as sarcopenic.

**Results** PA, CRF, and STR were significantly associated with sarcopenia components (muscle mass, muscle strength, and muscle function). The upper two-thirds of CRF had significantly lower odds of having sarcopenia, whereas the strongest third of STR was associated with lower odds of sarcopenia. All exposure variables had significant odds ratios associated with at least one component of sarcopenia. Joint analyses indicated additional benefit may be gained from being both active ($\geq 5000$ daily steps) and fit (top two-thirds), active and strong (top two-thirds), and fit and strong.

**Discussion** Overall, objectively measured PA, CRF, and STR, and self-reported SED, are associated with sarcopenia and its components.

**Conclusion** Therefore, older adults who are physically active, maintain higher levels of cardiorespiratory fitness, upper and lower body strength, and avoid sedentary time may have significantly lower odds of sarcopenia.

**Keywords** Sarcopenia · Physical activity · Cross-sectional study · Prevention · Objective measurement · Aging

## Introduction

Many older adults are unaware of the benefits of physical activity (PA) and often consider physical activity unnecessary or even harmful [1]. Quite the opposite is true. If inactivity was eliminated, worldwide life expectancy would rise on average by 0.7 years and 0.8 years in the USA, demonstrating inactivity is as detrimental to health as established risk factors such as obesity and smoking [2]. The specific effect of getting inactive people to become physically active would add 1.3–3.7 years to their life [3, 4].

Older adults are less active and suffer from more chronic diseases than younger people. One common disease is the age-related reduction of muscle mass, strength, and function, also known as sarcopenia. It is also comorbid with other diseases, such as obesity, osteoporosis, and type II diabetes [5], as well as elevated risk of falls, decreased quality of life, loss of independence, and mortality [6]. Although its causes are not fully understood, inactivity, changes in hormonal levels, inflammation, and altered neuronal activity all contribute to sarcopenia [7].

Prevalence rates of sarcopenia vary due to lack of a universal definition [8] and measurement devices used in diagnosis. 1–29% and 10–33% in community-dwelling and dependent-living older adults, respectively, are reported to have sarcopenia [9]. Sarcopenia incidence is projected to grow 1.8–2.1% annually, resulting in a dramatic 8–12

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million new cases in Europe alone over the next 30 years [10]. A recent systematic review of 35 studies on community-dwelling adults over 60 years of age estimated 10% prevalence using the definitions from the European Working Group on Sarcopenia in Older People (EWGSOP) and Asian Working Group on Sarcopenia (AWGS) in for non-Asian and Asian populations, respectively [11]. Therefore, 10% prevalence may be more reliable due to consistent use of sarcopenia definition and ethnic population, but it is likely too conservative due to inclusion of only independent older adults.

Sarcopenia carries a significant financial ($18.5 billion in US health care costs in 2000) and social (decreased quality of life) burden [12]. According to the U.S. Census Bureau, by the year 2050 the number of individuals over 65 years old will double from 40 to 88.5 million, which is nearly 20% of the US population [13]. Both prevention and treatment of sarcopenia consist of increased PA, specifically progressive resistance training, appropriate amounts of high-quality dietary protein, and vitamin D supplementation, but currently pharmaceutical treatments have not been fully established [14]. Given the relationship between modifiable risk factors and sarcopenia, further investigation into physical activity habits is needed, such as cross-sectional and longitudinal studies including objectively measured data.

A recent systematic review and meta-analysis of cross-sectional and cohort studies examined the relationship between PA and sarcopenia [15]. Overall, participants who were at least somewhat active had lower odds [OR (95% CI), 0.45 (0.37, 0.55)] of sarcopenia compared to inactive. Each of the 17 cross-sectional studies assessed PA using self-report, and 12 of 17 studies used only low muscle mass to define sarcopenia instead of a standardized definition. Therefore, further research should use objectively measured PA and accepted sarcopenia definitions. Consistent use of the EWGSOP definition in non-Asian populations (AWGS has identified racial differences in diagnosing sarcopenia) would improve synthesis of data that could be compared across studies.

A recent review of randomized controlled trials [16] that combine exercise intervention and dietary intervention provided mixed results on the efficacy of treatment due to a range of differences. Differences included exercise adherence, type, dose, intensity, and duration, as well as type of supplement and dose, and finally the baseline functional and nutritional (especially lacking protein intake data at baseline) status of the subjects. These limitations allow important questions to remain unanswered, such as the effects of combined interventions in sarcopenic and frail populations, populations with nutrition deficiency, and populations at risk for malnutrition. Baseline physical activity and nutritional status are very important in addressing these issues in the future.

Existing data on physical activity and sarcopenia in older adults have been collected using predominantly self-reported measures, which tend to over-report physical activity and have lower accuracy due to recall limitations [17]. The most common form of PA for older adults is walking [18]. Therefore, the use of an objective measurement device that accurately captures ambulatory movement, such as a pedometer, will record most physical activity in an older adult population. This study aims to quantify the association objectively measured PA, fitness, and strength, as well as subjectively measured sedentary time with sarcopenia in a large group of community-dwelling older adults using a standard definition of sarcopenia from the EWGSOP.

## Methods

Participants were recruited from a mid-west university town and surrounding communities through postings, advertisements, and informational talks in local organizations. Between October 2015 and May 2016, 304 older adults, ages 65 years and older, who planned to live in the area long-term, were recruited. The exclusion criteria were cancer treatment in the past 5 years, or other severe conditions that would interfere with or make exercise unsafe and/or difficult, for example major heart, psychological, degenerative, or physical impairments.

Participants were part of an ongoing, longitudinal cohort called the Physical Activity and Aging Study (PAAS). Individuals participated in a series of laboratory visits over the course of 2 weeks involving completing questionnaires, and measurement of physical activity, body composition, fitness, physical function, and strength. This study was approved by the Institutional Review Board at a mid-west university in the USA. Procedures were fully explained to all participants. Prior to participation, all individuals provided written informed consent.

Height was measured using a standard stadiometer in centimeters. Weight was measured with a digital scale (Cardinal Detecto 758C Digital Scale, Webb City, Mo, USA) in kilograms. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Waist circumference was measured in a standing position at the level of the umbilicus using a measuring tape after exhalation. Measurements were taken while participants wore scrubs with no shoes.

