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Review Article

Associations Between Measures of Physical Activity and Muscle Size and Strength: A Systematic Review

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Exercise;
Muscle, skeletal;
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Abstract *Objective:* To determine whether physical activity is associated with lower limb muscle size and strength within the general population.
Data Sources: Six databases were systematically searched from inception using 3 main constructs: lower extremity, muscle volume, and muscle strength.
Study Selection: Studies that measured physical activity (using either objective or subjective measurements), lower limb muscle size, and strength were included. Available discrete group data were standardized using previously published age- and sex-specific normative values prior to analysis.
Data Extraction: The final analysis included 47 studies from an initial yield of 5402 studies. Standardized scores for outcome measures were calculated for 97 discrete groups.
Data Synthesis: As anticipated, lower limb muscle size was positively correlated with lower limb muscle strength (r=0.26, P<.01; n=4812). Objectively measured physical activity (ie, accelerometry, pedometry) (n=1944) was positively correlated with both lower limb muscle size (r=0.30, P<.01; n=1626) and lower limb strength (r=0.24, P<.01; n=1869). However, subjectively measured physical activity (ie, questionnaires) (n=3949) was negatively associated with lower limb muscle size (r=−0.59, P<.01; n=3243) and lower limb muscle strength (r=−0.48, P<. 01; n=3882).
Conclusions: This review identified that objective measures of physical activity are moderately associated with lower limb muscle size and muscle strength and can, therefore, be used to predict muscle changes within the lower limbs associated with exercise-based rehabilitation programs.

List of abbreviations: BMI, body mass index; CSA, cross-sectional area; IPAQ, international physical activity questionnaire; MRI, magnetic resonance imaging; MVPA, moderate to vigorous physical activity; 1RM, 1 repetition maximum.
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Physical activity has been shown to have widespread benefits for health and disease prevention[1] with a positive effect on various health conditions, including coronary heart disease, type 2 diabetes, and obesity.[2] Consistent with this, lower levels of physical activity may result in various negative effects such as a decline in muscle function, particularly strength[3] and muscle size.[4] Decreased muscle strength, in turn negatively affects the ability of older adults to live independently and contributes to the frailty syndrome.[5]

Strong associations have previously been identified between overall muscle strength and higher intensity physical activity in young healthy adults,[6] and age-related decline in muscle size and strength has been observed to coincide with diminished activity levels.[7] Similarly, reductions in physical activity, hip stabilizer muscle size, and strength have all been reported in pathologic populations, including individuals with hip osteoarthritis[8] and gluteal tendinopathy.[9] Therefore, muscle size and strength appear to be related to the amount and intensity of regular activity performed. Strength is an indicator of functional disability and strength tests (eg, using a hand-held dynamometer) assess the ability of groups of muscles to produce combined force during particular joint movements. For example, a hip abduction strength test will measure the overall force produced by the combined activation of gluteus medius, gluteus minimus, and tensor fascia lata. However, because these tests are reliant on neuromuscular activation of a group of muscles, they cannot identify changes in any one particular muscle. In contrast, muscle size assesses a single muscle (or sometimes a muscle part) that may be linked to a particular functional task. For example, imaging techniques that identify structural changes within a given muscle (eg, atrophy and fatty infiltration) can identify changes within a specific muscle, which can be the result of multiple factors, including declining age or decreased activity. Again, this relates to functional tasks (eg, the anterior fibers of gluteus minimus are known to be active later than the rest of the gluteal muscles during the stance phase of walking to stabilize the anterior hip joint).[10] Therefore, strength and muscle size are different, but potentially related, constructs.

Global descriptors for intensity of physical activity include sedentary, light, moderate, and vigorous.[11] The quantity of moderate to vigorous physical activity (MVPA) has been associated with greater physical benefits such as increased cardiorespiratory fitness and overall work capacity[12] but not specifically with improvements in muscle size and strength as far as we know. Neuromuscular adaptations, such as more efficient recruitment of motor units,[13] can result in improved muscle strength after increased physical activity and may not necessarily be linked to changes in muscle size. Consequently, to compare the associations between physical activity with muscle size and strength, it is important to undertake these comparisons within the same population.

Physical activity can be quantified using measures, such as frequency and intensity, that can be measured both objectively and subjectively. Objective measures of physical activity (eg, accelerometry, pedometry) provide a direct measure of an individual's physical activity throughout a specified time period ranging from hours to days or weeks.[14] In contrast, subjective measures of physical activity typically use self-reported questionnaires, which can be less time consuming and less expensive to collect and analyze data. For example, the International Physical Activity Questionnaire (IPAQ) is a validated, self-administered questionnaire that determines an individual's physical activity level of the previous 7 days.[15] However, data from self-reported questionnaires can over- or underestimate intensity and duration of physical activity.[16]

Clinicians and exercise professionals often promote physical activity with the intention to improve muscle size and/or strength.[17] Therefore, measures of muscle size and/or strength are crucial when assessing the individual's progression, prior to, during, and after clinical rehabilitation programs that incorporate physical activity. Muscle size can be accurately measured using techniques such as magnetic resonance imaging (MRI).[18] However, techniques like MRI are not readily available in rehabilitation settings owing to cost and lack of technical expertise. Therefore, strength testing is commonly used to assess changes in muscle function in rehabilitation settings because it is less time consuming and does not require a great amount of technical expertise when compared with other measures.[19]

Commonly used measures of physical activity (eg, questionnaires, pedometers) are generally related to weight-bearing tasks (eg, walking, running) that primarily recruit the muscles of the lower limbs. Skeletal muscle mass of the lower limb accounts for more than half of the total body skeletal muscle mass.[20] Therefore, it might be expected that these measures of physical activity, which rely on lower limb muscle mass recruitment, will be good predictors of lower limb muscle size and strength.