Daily steps were measure using a widely used, validated, and accelerometer-based pedometer from Omron (Model HJ-321, Illinois, USA) [19]. The pedometer, worn at waist level, calculated total daily steps over the course of 7 days. Overall, 94.4% had complete data, 3.6% had 6 days of step data, and 2% had only 5 days. Three categories were made based on published cut-points for older adults of < 2500

steps per day (low), $\geq 2500$–4999 (moderate), and $\geq 5000$ (high) [20].

Sedentary time was assessed using a comprehensive survey recording weekly time spent on average in each of the four domains (occupational, household, leisure-time, and transportation) based on the Compendium of Physical Activities [21] and the International Physical Activity Questionnaire [22]. Three categories were made based on cut-points for older adults of $< 8$ h per day (low), $\geq 8$ and $< 11$ (moderate), and $\geq 11$ (high) [23–25].

The 400-m walk test was the time required to walk 10 laps "as fast as possible" on a 20-m long course. Rests of up to 60 s while standing were permitted. The test was conducted in a long hallway that was approximately 5 ft wide. Cones marked the ends of the course. The researcher told the participant the number of laps completed and remaining each round. Three categories (low, moderate, and high) were made based on tertiles of 400 m walk time for the present sample. Other existing references for fitness could not be applied to this sample, for instance none of the participants had the failed to complete the 400 m walk test [26], and only two failed to complete the test at slower than 1.19 m/s [27] which indicates high mortality risk and future mobility disability, respectively.

ACSM guidelines were followed to determine muscular strength from one-repetition maximum (1RM) chest and leg press [28]. The participant was given three progressive warm-up sets each followed by a 2-min rest. The 1RM was determined within four trials with rest periods of 2 min between trials. The initial weight was selected to be within the individual's perceived capacity, and then resistance was progressively increased until the subject could not complete the repetition throughout the whole range of motion. The final weight lifted successfully was considered the individual's 1RM. The 1RMs were normalized by body weight (1RM/body weight), standardized [(value − mean)/SD] by age (65–69, 70–79, $\geq 80$) and sex-specific mean and SD, and divided into tertiles (low, moderate, and high) for analysis [29, 30].

The full body scan was performed on the Hologic Horizon W model DXA (Hologic Inc., Bedford, MA) and Apex Software (Version 5.5.3). A trained technician performed the scan with the participant supine in the standard fashion and wearing scrubs. Software automatically defined regions on the trunk and appendages, which were then adjusted manually by one trained technician. DXA software measured whole and regional body composition measures, including fat mass (FM), percentage body fat (%BF), fat-free mass (FFM), appendicular lean mass (ALM), bone mineral content, and bone mineral density. The DXA machine was calibrated daily using the manufacturer-provided phantom spine segment.

Usual gait speed was measured as part of the Short Physical Performance Battery (SPPB) [31], which is a series of tests (balance, 4 m gait speed, and chair stand) that gives a composite score (range 0–12, with higher indicating better function). The participant's usual gait speed was measured over 4 m. Participants began walking at the start line and were instructed to walk through the finish line as not to decelerate early. Walking aids were allowed if used in everyday life. Time to complete the 4 m course was recorded.

Handgrip strength was measured using a digital dynamometer (Jamar Plus +, Lafayette Instrument, Lafayette, IN, USA). The width of the device was adjusted to the size of the participant's hand such that the middle phalanx rests on the inner handle [32]. Participants sat and held their elbow joint at a right angle and gripped the dynamometer for 2 s using each hand with maximal effort. The best of three trials with 1-min rest between trials was used [33].

Sarcopenia was defined following the European Working Group on Sarcopenia in Older People (EWGSOP) guidelines due to Caucasian population and frequent use in published literature. Other definitions were calculated and reported in Table 1 [34–36]. Diagnosis of sarcopenia using the EWGSOP definition required low appendicular lean mass (ALM/ht$^2$ female: $\leq 5.67$, male: $\leq 7.23$) and either gait speed $\leq 0.8$ m/s or low handgrip strength (female $< 20$ kg, male $< 30$ kg). Recent meta-analyses on sarcopenia have also

**Table 1** Prevalence of sarcopenia by clinical definition, age, and sex

| Definition | Prevalence | | | | | | |
|---|---|---|---|---|---|---|---|
| | All | Females | | | Males | | |
| | | 65–69 | 70–79 | $\geq 80$ | 65–69 | 70–79 | $\geq 80$ |
| EWGSOP | 33/304 (10.9%) | 5/73 (6.9%) | 14/78 (18.0%) | 4/26 (15.4%) | 3/50 (6.0%) | 5/59 (8.5%) | 2/18 (11.1%) |
| IWGS | 29/304 (9.5%) | 3/73 (4.1%) | 10/78 (12.8%) | 4/26 (15.4%) | 3/50 (6.0%) | 6/59 (10.2%) | 3/18 (16.7%) |
| FNIHSP | 2/304 (0.6%) | 0/73 (0.0%) | 0/78 (0.0%) | 1/26 (3.9%) | 0/50 (0.0%) | 0/59 (0.0%) | 0/18 (0.0%) |
| FNIHSP$_{Revised}$ | 5/304 (1.6%) | 0/73 (0.0%) | 1/78 (1.3%) | 3/26 (11.5%) | 0/50 (0.0%) | 0/59 (0.0%) | 1/18 (5.6%) |

*EWGSOP* European Working Group on Sarcopenia in Older People, *IWGS* International Working Group on Sarcopenia, *FNIHSP* Foundation for the National Institutes of Health Sarcopenia Project, *FNIHSP$_{Revised}$* revised definition includes less conservative cut-points for handgrip strength and ALM

used literature following the EWGSOP definitions for pooling [37, 38].

Sociodemographic, lifestyle, personal and family medical history, depressive symptoms (Geriatric Depression Scale) [39], and self-reported health [40] were collected using a comprehensive survey. This provided measures of income (< $12,000, $12,000–24,999, $25,000–49,999, $50,000–74,999, $75,000–99,999, > $100,000), education (Elementary, Jr. High, High School, College, Graduate School), smoking status (current smoker, not current smoker), heavy alcohol consumption (yes, no), and number of major medical conditions (0–7) including heart attack, heart failure, heart arrhythmia, stroke, abnormal ECG, type 2 diabetes, and chronic obstructive pulmonary disease. Heavy alcohol consumption was drinking > 14 drinks per week for men and > 7 drinks per week for females [41]. Total kilocalories per day and daily protein intake were calculated using data from a 3-day diet record, which was entered into a nutrient analysis program (The Food Processor SQL version 10.14.1, ESHA Research, Salem OR). Of the 304 participants, 213 (70%) diet records had sufficient quality to be analyzed. Exclusion criteria for diet records included inadequate nutrient information, improper recording of weekday to weekend-day ratio, and ineligible handwriting.

Continuous variables are displayed as mean ± SD, and categorical variables as number (percentage). Comparisons between sex and age group (sarcopenic and non-sarcopenic groups) were performed using $t$ tests or ANOVA for continuous variables and using Chi square tests or Fisher exact test for categorical variables, as appropriate. Age- and sex-specific prevalence were calculated. Multivariable linear regression examined the relationship between continuous PA (daily steps from pedometer), CRF (400 m walk performance), STR (1RM chest and leg press), and SED (self-reported sitting time) with sarcopenia variables (muscle mass, function, and strength). Model selection was based off of a review of published papers on physical activity and sarcopenia [15] and includes socioeconomic, lifestyle, health, and multiple exposures of interest. Multivariable logistic regression was used to examine physical activity variables, potential clinical and functional risk factors, and the likelihood of having sarcopenia. Statistical significance was set at $p < 0.05$. All statistical analyses were done using SAS for Windows version 9.4 (SAS Institute Inc., Cary, NC, USA).

## Results

Overall, participants were 72.2 ± 5.8 years of age, 60% were female, with a BMI of 27 ± 4.9. They had SPPB scores of 11.4 ± 1.1 and completed a 400-m walk in 4.5 ± 0.8 min (1.5 m/s). Participants reported being physically active on the self-report survey but daily steps from

7-days of pedometer indicated ~ 5,000 ± 2632 steps per day, which indicates that most are on the border between active and sedentary. 79% reported "Good", "Very Good" or "Excellent" health, which corresponds with a similar percentage reporting zero comorbidities as defined above.

The more physically active participants were younger, had better function and fitness (SPPB, gait speed, 400 m walk), reported less sedentary time and higher health-related quality of life, and had fewer comorbidities. Sarcopenic participants were older, differed in body composition (weight, waist circumference, BMI, fat and fat-free mass, ALM), consumed more daily protein, had lower strength, function and fitness (1RM, handgrip strength, SPPB, gait speed, 400 m walk), and spent less time in resistance-type activities (see Table 2).

Prevalence of sarcopenia ranged from 0.6 to 10.9% depending on the definition (see Table 1). EWGSOP identified the most individuals and FNIHSP identified the least. More females were sarcopenic than males.

Sarcopenia variables were associated with the main variables of interest (see Table 3). A significant portion of the variance was explained in models for ALM and handgrip strength. PA (daily steps from 7-day pedometer wearing), CRF (time to complete 400 m walk), and STR (lbs from bench and leg press) all appear to be significantly associated with ALM, but in model 3 (fully adjusted) STR had the only significant association, despite only low-to-moderate correlation between SED (hours/day), PA, CRF, and STR (data not shown). Both CRF and STR were significantly associated with handgrip strength. Only CRF was significantly associated with gait speed, although the total variance accounted for was low. This may be due to the fact that gait speed has a complex association with overall health, multiple organ systems and physical activity, as well as being a metric for vitality [42, 43].

The coefficients of the lifestyle variables were in the expected directions. For PA, additional steps per day correspond to an increase in ALM. For CRF, one additional minute of time required to complete the 400 m walk test resulted in a decrease in ALM, handgrip strength, and a slower gait speed or a decrease in meters per second walked. For STR, a one-unit increase in strength resulted in increased ALM, handgrip strength, and faster gait speed.

Physical activity was associated with insignificant trend of lower odds of sarcopenia prevalence with OR (95% CI) of 0.58 (0.14–2.38) in high active group (> 5,000 steps/day) compared to the low active group (< 2500 steps/day) (see Table 4). However, achieving more than 5000 steps/day was significantly associated with reduced odds of having low muscle mass and slow gait speed indicating that being active was associated with higher muscle mass and faster gait speed ($p$-trend < 0.05).