The objective of this systematic review was to determine the relationships between objective and subjective measures of physical activity with lower limb muscular size and strength in a broad cross-section of the general population.

Methods

Search strategy with study identification

Literature searches were systematically completed using 6 databases (Australian sport database, The Cumulative Index to Nursing & Allied Health Literature database, The Cochrane Library database, Embase, Medline, and Scopus) from the earliest possible date to August 2020. Three main constructs were used: lower extremity, muscle size, and muscle strength, which were combined using the "AND" boolean operator (table 1). Synonyms were then used for each construct and pooled using the "OR" operator. Only

Table 1 Main construct terms and synonyms

Constructs	Lower Extremity	Muscle Size	Muscle Strength
Synonyms	Lower limb muscle	Muscle volume	Muscle strength
	Hip	Muscle structure	
	Knee	CSA	
	Ankle	CSA	
	Hip muscle	MRI	
	Knee muscle	MRI	
	Glute*	Ultrasound	
	Quad*		
	Gluteus minimus		
	Gluteus medius		
	Gluteus maximus		
	Vastus lateralis		
	Vastus medialis		
	Rectus femoris		
	Sartorius		
	Gastrocnemius		
	Soleus		

Abbreviation: CSA, cross-sectional area.
* Truncated term.

studies that included all 3 constructs (physical activity, muscle size, strength) were included because we intended to evaluate the relationship between measures of physical activity with both muscle strength and muscle size in the same participants. "Physical activity" was not used as a construct within this search because of very low yields when combined with the other constructs during initial screening, but it was instead used as an inclusion criterion (supplemental table S1, available online only at http://www.archives-pmr.org/) during full-text screening.

Title and abstract screening were completed independently by 2 reviewers (Z. R, A. Z) using the inclusion criteria (see supplemental table S1, available online only at http://www.archives-pmr.org/). Differences in opinion were discussed until a consensus was reached. The included full-text studies were then screened using the same criteria to identify the final studies for data extraction (fig 1).

Study selection

Population

The included studies were restricted to human participants over the age of 18 years (ie, adults). No studies were excluded on the basis of population type, and therefore included a variety of participants (eg, older, healthy, athletes, pathologic).

Outcomes

This study aimed to identify whether physical activity was associated with both muscle strength and muscle size. Therefore, all included studies required a measure of physical activity (objective or subjective), muscle size, and muscle strength to allow for a comparison to be made. For intervention studies, only baseline data were included when reported. Studies were required to use an objective measure of lower limb muscular strength; for example, 1 repetition maximum (1RM), multiple repetition maximum, or maximal voluntary contraction.

Included studies were required to contain a measure of lower limb muscle size. For example, volume, thickness, mass, or cross-sectional area and could be determined using a range of imaging techniques (eg, MRI, ultrasound, dual-energy x-ray absorptiometry). The search was restricted to large weight-bearing muscles or muscle groups of the lower limb (eg, quadriceps femoris, gluteals, gastrocnemius), which were likely to be acting as prime movers during most types of weight-bearing physical activities and are therefore more likely to show a link between weight-bearing activities and muscle size or strength.

A quantifiable measure of physical activity or exercise was also required for inclusion, using either objective (eg, accelerometer, pedometer) or subjective (typically a questionnaire) measures. This could include studies with appropriate frequency, intensity, time, and type information or other quantifiable measures of physical activity (eg, arbitrary units, steps).

Research design

Cross-sectional and intervention (baseline data only) study designs were included. Studies were included in which original data were published in English-language peer reviewed full papers (conference proceedings, letters to the editors, and reviews were excluded).

Data extraction

Data from included studies were extracted by 1 reviewer (Z. R) using a custom spreadsheet (supplemental table S2, available online only at http://www.archives-pmr.org/) created for this review and verified by a second reviewer (A. Z). Data extracted included demographic characteristics, if reported, of participants (age, sex, body mass index [BMI], health status [eg, healthy young adults, older adults with rheumatoid