**Table 2** Participant characteristics by physical activity and sarcopenia status

| | All | Very sedentary (< 2500 steps/day) | Sedentary (2500–4999 steps/day) | Active (≥ 5000 steps/day) | P value | Sarcopenic | Not sarcopenic | P value |
|---|---|---|---|---|---|---|---|---|
| n | 304 | 44 | 140 | 120 | | 33 | 271 | |
| Age | 72.8 (5.8) | 76.1 (7.1) | 72.3 (5.2) | 70.7 (5.3) | <.0001 | 74.8 (6.3) | 71.9 (5.7) | 0.007 |
| Sex (% female) | 58.2 (177) | 27 (61.4) | 79 (56.4) | 71 (59.2) | 0.82 | 69.7 (23) | 56.8 (154) | 0.16 |
| Height (cm) | 168.4 (9.6) | 167.6 (10.9) | 168.7 (9.7) | 168.2 (9) | 0.8 | 163.9 (6.5) | 168.9 (9.8) | 0.01 |
| Weight (kg) | 76.9 (16.6) | 79.8 (19.4) | 77.1 (16.4) | 75.6 (15.6) | 0.34 | 64.5 (9.1) | 78.4 (16.7) | <.0001 |
| Waist circumference (cm) | 92.9 (14.3) | 97.1 (14.6) | 92.9 (14.9) | 91.3 (13.1) | 0.07 | 84.8 (11.6) | 93.9 (14.3) | 0.001 |
| Body composition | | | | | | | | |
| Body mass index (kg/m2) | 27.0 (4.9) | 28.2 (5.5) | 26.9 (4.9) | 26.5 (4.3) | 0.14 | 24.0 (3.3) | 27.4 (4.8) | 0.0001 |
| Percentage body fat (%) | 39.7 (7.7) | 41.7 (8.3) | 39.9 (7.7) | 38.7 (7.4) | 0.08 | 40.5 (7.5) | 39.6 (7.8) | 0.55 |
| Fat mass (g) | 30,179 (9739) | 33,325 (11,621) | 30,278 (9584) | 28,909 (8950) | 0.04 | 25,851 (6671) | 30,706 (9929) | 0.007 |
| Fat-free mass (g) | 42,876 (10,030) | 42,773 (10,278) | 42,882 (10,097) | 42,907 (9945) | 0.99 | 36,389 (7234) | 43,666 (10,046) | <.0001 |
| Appendicular lean mass (kg/m2) | 6.5 (1.2) | 6.4 (1.2) | 6.4 (1.2) | 6.5 (1.1) | 0.7 | 5.4 (0.7) | 6.6 (1.2) | <.0001 |
| Smoking status | | | | | 0.6 | | | 0.37 |
| Never | 65.7 (199) | 30 (68.2) | 90 (64.8) | 79 (65.8) | | 66.7 (22) | 65.3 (177) | |
| Current | 1.0 (3) | 1 (2.3) | 2 (1.4) | 0 (0) | | 3.0 (1) | 0.7 (2) | |
| Former | 33.3 (101) | 13 (29.5) | 47 (33.6) | 41 (34.2) | | 30.3 (10) | 34.0 (92) | |
| Daily alcoholic drinks | 0.5 (0.6) | 0.4 (0.6) | 0.4 (0.6) | 0.4 (0.5) | 0.75 | 0.5 (0.6) | 0.5 (0.6) | 0.94 |
| Heavy alcohol consumption | 5.3 (16) | 3 (6.8) | 9 (6.4) | 4 (3.3) | 0.47 | 6.0 (2) | 5.2 (14) | 0.69 |
| Average daily calories | 1791 (469) | 1739 (345) | 1826 (491) | 1769 (486) | 0.56 | 1717 (419) | 1804 (477) | 0.35 |
| Dietary protein intake (g/kg/day) | 1.0 (0.4) | 1.0 (0.3) | 1.0 (0.3) | 1.0 (0.3) | 0.61 | 1.2 (0.3) | 1.0 (0.4) | 0.03 |
| Strength | | | | | | | | |
| 1 Rep. max chest press (lbs) | 75.2 (37.2) | 64.1 (38.4) | 76.4 (37.9) | 77.3 (35.6) | 0.15 | 46.6 (19.6) | 78.5 (37.4) | <.0001 |
| 1 Rep. max leg press (lbs) | 183.9 (78.0) | 165.6 (93) | 181.7 (76) | 191.9 (74.3) | 0.17 | 117.1 (44.7) | 191.2 (77.4) | <.0001 |
| Grip strength (kg) | 29.9 (10.3) | 26.9 (10) | 30.3 (10.8) | 30.5 (9.5) | 0.11 | 20.4 (6.2) | 31.1 (10.1) | <.0001 |
| Function | | | | | | | | |
| SPPB total score | 11.4 (1.1) | 10.5 (1.8) | 11.4 (0.8) | 11.6 (0.8) | <.0001 | 11.0 (1.2) | 11.4 (1.1) | 0.03 |
| Gait speed (m/s) | 1.1 (0.2) | 1 (0.1) | 1.1 (0.2) | 1.04 (0.43) | 0.001 | 1.0 (0.2) | 1.2 (0.2) | <.0001 |
| Fitness | | | | | | | | |
| 400 m walk (time in min) | 4.5 (0.8) | 5.4 (1.2) | 4.4 (0.5) | 4.2 (0.5) | <.0001 | 5.0 (0.9) | 4.4 (0.8) | 0.0004 |
| Daily steps | 4943 (2632) | 1703 (621) | 3790 (719) | 7476 (2232) | <.0001 | 4063 (2213) | 5050 (2663) | 0.04 |
| Physical activity (MET-h/week) | | | | | | | | |
| Vigorous aerobic | 14.1 (18.7) | 6.4 (11.8) | 12.7 (18) | 18.5 (20.2) | 0.001 | 13.0 (17.8) | 14.3 (18.8) | 0.72 |

**Table 2** (continued)

| | All | Very sedentary (< 2500 steps/day) | Sedentary (2500–4999 steps/day) | Active (≥ 5000 steps/day) | P value | Sarcopenic | Not sarcopenic | P value |
|---|---|---|---|---|---|---|---|---|
| Moderate aerobic | 81.7 (65.5) | 81 (65.3) | 74.6 (66) | 90.2 (64.4) | 0.16 | 73.0 (67.5) | 82.8 (65.3) | 0.42 |
| Light aerobic | 67.3 (36.4) | 73.5 (34.4) | 64 (38.3) | 68.7 (34.5) | 0.27 | 66.1 (26.7) | 67.4 (37.4) | 0.85 |
| Resistance time | 17.7 (23.1) | 21.9 (38) | 17.9 (22.9) | 15.7 (14.5) | 0.31 | 10.2 (14.8) | 18.6 (23.8) | 0.049 |
| Sedentary time (h/day) | 11.9 (5.0) | 13.3 (6.3) | 12.2 (4.8) | 10.8 (4.3) | 0.008 | 10.6 (4.0) | 12.0 (5.1) | 0.13 |
| Self-reported health | | | | | 0.006 | | | 0.60 |
| Excellent | 0.7 (2) | 1 (2.3) | 1 (0.7) | 0 (0) | | 0.0 (0) | 0.7 (2) | |
| Very good | 25.3 (77) | 9 (20.5) | 30 (21.4) | 38 (31.7) | | 21.2 (7) | 25.8 (70) | |
| Good | 53.3 (162) | 19 (43.2) | 83 (59.3) | 60 (50.0) | | 51.5 (17) | 53.5 (145) | |
| Fair | 19.4 (59) | 12 (27.3) | 26 (18.6) | 21 (17.5) | | 24.2 (8) | 18.8 (51) | |
| Poor | 1.3 (4) | 3 (6.8) | 0 (0) | 1 (0.8) | | 3.0 (1) | 1.1 (3) | |
| Health-related quality of life (SF-36) | 725 (92) | 664 (110) | 724 (95) | 747 (70) | <.0001 | 723 (72) | 725 (94) | 0.9 |
| Geriatric depression scale (GDS) | 0.9 (1.4) | 1.1 (1.1) | 0.8 (1.3) | 0.7 (1.5) | 0.46 | 0.8 (1.4) | 0.9 (1.4) | 0.62 |
| Education | | | | | 0.73 | | | 0.49 |
| High school | 12.2 (37) | 6 (13.6) | 14 (10.0) | 17 (14.2) | | 6.1 (2) | 12.9 (35) | |
| College | 39.5 (120) | 19 (43.2) | 58 (41.4) | 43 (35.8) | | 39.4 (13) | 39.5 (107) | |
| Graduate | 48.4 (147) | 19 (43.2) | 68 (48.6) | 60 (50.0) | | 54.6 (18) | 47.6 (129) | |
| Income | | | | | 0.24 | | | 0.93 |
| Low (< $50,000) | 17.0 (59) | 9 (21.4) | 30 (3.7) | 11 (9.5) | | 9.7 (3) | 17.8 (47) | |
| Moderate ($50,000–74,999) | 22.6 (67) | 10 (23.8) | 31 (22.6) | 26 (22.4) | | 22.6 (7) | 22.7 (60) | |
| High (≥ $75,000) | 60.4 (178) | 23 (54.8) | 76 (55.5) | 79 (70.1) | | 67.7 (21) | 58.5 (157) | |
| Comorbidities | | | | | 0.04 | | | 0.53 |
| 0 | 74.9 (218) | 24 (57.1) | 104 (77.0) | 90 (79.0) | | 68.8 (22) | 75.7 (196) | |
| 1 | 19.2 (56 | 12 (28.6) | 24 (17.8) | 20 (17.5) | | 21.9 (7) | 18.9 (49) | |
| 2 | 5.5 (16) | 5 (11.9) | 7 (5.2) | 4 (3.5) | | 9.4 (3) | 5.0 (13) | |
| 3 | 0 (0) | 0 (0) | 0 (0) | 0 (0) | | 0 (0) | 0 (0) | |
| 4 | 0.3 (1) | 1 (2.4) | 0 (0) | 0 (0) | | 0 (0) | 0.4 (1) | |

Data are presented as mean (SD) or % (n). Heavy alcohol consumption was considered > 14 & > 7 alcohol drinks per week for males and females, respectively. Comorbidities include: myocardial infarction, congestive heart failure, heart arrhythmia, stroke, abnormal ECG, type 2 diabetes, and chronic obstructive pulmonary disease

*SPPB* Short Physical Performance Battery, *MET* Metabolic Equivalent

Cardiorespiratory fitness was associated with a significantly lower prevalence of sarcopenia, low muscle mass, and low handgrip strength (see Table 4). The moderate tertile of 400 m walk test was associated with reduced prevalence of having sarcopenia [0.19 (0.06, 0.57)] and low handgrip strength [0.28 (0.12, 0.63)]. The high tertile had reduced prevalence of sarcopenia [0.14 (0.04, 0.50)], low muscle mass [0.17 (0.06, 0.50)], and low handgrip strength [0.25 (0.09, 0.70)]. Overall, being fitter was associated with lower prevalence of sarcopenia, higher muscle mass, and higher handgrip strength ($p$-trend ≤ 0.003).

Sedentary time was not associated with sarcopenia [1.08 (0.37, 3.15)] (see Table 4). Reporting sedentary time less than 8 h per day was associated with lower odds of having low muscle mass and had a significant linear relationship ($p$-trend = 0.02).

**Table 3** Multinomial Linear Regression Analysis of muscle mass, muscle strength, and muscle function by lifestyle variables

| Variables | Model 1 | | | | Model 2 | | | | Model 3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | β | SE | P | Adj. $R^2$ | β | SE | P | Adj. $R^2$ | β | Standard β | SE | P | Adj. $R^2$ |
| **ALM (kg/ht²)** | | | | | | | | | | | | | 0.83 |
| SED | −0.01 | 0.01 | 0.21 | 0.78 | −0.01 | 0.01 | 0.17 | 0.78 | −0.004 | −0.01 | 0.01 | 0.61 | |
| PA | 0.05 | 0.01 | 0.001 | 0.79 | 0.05 | 0.01 | 0.001 | 0.78 | 0.02 | 0.05 | 0.01 | 0.09 | |
| CRF | −0.22 | 0.06 | <.0001 | 0.79 | −0.23 | 0.06 | 0.000 | 0.79 | −0.05 | −0.03 | 0.07 | 0.47 | |
| STR* | 0.36 | 0.04 | <.0001 | 0.84 | 0.36 | 0.04 | <.0001 | 0.83 | 0.33 | 0.23 | 0.04 | <.0001 | |
| STR† | 0.37 | 0.04 | <.0001 | 0.83 | 0.37 | 0.04 | <.0001 | 0.85 | 0.34 | 0.29 | 0.05 | <.0001 | |
| **Handgrip strength (kg)** | | | | | | | | | | | | | 0.62 |
| SED | 0.01 | 0.08 | 0.88 | 0.58 | 0.01 | 0.08 | 0.91 | 0.58 | 0.12 | 0.06 | 0.09 | 0.18 | |
| PA | 0.01 | 0.16 | 0.53 | 0.58 | 0.03 | 0.16 | 0.84 | 0.58 | −0.17 | −0.04 | 0.17 | 0.33 | |
| CRF | −3.18 | 0.62 | <.0001 | 0.62 | −3.18 | 0.67 | <.0001 | 0.61 | −3.75 | −0.25 | 0.85 | <.0001 | |
| STR* | 2.33 | 0.50 | <.0001 | 0.60 | 2.20 | 0.54 | <.0001 | 0.60 | 1.67 | 0.14 | 0.55 | 0.003 | |
| STR† | 2.56 | 0.53 | <.0001 | 0.60 | 2.38 | 0.56 | <.0001 | 0.60 | 1.78 | 0.18 | 0.59 | 0.003 | |
| **Usual gait speed (m/s)** | | | | | | | | | | | | | 0.14 |
| SED | −0.002 | 0.002 | 0.36 | 0.05 | −0.001 | 0.002 | 0.59 | 0.05 | −0.00004 | −0.001 | 0.002 | 0.99 | |
| PA | 0.01 | 0.004 | 0.05 | 0.06 | 0.01 | 0.004 | 0.21 | 0.06 | −0.001 | −0.001 | 0.01 | 0.90 | |
| CRF | −0.13 | 0.02 | <.0001 | 0.21 | −0.12 | 0.02 | <.0001 | 0.19 | −0.12 | −0.45 | 0.02 | <.0001 | |
| STR* | 0.03 | 0.01 | <.0001 | 0.02 | 0.03 | 0.02 | 0.07 | 0.04 | 0.002 | 0.01 | 0.01 | 0.87 | |
| STR† | 0.04 | 0.01 | 0.01 | 0.06 | 0.04 | 0.02 | 0.04 | 0.05 | 0.01 | 0.05 | 0.02 | 0.64 | |