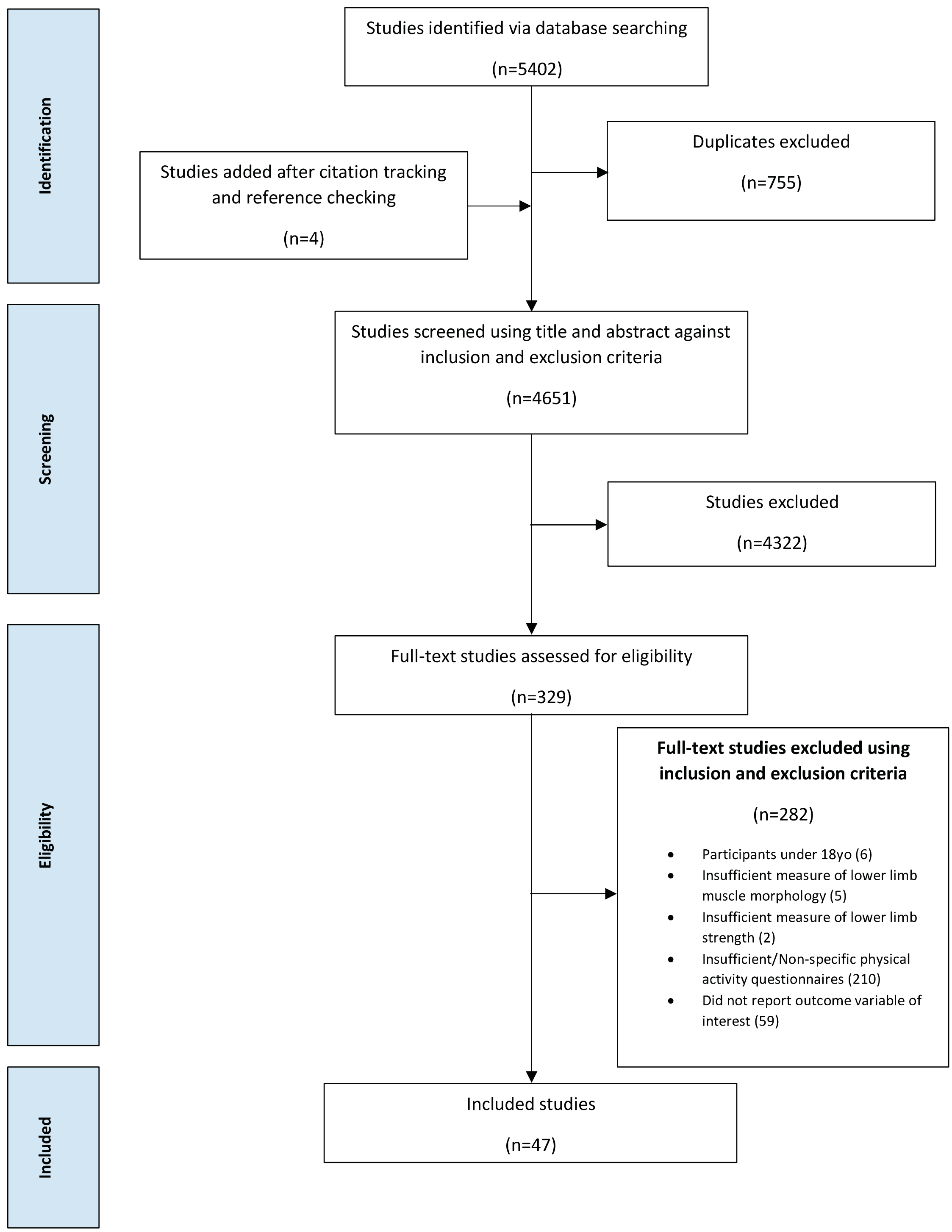


Fig 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses flowchart summarizing the yield of the search strategy and screen procedure.

arthritis]) and outcome measures of physical activity, muscle size, and muscle strength. Values for all outcome variables were extracted for each study and any participant subgroups. A subgroup was classified as a group of participants for which data were reported separately in the original study. At least 1 data point was required for each study or subgroup, so when multiple outcome measures were reported (eg, for multiple muscle groups such as quadriceps and hamstrings), data for 1 muscle group were extracted for analysis. This was selected on the basis that appropriate normative values were available for that outcome measure.

We extracted and categorized physical activity data as either objective or subjective measures of physical activity. Data obtained via questionnaires were classified as subjective; if a device (eg, accelerometer or pedometer) was used to measure activity, the method was classified as being objective. To allow for comparison between studies, values were converted to common units (details of conversion calculations in supplemental table S3, available online only at http://www.archives-pmr.org/). The units of objective physical activity data included minutes per week of MVPA, metabolic equivalent × minutes per week, kilocalories per week, accelerometry arbitrary units via accelerometry, and steps per day collected via a pedometer. All physical activity data collected subjectively were calculated and represented as minutes per week of MVPA or metabolic equivalent × minutes per week. Some studies reported energy expenditure values, which were subsequently converted to metabolic equivalent values.

Muscle size data were extracted for each included study and then, when necessary, converted to common units including cross-sectional area (cm^2), muscle volume (cm^3), muscle thickness (cm), and lean muscle mass (kg). If normative data were only available for bilateral lower limb muscle size, extracted data for unilateral size outcomes were multiplied by 2.

Muscle strength was reported for different types of muscle contractions (eg, isometric or isokinetic) and included multiple measures (eg, isometric at different points in the range of movement). Strength data were extracted for 1 measure (based on availability of normative data) and converted to common units including 1RM in kilograms or newtons. If normative data were only available for bilateral measures, extracted data for unilateral strength outcomes were multiplied by 2.

Quality assessment

Methodological quality of the included studies was assessed using a modified version of a questionnaire originally reported by Downs and Black.[21] Only 9 of the 27 items were used to assess any bias in reporting (items 2, 3, 5, 6, 7, and 10), validity (items 11 and 20), and power (item 27).

Data analysis

To allow comparison of different variables (eg, quadriceps cross-sectional area vs thigh muscle volume) for the same outcome measure (in this case, muscle size) between subgroups, data were normalized based on the age and sex of the participants in each subgroup. Normative values were obtained for measures of physical activity,[22-26] muscle size,[27-34] and muscle strength[35-41] from large studies with data for a range of age groups and both sexes when possible (supplemental table S4, available online only at http://www.archives-pmr.org/). Mean data for each included subgroup were converted to *z* scores through comparison to age- and sex-specific normative data using standard equations. To allow inclusion of data from mixed-sex subgroups in which data (extracted from subgroups or normative values) were not reported separately for male and female participants (mixed-sex groups), factors to account for typical sex differences in outcome measures were used to calculate standardized scores. These factors were based on large studies reporting male and female data separately on a variable for each outcome measure (supplemental table S5, available online only at http://www.archives-pmr.org/). The factor to account for sex differences (ratio of male to female data) in outcome measures were calculated as follows: physical activity (1.68),[42] muscle size (1.38),[43] and muscle strength (1.62).[44] Standardized scores for any included subgroup were capped at a maximum value of 3 to limit the influence of extreme values on the correlations between outcomes on the basis that such a *z* score is statistically unlikely.

To determine the strength of relationships between measures of physical activity with both muscle size and strength, and the relationship between muscle size and strength, weighted correlation analyses were conducted to combine standardized data from all included subgroups for each pair of outcome measures. Weighted linear regression correlations (*r*) were calculated between mean *z* scores for each pair of outcome measures with each study subgroup treated as a separate data point and weighted on subgroup size. Analyses were conducted separately for objective and subjective measures of physical activity. Because subjective assessment of physical activity has been suggested to be less accurate for older overweight populations,[45] sensitivity analyses were conducted by calculating a separate correlation for subgroups in younger (<35y), middle (35-50y), and older (>50y) age groups for both subjective and objective measures of physical activity. Correlation coefficient (*r*) values can range from −1.00 (a perfect negative correlation) to 1.00 (a perfect positive correlation), with a value of 0.00 indicating no relationship between the 2 variables.[46] The strength of the correlation was defined using the following criteria: trivial ($r<0.1$), small (r, ≤0.1 to <0.3), moderate (r, ≤0.3 to <0.5), strong (r, ≤0.5 to <0.7), very strong (r, ≤0.7 to <0.9), nearly perfect (r, ≤0.9 to <1.0), and perfect (r=1.0).[47] Data analysis was completed using IBM SPSS Statistics for Windows, version 27.0.[a]

Results

Search yield

After the initial database search, a total of 5402 studies were identified (fig 1). Removal of duplicates, title and abstract screening, and full-text screening was completed, resulting in a final yield of 47 studies, with a total of 5893 participants (table 2). The studies included 14 randomized controlled trials,[48-61] 27 cross-sectional studies,[62-88] and 6 longitudinal studies.[89-94] Studies that reported objective measures of physical activity included 23 of the 47 (18 using accelerometers and 5 using pedometers), with 1944 participants (46.2% men, 53.8% women) with a weighted mean age of 57.7±9.4 years and BMI of 27.3 kg/m^2 (available for only 16 studies). Studies that reported subjective measures of physical activity included 24 of the 47 (10 using the IPAQ, 7 using a version of the Yale questionnaire, and 7 using population-specific physical activity questionnaires) with 3949 participants (50.8% men, 49.2% women) with a weighted mean age of 58.8±14.9 years and a BMI of 26.8 kg/m^2 (available for only 16 studies). There were 97 subgroups available for the weighted linear regression analysis, including 43 data points with a measure of objective physical activity and a 54 with a measure of subjective physical activity.

Table 2 Measures of physical activity, muscle size, and strength of subgroups in the included studies.