Model 1: age, sex, BMI, education, and income

Model 2: further adjusted for smoking, heavy alcohol consumption, chronic conditions, and depressive symptoms

Model 3: further adjusted for other exposure variables

*ALM* Appendicular lean mass, *SED* average hours per day, *PA* average daily steps from 7 days/1000, *CRF* Time to complete a 400 m walk, *STR* chest press and leg press normalized by body weight and standardized by age- and sex-specific means and SD. *STR\** chest press and leg press normalized by body weight and standardized using sex- and age-specific values. *STR†* chest press and leg press normalized by body weight

**Table 4** Multinomial logistic regression analysis of sarcopenia according to physical activity, cardiorespiratory fitness, sedentary time, and normalized strength

| All participants (N=304) | Daily steps | | | |
|---|---|---|---|---|
| | Low (<2500) | Moderate (≥2500–<5000) | High (≥5000) | *p*-trend |
| Sarcopenia (EWGSOP) | 1.0 (Ref.) | 1.22 (0.34, 4.36) | 0.58 (0.14, 2.38) | 0.24 |
| Low muscle mass | 1.0 (Ref.) | 0.98 (0.36, 2.69) | 0.32 (0.11, 0.93) | 0.003 |
| Low handgrip strength | 1.0 (Ref.) | 0.49 (0.20, 1.21) | 0.45 (0.17, 1.21) | 0.18 |
| Low gait speed | 1.0 (Ref.) | 0.24 (0.05, 1.08) | 0.16 (0.02, 1.01) | 0.048 |
| | 400 m walk test tertile | | | |
| | Low | Moderate | High | *p*-trend |
| Sarcopenia (EWGSOP) | 1.0 (Ref.) | 0.19 (0.06, 0.57) | 0.14 (0.04, 0.50) | 0.001 |
| Low muscle mass | 1.0 (Ref.) | 0.46 (0.20, 1.08) | 0.17 (0.06, 0.50) | 0.001 |
| Low handgrip strength | 1.0 (Ref.) | 0.28 (0.12, 0.63) | 0.25 (0.09, 0.70) | 0.003 |
| Low gait speed | 1.0 (Ref.) | 0.76 (0.17, 3.39) | 0.50 (0.07, 3.62) | 0.49 |
| | Sedentary time categories | | | |
| | High (≥11 h/day) | Moderate (8–10 h/day) | Low (<8 h/day) | *p*-trend |
| Sarcopenia (EWGSOP) | 1.0 (Ref.) | 1.34 (0.52, 3.42) | 1.08 (0.37, 3.15) | 0.77 |
| Low muscle mass | 1.0 (Ref.) | 0.49 (0.23, 1.004) | 0.43 (0.19, 0.98) | 0.02 |
| Low handgrip strength | 1.0 (Ref.) | 0.84 (0.38, 1.86) | 1.54 (0.70, 3.43) | 0.40 |
| Low gait speed | 1.0 (Ref.) | 2.27 (0.61, 8.45) | 0.57 (0.06, 5.26) | 0.98 |
| | Body weight normalized and age- and sex-standardized strength tertiles | | | |
| | Low | Moderate | High | *p*-trend |
| Sarcopenia (EWGSOP) | 1.0 (Ref.) | 0.49 (0.18, 1.39) | 0.07 (0.01, 0.35) | 0.001 |
| Low muscle mass | 1.0 (Ref.) | 0.32 (0.13, 0.77) | 0.12 (0.04, 0.31) | <.0001 |
| Low handgrip strength | 1.0 (Ref.) | 0.31 (0.13, 0.70) | 0.07 (0.02, 0.25) | <.0001 |
| Low gait speed | 1.0 (Ref.) | 0.67 (0.12, 3.92) | 0.87 (0.15, 5.13) | 0.88 |

Model: adjusted for age, sex, BMI, education, income, smoking, heavy alcohol consumption, chronic conditions, and depressive symptoms

*ALM* Appendicular lean mass, *EWGSOP* European Working Group on Sarcopenia in Older People

Strength was associated with a significantly lower prevalence of sarcopenia, low muscle mass, and low handgrip strength, but not low gait speed (see Table 4). Being in the moderate tertile was associated with reduced odds of having low muscle mass [0.32 (0.13, 0.77)] and low handgrip strength [0.31 (0.13, 0.70)]. Being in the high tertile was associated with lower prevalence of sarcopenia [0.07 (0.01, 0.35)], low muscle mass [0.12 (0.04, 0.31)], and low handgrip strength [0.07 (0.02, 0.25)]. Being stronger was significantly associated with having reduced prevalence of sarcopenia, higher muscle mass, and higher handgrip strength (*p*-trend ≤ 0.001). A sensitivity analysis using strength from chest and leg press normalized by body weight without age- and sex-specific standardization revealed slightly stronger associations between strength and reduced odds of sarcopenia, low muscle mass, and low handgrip strength (see Table 5). These associations were

stronger due to higher number of cases in the reference groups for these analyses.