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
Abe et al[62] Cross-sectional study	Healthy women, n=57 3 groups, based on timed balance: G1: < 60 s (n=19) G2: 60-120 s (n=12) G3: > 120 s (n=26) Mean age: G1: 69±5 y G2: 68±7 y G3: 64±7 y BMI (kg/m^2): G1: 21.0±2.7 G2: 23.0±1.9 G3: 22.4±2.6	Ultrasound Unilateral upper thigh mass (kgs): G1: 5.0±0.6 G2: 4.9±0.7 G3: 5.0±0.7 z score: G1: −2.89±0.32 G2: −2.95±0.37 G3: −2.89±0.37	Dynamometer Unilateral isometric knee extension 90 degrees (Nm): G1: 99±25 G2: 107±26 G3: 106±25 z score: G1: 0.64±0.93 G2: 0.94±0.97 G3: 0.90±0.93	Accelerometry Moderate exercise (min/d): G1: 15.1±16.6 G2: 15.7±12.8 G3: 28.4±15.4 Vigorous exercise (min/d): G1: 0.6±0.6 G2: 1.2±1.4 G3: 2.4±1.7 MVPA (min/d): G1: 15.7±16.6 G2: 16.9±12.9 G3: 30.8±15.5 MVPA (min/wk)*: G1: 109.9±116.2 G2: 118.3±90.3 G3: 215.6±108.5 z score: G1: −0.42±0.71 G2: −0.37±0.55 G3: −0.15±1.63
Abe et al[63] Cross-sectional study	Healthy men, n = 55 3 groups: G1: young men (n=16) G2: middle-aged men (n=13) G3: older men (n=26) Mean age: G1: 24±6 y G2: 56±7 y G3: 72±4 y BMI (kg/m^2): G1: 22.2±2.6 G2: 23.0±3.5 G3: 23.9±1.9	Ultrasound Unilateral anterior thigh muscle thickness (cm): G1: 5.36±0.77 G2: 4.69±0.53 G3: 4.38±0.49 z score: G1: 0.06±0.76 G2: −0.60±0.52 G3: −0.91±0.49	Dynamometer Bilateral isometric knee extension 90 degrees (Nm): G1: 267±75 G2: 208±59 G3: 154±30 z score: G1: 1.16±1.34 G2: 0.11±1.05 G3: 0.18±0.84	Accelerometry MVPA (min/d): G1: 41.0±12.8 G2: 40.5±15.6 G3: 25.9± 18.0 MVPA (min/wk)*: G1: 280.0±89.6 G2: 283.5±109.2 G3: 181.3±126.0 z score: G1: 0.18±0.52 G2: 0.16±0.63 G3: −0.17±0.72
Ahedi et al[64] Cross-sectional study	Older adults, n = 325 2 groups: G1: men (n=167) G2: women (n=158) Mean age: G1: 64.04±7.47 y G2: 63.26±6.60 y	MRI Unilateral gluteus maximus CSA (cm^2): G1: 51.4±13.6 G2: 42.20±8.05 z score: G1: 0.68±1.64	Dynamometer Bilateral isometric knee extension (kg): G1: 135.32±45.70 G2: 63.11±28.90 z score: G1: 2.12±2.22	Pedometer Step counts (steps/d): G1: 8268±3703 G2: 7384±3234 z score: G1: −0.60±3.69 G2: 0.12±−2.25

(continued)

Table 2 (*Continued*)

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
	BMI (kg/m^2): G1: 27.50±3.91 G2: 28.13±5.23	G2: 1.68±0.97	G2: 0.16±1.70	
Baker et al[65] Cross-sectional study	Adults with RA, n = 550 2 groups: G1: RA patients (n=50) G2: controls (n=500) Mean age: G1: 51.2±13.3 y G2: 50.0±16.0 y BMI (kg/m^2): G1: 30.1±8.5 G2: 26.6±5.6	CT Unilateral calf muscle CSA (cm^2): G1: 64.4±12.5 G2: 71.7±13.0 z score[†]:	Dynamometer Unilateral isokinetic dorsiflexion 20 degrees/s (foot-pounds): G1: 19.4±7.2 G2: 23.7±8.5 Dorsiflexion 20 degrees/s (Nm)[‡] G1: 26.3±9.8 G2: 32.1±11.5 z score: G1: −0.23±1.07 G2: 0.40±1.25	Adapted physical activity questionnaire Intentional exercise, median (IQR) (MET-h/wk): G1: 17.7 (1.6-47.5) G2: 26.8 (7.7-69.6) MET-h/wk[§]: G1: 22.5±35.0 G2: 35.1±46.0 MET-min/wk[‖]: G1: 1350.0±2100.0 G2: 2106.0±2760.0 z score: G1: −0.18±−8.41 G2: 0.07±−18.67
Berger et al[66] Cross-sectional study	Healthy adults, n = 105 4 groups: G1: young women (n=27) G2: young men (n=27) G3: older women (n=26) G4: older men (n=25) Mean age: G1: 32.4±7.1 G2: 34.6±6.7 G3: 72.5±5.8 G4: 74.5±6.5 BMI (kg/m^2): G1: 24.0±3.0 G2: 26.9±3.7 G3: 30.4±4.3 G4: 27.6±3.4	Ultrasound Unilateral rectus femoris thickness (mm): G1: 21.0±2.2 G2: 26.9±3.5 G3: 18.2±2.3 G4: 21.6±3.1 Thickness (cm)[¶]: G1: 2.1±0.2 G2: 2.7±0.4 G3: 1.8±0.2 G4: 2.2±0.3 z score: G1: 1.45±0.55 G2: 1.48±0.88 G3: 3.61±1.21 G4: 3.13±1.63	Isometric force transducer Unilateral (right) isometric knee extension 70 degrees (kg): G1: 37.4±6.6 G2: 48.7±11.9 G3: 24.9±6.4 G4: 35.8±7.6 Unilateral (left) isometric knee extension 70 degrees (kg): G1: 35.4±5.1 G2: 51.7±11.4 G3: 27.2±9 G4: 42.1±12.5 Bilateral isometric knee extension 70 degrees (kg)[#]: G1: 72.8±8.3 G2: 100.4±16.5 G3: 52.1±11 G4: 77.9±14.6 z score:	IPAQ Physical activity (MET-min/wk): G1: 1119.8±848.5 G2: 1871.7±1490.4 G3: 729.4±413.8 G4: 1225.3±1243.8 z score: G1: −0.07±0.47 G2: −0.12±0.82 G3: −0.08±0.10 G4: −0.13±0.30

(continued)

Table 2 (*Continued*)

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
			G1: 2.04±0.52 G2: 2.05±1.04 G3: −0.24±0.65 G4 = −0.15±0.68	
Campbell et al[48] RCT	Healthy adults, n = 29 3 groups: G1: sedentary adults (n=10) G2: lower body resistance (n=9) G3: whole body resistance (n=10) Mean age: G1: 66±3 y G2: 67±3 y G3: 65±2 y BMI (kg/m^2)[†]:	CT Unilateral midthigh CSA (cm^2): G1 (n=8): 100.4±8.0 G2: 115.6±12.6 G3: 113.5±8.8 SEM converted to SD[**]: G1: 100.4±22.6 G2: 115.6±37.8 G3: 113.5±27.8 z score: G1: −1.02±0.87 G2: −0.43±1.45 G3: −0.51±1.07	Keiser pneumatic resistive exercise equipment Bilateral knee extension and flexion 1RM (Nm): G1: 297±42 G2: 290±50 G3: 280±40 SEM converted to SD[**]: G1: 297.0±132.8 G2:290.0± 150.0 G3: 280.0±126.5 z score: G1: 1.74±2.11 G2: 1.63±2.38 G3: 1.47±2.01	Physical activity questionnaire (Yale survey) Energy expenditure of physical activity (MJ/d): G1: 3.10±0.53 G2: 2.70±0.53 G3: 3.03±0.56 MJ converted to kcal/d[††]: G1: 740.4±126.6 G2: 644.9±126.6 G3: 723.7±133.8 kcal/d converted to kcal/wk[‡‡]: G1: 5182.8±886.2 G2: 4514.3±886.2 G3: 5065.9±935.9 z score: G1: 0.06±0.34 G2: −0.20±0.34 G3: 0.01±0.35
Cebollero et al[49] RCT	Men with stable COPD, n = 35 2 groups, based on lung capacity: G1: n=16 G2: n=19 Mean age: G1: 71±5 y G2: 68±5 y BMI (kg/m^2): G1: 25.3±3.7 G2: 29.6±5.3	MRI Bilateral thigh muscle volume (cm^3): G1: 413.91±89.42 G2: 575.20±115.25 z score: G1: −1.67±0.91 G2: −0.03±1.18	Leg press exercise Bilateral knee extension 1RM (kg)[§§]: G1: 148±29 G2: 199±50 z score: G1: −2.38±2.07 G2: 1.27±3.57	Accelerometry Habitual physical activity (kcals/wk): G1: 7228±1459 G2: 9250±1952 z score: G1: 1.56±0.56 G2: 2.34±0.75
Centner et al[61] RCT	Healthy women, n = 40 2 groups based on intervention: G1: n=21 G2: n=19 Mean age: G1: 26.1±4.4 y	Ultrasound Unilateral vastus lateralis CSA (cm^2): G1: 19.2±3.0 G2: 17.4±2.2 z score: G1: 0.58±1.05	Custom built muscular strength device Bilateral isometric knee extension 90 degrees (N): G1: 1221.4±258.6 G2: 1180.1±250.1 Converted to kgs[‖‖]:	Physical activity questionnaire (Freiburg questionnaire) Physical activity (kcals/wk): G1: 2617.9±2184.2 G2: 2875.9±2131.8 z score:

(*continued*)

Table 2 (*Continued*)

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
	G2: 25.3±4.2 y BMI (kg/m^2): G1: 23.0±3.3 G2: 22.5±1.6	G2: −0.06±0.77	G1: 124.6±26.4 G2: 120.4±25.5 z score: G1: 1.32±0.83 G2: 1.19±0.80	G1: 1.78±1.80 G2: 1.99±1.76
Cleary et al[67] Cross-sectional study	Pathological adults (idiopathic inflammatory myopathies), n=27 2 groups: G1: patients (n=17) G2: healthy controls (n=10) Mean age: G1: 55.55±17.26 y G2: 49.22±10.57 y BMI (kg/m^2): G1: 30.51±7.22 G2: 27.29±3.57	CT Bilateral quadriceps midthigh CSA (cm^2): G1: 113.32 (74.76-146.68) G2: 176.37 (124.00-222.55) Median (IQR) converted to mean ± SD[§]: G1: 113.3±58.1 G2: 176.4±84.8 z score: G1: 3.15±3.75 G2: −4.46±13.18	Dynamometer Unilateral isometric knee extension 90 degrees/thigh mineral-free lean mass (Nm/$kgx10^3$): G1 (n=15): 17856.66±9697.05 G2: 34626.56±8442.52 z score[†]:	IPAQ Total moderate (min/wk): G1 (n=15): 1080 (180-2040) G2: 2820 (1815-4988) Total vigorous (min/wk): G1 (n=15): 0 (0-0) G2: 240 (0-1140) Median (IQR) converted to mean ± SD[§]: Total moderate (min/wk): G1: 1101.8±1521.3 G2: 3249.5±2728.4 Total vigorous (min/wk): G1: 0±0 G2: 483.9±980.4 MVPA (min/wk)[*]: G1: 1101.8±1524.3 G2: 3733.4±2899.2 z score: G1: −0.26±0.53 G2: 0.76±1.24
Delmonico et al[89] Longitudinal observational study	Healthy older adults, n = 1367 6 groups, based on genotypes: G1: n=234 G2: n=348 G3: n=144 G4: n=186 G5: n=330 G6: n=125 Mean age: G1: 73.7±3.0 y G2: 73.9±2.7 y G3: 74.2±3.0 y G4: 73.6±2.6 y	CT Unilateral midthigh CSA (cm^2): G1: 127±2, G2: 125±2, G3: 128±2, G4 = 86±1, G5 = 86±1, G6 = 85±1 SEM converted to mean ± SD[**]: G1: 127.0±30.6 G2: 125.0±37.3 G3: 128.0±24.0 G4: 86.0±13.6 G5: 86.0±18.2 G6: 85.0±11.2 z score:	Dynamometer Unilateral isokinetic knee extension 60 degrees/s (Nm): G1: 128±4 G2: 129±4 G3: 133±4 G4: 78±2 G5: 77±2 G6: 78±2 SEM converted to mean ± SD[**]: G1: 128.0±61.2 G2: 129.0±74.6 G3: 133.0±48.0	Adapted physical activity questionnaire Physical activity (kcal/wk): G1: 7630±6416 G2: 6290±5165 G3: 7021±5632 G4: 5722±4233 G5: 5743±4271 G6: 6102±4544 z score: G1: 1.71±2.47 G2: 1.20±1.99 G3: 1.48±2.17 G4: 1.75±2.28 G5: 1.76±2.30