Joint associations between predictor variables were conducted to compare the independent and additive effects of combinations of PA, SED, CRF, and STR variables (see Table 6) on odds of having sarcopenia. These joint analyses have great potential public health implications to maximize the benefits of PA, reduced sitting time, and improved fitness and strength in relation to sarcopenia. Being physically active and sedentary was associated with lower odds of having sarcopenia. Being fit, regardless of physical activity level, resulted in lower odds of having sarcopenia. Being in the top two-thirds of strength was associated with lower odds of having sarcopenia, but additional benefit was gained from also being physically active. Being in the top two-thirds of fitness was associated with lower odds of having sarcopenia, but also being

sedentary seemed to confer additional benefit. Being both strong and sedentary was associated with lower odds of having sarcopenia. Finally, being in the top two-thirds of either fitness or strength was associated with lower risk of having sarcopenia, but some additional benefit was seen for those in the top two-thirds of both fitness and strength.

Given the low number of cases of low gait speed observed ($n = 14$), it is unlikely for significant associations to be revealed due to lower statistical power. In general, adding diet variables relevant to sarcopenia (total kcals per day, daily protein intake) into the logistic regression models reduced the number of cases (9–22%) and significantly decreased the sample size (30%) because of the significant missing or insufficient data on diet (30%). This resulted in smaller associations between exposure and outcome variables and wider confidence intervals (data not shown), although the trends of the results were generally similar. Therefore, the final model did not include diet variables despite their clear importance in analyzing the data.

## Discussion

In this study of community-dwelling older adults, the results indicate that physical activity (PA), sedentary time (SED), cardiorespiratory fitness (CRF), and strength (STR) were associated with sarcopenia or components of sarcopenia (low muscle mass, low grip strength, or slow gait speed). The 10.9% prevalence of sarcopenia observed was similar to data summarized in a recent review [11]. Therefore, older adults who are physically active, maintain higher levels of cardiorespiratory fitness, upper and lower body strength, and avoid sedentary time may have significantly lower odds of sarcopenia.

Our results regarding the associations between PA and sarcopenia are consistent with earlier literature. A recent review and meta-analysis indicated a consistent relationship between PA and sarcopenia in cross-sectional and cohort studies as well as lower odds of having sarcopenia in more active groups compared to less active groups [0.45 (0.37, 0.55)] [15]. Most studies lacked objectively measured PA, standard measurements of ALM like DXA, and failed to follow an established sarcopenia definition. A recent study in older adults from England using accelerometry-based PA indicated that a standard deviation (SD) increase in average acceleration reduced the risk of having sarcopenia [0.65 (0.43, 0.99)], but single SD increases in moderate to vigorous physical activity (MVPA) and non-sedentary time were not significant in the fully adjusted model including gender, age, height, weight-for-height residual, smoking history, alcohol consumption, and social class as potential confounders [0.67 (0.44, 1.01) and 0.70 (0.43, 1.13)] [44]. Objectively measured PA was

associated with severe sarcopenia even after adjusting for SED, although only mid-arm muscle circumference was used to identify low muscle mass instead of DXA [17]. Over 71% of our sample failed to accumulate on average 5000 steps per day, classifying them as sedentary. Normative data indicate that healthy older adults accumulate > 6000 steps daily [20].

Regarding the associations between SED and sarcopenia, stronger associations were present in other studies, whereas sitting less than 8 h per day was associated with lower odds of low muscle mass [0.43 (0.19, 0.98)] in the present study. Six of the nine regression models indicated that SED was a significant risk factor for older adults [15]. Aggio and colleagues reported that additional sedentary time was associated with severe sarcopenia, although the relationship was no longer significant after adjusting for MVPA [17].

The results exploring the association between CRF and sarcopenia indicate a strong relationship. Being in the fastest two tertiles of the 400-m walk test was significantly associated with sarcopenia (80–85% lower odds), low muscle mass, and low grip strength. Few other studies have explored this relationship. One study found associations between components of fitness (balance, strength, flexibility, aerobic capacity) and sarcopenia, identified by low fat-free mass measured by bioelectrical impendance [45], and another found an association using a 3-min step test for fitness and sarcopenia identified by low muscle mass only [46].

No other studies were found exploring the relationship between STR and sarcopenia. Our results indicate a low prevalence of sarcopenia (93% lower odds) by being in the strongest tertile, as well as a 68–78% lower odds of having low muscle mass and 69–93% lower odds of low grip strength by being in the top two strongest tertiles.

Inactivity, indicated by low step counts, is a form of mild immobilization or disuse and occurs more often in older adult populations compared to younger adults [47]. Older adults subjected to 4 days of reduced steps failed to return to baseline values of dynamic strength, isometric strength, and rate of force development after a 7 day recovery, but the young individuals showed a full recovery [48]. Another reduced ambulation study in older adults recorded a loss of 3.9% (0.4 kg) reduction in leg lean mass, which is equivalent to a twice the typical annual loss in just 2 weeks [49]. Reduced steps and sedentary behavior appear to blunt the response to ingestion of dietary protein, leading to lower muscle protein synthesis and a net loss in muscle mass [47]. Due to its role in lipid oxidation and post-prandial glucose disposal, maintenance of muscle mass is critical for metabolic health [47]. Overall, physical inactivity in older adults is a primary cause of insulin resistance and progression of type 2 diabetes [50].

Several limitations should be acknowledged. Overall, only 33 cases of sarcopenia were observed at baseline, of which the lowest cases came from low gait speed, therefore the associations with low gait speed were limited across all exposure variables. Although PA, CRF, and STR were objectively measured, SED was self-reported, therefore this measurement is subject to recall error and over/underestimation that the other variables were not. Assessments were conducted at time points across multiple seasons allowing for some variation due to seasonal weather that was not controlled. The cross-sectional design allowed exploration of the associations between variables, but causal links were not possible, therefore it is possible that sarcopenia was the cause of low PA, CRF, STR and high SED. Finally, the sample appeared to be quite healthy, possibly indicating a healthy responder bias, and came from a sample without ethnic diversity, therefore generalizability to the population may be limited.

The study had various strengths. This is one of the few studies that included objective measurement of exposure variables and a DXA-derived definition of sarcopenia. To our knowledge, this is the only study to explore all PA, SED, CRF, and STR and sarcopenia in the same study. Finally, the full model included a comprehensive set of variables associated with sarcopenia, which is lacking in many cross-sectional studies.

## Conclusions

In conclusion, we have shown that objectively measured physical activity, cardiorespiratory fitness, and strength, as well as self-reported sedentary time, appear to be associated with sarcopenia and its components. Therefore, older adults who are physically active, maintain higher levels of cardiorespiratory fitness, upper and lower body strength, and avoid sedentary time may have lower odds of sarcopenia prevalence. Further prospective study is clearly required to see the causal relationship between physical activity, cardiorespiratory fitness, strength and sedentary behavior and sarcopenia.

### Compliance with ethical standards

## Appendix

See Tables 5 and 6.

**Table 5** Multinomial logistic regression analysis of sarcopenia according to strength (sensitivity analysis)

| Body weight normalized strength tertiles | | | | |
|---|---|---|---|---|
| All participants (N=304) | Low | Moderate | High | p-trend |
| Sarcopenia (EWGSOP) | | | | |
| Model 1 | 1.0 (Ref.) | 0.11 (0.03, 0.43) | 0.02 (0.003, 0.21) | |
| Model 2 | 1.0 (Ref.) | 0.13 (0.03, 0.52) | 0.02 (0.002, 0.20) | 0.0003 |
| Low muscle mass | | | | |
| Model 1 | 1.0 (Ref.) | 0.38 (0.16, 0.92) | 0.07 (0.02, 0.25) | |
| Model 2 | 1.0 (Ref.) | 0.40 (0.16, 1.01) | 0.07 (0.02, 0.25) | <.0001 |
| Low handgrip strength | | | | |
| Model 1 | 1.0 (Ref.) | 0.08 (0.02, 0.25) | 0.03 (0.01, 0.16) | |
| Model 2 | 1.0 (Ref.) | 0.08 (0.02, 0.27) | 0.03 (0.01, 0.18) | <.0001 |
| Low gait speed | | | | |
| Model 1 | 1.0 (Ref.) | 0.27 (0.04, 1.66) | 0.26 (0.02, 2.89) | |
| Model 2 | 1.0 (Ref.) | 0.41 (0.05, 3.16) | 0.77 (0.06, 9.43) | 0.69 |

Model 1: adjusted for age, sex, BMI, education, and income

Model 2: further adjusted for smoking, heavy alcohol consumption, chronic conditions, and depressive symptoms

*ALM* Appendicular lean mass, *EWGSOP* European Working Group on Sarcopenia in Older People

**Table 6** Joint analysis between physical activity, sedentary time, fitness, and strength on sarcopenia in 304 older people

|  | Physical activity and sedentary time | | | |
|---|---|---|---|---|
|  | Inactive and sedentary | Inactive and not sedentary | Active and sedentary | Active and not sedentary |
| n (cases) | 76 (15) | 108 (10) | 63 (3) | 57 (5) |
| Odds ratio (95% CI) | 1.0 (Ref.) | 0.48 (0.18, 1.29) | 0.22 (0.06, 0.88) | 0.50 (0.15, 1.65) |
|  | Physical activity and cardiorespiratory fitness | | | |
|  | Inactive and unfit | Inactive and fit | Active and unfit | Active and fit |
| n (cases) | 79 (18) | 105 (7) | 25 (3) | 95 (5) |
| Odds ratio (95% CI) | 1.0 (Ref.) | 0.15 (0.05, 0.46) | 0.39 (0.09, 1.65) | 0.11 (0.03, 0.41) |
|  | Physical activity and strength | | | |
|  | Inactive and weak | Inactive and strong | Active and weak | Active and strong |
| n (cases) | 62 (11) | 98 (9) | 28 (3) | 86 (3) |
| Odds ratio (95% CI) | 1.0 (Ref.) | 0.27 (0.09, 0.82) | 0.47 (0.10, 2.29) | 0.10 (0.02, 0.45) |
|  | Sedentary time and cardiorespiratory fitness | | | |
|  | Sedentary and unfit | Sedentary and fit | Not sedentary and unfit | Not sedentary and fit |
| n (cases) | 64 (13) | 101 (2) | 40 (8) | 99 (10) |
| Odds ratio (95% CI) | 1.0 (Ref.) | 0.04 (0.01, 0.21) | 0.44 (0.13, 1.52) | 0.23 (0.07, 0.74) |
|  | Sedentary time and strength | | | |
|  | Sedentary and weak | Sedentary and strong | Not sedentary and weak | Not sedentary and strong |
| n (cases) | 58 (9) | 89 (3) | 35 (5) | 95 (9) |
| Odds ratio (95% CI) | 1.0 (Ref.) | 0.13 (0.03, 0.55) | 0.81 (0.19, 3.45) | 0.32 (0.10, 1.03) |
|  | Cardiorespiratory fitness and strength | | | |
|  | Unfit and weak | Unfit and strong | Fit and weak | Fit and strong |
| n (cases) | 42 (10) | 40 (4) | 48 (4) | 144 (8) |
| Odds ratio (95% CI) | 1.0 (Ref.) | 0.15 (0.03, 0.73) | 0.17 (0.04, 0.80) | 0.08 (0.02, 0.31) |

Model adjusted for age, sex, BMI, education, income, smoking, heavy alcohol consumption, chronic conditions, and depressive symptoms

Inactive: < 5000 steps per day, active: ≥ 5000 steps per day. Sedentary: ≥ 11 h sitting time per day. Not Sedentary: < 11 h sitting time per day. Unfit: slowest tertile on 400 m walk test. Fit: fastest two tertiles on 400 m walk test. Weak: bottom tertile in weight normalized and age-/sex-specific standardized strength category. Strong: upper two tertiles in weight-normalized and age-/sex-specific standardized strength category

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