(continued)

Table 2 (*Continued*)

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
	G5: 73.6±2.8 y G6: 73.4±3.1 y BMI (kg/m^2): G1: 27.1±3.9 G2: 26.9±3.6 G3: 27.1±3.7 G4: 26.0±4.9 G5: 25.9±4.3 G6: 26.3±4.5	G1: −1.83±1.05 G2: −1.90±1.28 G3: −1.80±0.82 G4: −2.51±0.38 G5: −2.51±0.51 G6: −2.54±0.31	G4: 78.0±27.3 G5: 77.0±36.3 G6: 78.0±22.4 z score: G1: −1.00±3.40 G2: −0.94±4.15 G3: −0.72±2.67 G4: −1.17±2.27 G5: −1.25±3.03 G6: −1.17±1.86	G6: 1.96±2.45
Evangelidis et al[68] Cross-sectional study	Healthy males, n=30 1 group Mean age: G1: 20.7±2.6 y BMI (kg/m^2)[†]:	MRI Unilateral biceps femoris (long head) muscle volume (cm^3): G1: 214.7±37.2 z score[†]:	Dynamometer Unilateral isometric knee flexion 30 degrees (Nm): G1: 131.0±19.9 z score: G1: 0.93±0.37	Adapted IPAQ Average energy expenditure MET-min/wk: G1: 1826±936 z score: G1: −0.33±0.29
Evangelidis et al[69] Cross-sectional study	Healthy males, n = 31 1 group Mean age: G1: 21±3 y BMI (kg/m^2)[†]:	MRI Unilateral hamstrings muscle volume (cm^3): G1: 794.1±122.2 z score: G1: −0.22±0.86	Dynamometer Unilateral isometric knee flexion 30 degrees (Nm): G1: 128.3±21.7 z score: G1: 0.83±0.82	IPAQ Average energy expenditure MET-min/wk: G1: 1739±814 z score: G1: −0.36±0.25
Frontera et al[90] Longitudinal study	Older adults, n=12 1 group Mean age: G1: 71.1±5.4 y BMI (kg/m^2): G1: 25.8±2.8	CT Unilateral midthigh CSA (cm^2): G1: 98.3±21.8 z score: G1: −2.81±0.75	Dynamometer Unilateral isometric knee extension 60 degrees (Nm): G1: 98.5±27.4 z score: G1: −2.64±1.52	Adapted physical activity questionnaire Physical activity index questionnaire (kcal/wk): G1: 2919±1631 z score: G1: −0.10±−0.61
Goodpaster et al[50] RCT	Healthy adults, n=42 2 groups: G1: control (n=20) G2: physical activity (n=22) Mean age: G1: 77.4±1.0 y G2: 76.7± 1.0 y SEM converted to SD[**]: G1: 77.4±5.6 G2:76.7±3.5	CT Unilateral midthigh CSA (cm^2): G1: 97.2±6.9 G2: 94.6±5.7 SEM converted to SD[**]: G1: 97.2±30.9 G2: 94.6±26.8 z score:	Dynamometer Unilateral isokinetic knee extension 60 degrees/s (Nm): G1: 76.3±8.7 G2: 71.2±6.4 SEM converted to SD[**]: G1: 76.3±38.9 G2: 71.2±30.1 z score:	Physical activity questionnaire (CHAMPS) Self-reported activity (kcal/wk): G1: 588±610 G2: 634±727 SEM converted to SD[**]: G1: 588±2728 G2: 634±3410 z score:

(continued)

Table 2 (*Continued*)

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
	BMI (kg/m^2): G1: 30.4±1.3 G2: 30.7±1.4	G1: −1.09±1.51 G2: −1.21±1.31	G1: −2.67±1.15 G2: −2.82±0.88	G1: −4.44±5.46 G2: −4.35±6.82
Gordon et al[70] Cross-sectional study	Hemodialysis patients, n=79 2 groups: G1: n=49 G2: n=30 Mean age: G1: 55.0±1.8 y G2: 56.0±2.5 y BMI (kg/m^2): G1: 28.0±1.0 G2: 26.0±1.0 SEM converted to SD**: Mean age: G1: 55.0±12.6 y G2: 56.0±13.7 y BMI (kg/m^2): G1: 28.0±7.0 G2: 26.0±5.5	MRI Unilateral midthigh CSA (cm^2): G1 (n=37): 106.5±5.6 G2 (n=25): 92.9±3.8 SEM converted to SD**: G1: 106.5±34.1 G2: 92.9±19 z score: G1: −0.94±1.31 G2: −1.39±0.69	Dynamometer Unilateral isokinetic knee extension 90 degrees/s (Nm): G1 (n=43): 44±4 G2 (n=27): 32±3 SEM converted to SD**: G1: 44.0±26.2 G2: 32.0±15.6 z score: G1: −2.41±0.65 G2: −2.69±0.38	Accelerometry Physical activity daily activity arbitrary units: G1 (n=38): 61907±7051 G2 (n=26): 71766±16461 SEM converted to SD**: G1: 61907±43465 G2: 71766±83935 z score: G1: −1.64±0.81 G2: −1.47±1.48
Gylling et al[59] RCT	Healthy adults, n=451 1 group Mean age: G1: 66±2.5 y BMI (kg/m^2): G1: 26.0±4.2	MRI Unilateral vastus lateralis CSA (mm^2)§§: G1: 1410±40 G2: 1360±35 G3: 1355±30 CSA (cm^2)¶¶: G1: 14.1±0.4 G2: 13.6±0.4 G3: 13.6±0.3 G1: 13.8±1.0 z score: G1: −0.13±0.22	Leg extensor exercise Unilateral isometric knee extension (Nm)§§: G1: 150±5 G2: 145±5 G3: 145±5 G1: 146.7±3.9 z score: G1: −0.64±0.06	Accelerometry Step counts (steps/d): G1: 9481±3262 G2: 9399±3140 G3: 9783±3941 G1: 9554.3±101.7 z score: G1: 0.10±0.02
He et al[87] Cross-sectional study	Postmenopausal women, n=40 2 groups: G1: n=12 G2: n=28 Mean age: G1: 57.5±4.6 y G2: 59.6±4.1 y	Ultrasound Unilateral rectus femoris CSA (mm^2): G1: 90.77±7.51 G2: 85.04±8.20 CSA (cm^2) ¶¶: G1: 0.91±0.08 G2: 0.85±0.08	Dynamometer Unilateral isokinetic knee extension 60 degrees/s (Nm/kg): G1: 1.25±0.15 G2: 1.35±0.16 z score†:	IPAQ Moderate physical activity (MET-min/wk): G1: 4195.0±358.2 G2: 4026.4±494.7 Vigorous physical activity (MET-min/wk): G1: 1026.7±130.6

(continued)

Table 2 (*Continued*)

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
	BMI (kg/m^2): G1: 25.7±1.8 G2: 23.6±2.0	z score: G1: −2.34±0.07 G2: −2.39±0.07		G2: 1062.9±256.2 MVPA (MET-min/wk): G1: 5221.7±381.3 G2: 5089.3±557.1 z score: G1: 1.25±0.13 G2: 1.21±0.18
Higgins et al[71] Cross-sectional study	Healthy young adults, n=142 2 groups: G1: male (n=67) G2: female (n=75) Mean age: G1: 19.6±0.7 y G2: 19.7±0.8 y BMI (kg/m^2)[†]:	CT Unilateral lower leg (tibia) CSA (mm^2): G1: 8113±1104 G2: 6866±854 CSA (cm^2)[¶¶]: G1: 81.1±11.1 G2: 687±85.4 z score[†]:	Dynamometer Unilateral isokinetic knee extension 60 degrees/s (Nm): G1: 161.1± 30.2 G2: 101.9±18.9 z score: G1: −1.42±0.41 G2: −1.77±0.40	Accelerometer MVPA (min/d): G1: 93.0±27.8 G2: 85.9±27.4 MVPA (min/wk)[*]: G1: 651.0±194.6 G2: 601.3±191.8 z score: G1: 1.35±0.48 G2: 1.33±0.47
Hwang et al[91] Longitudinal study	Active men, n=20 2 groups: G1: n=9 G2: n=11 Mean age: G1: 21.0±1.1 y G2: 21.0±1.3 y BMI (kg/m^2) [†]:	Ultrasound Bilateral rectus femoris CSA (cm^2): G1: 58.0±4.5 G2: 59.0±6.1 z score[†]:	Angled leg press exercise Bilateral knee extension 1RM (kg): G1: 324.8±57.3 G2: 327.8±69.0 z score: G1: 0.09±0.76 G2: 0.13 ±0.92	Adapted physical activity questionnaire TDEE (kcal/d): G1: 3037.6±159.1 G2: 3110.2±170.2 TDEE (kcal/wk)[‡‡]: G1: 21263.2±1113.8 G2: 21771.2±1191.1 z score: G1: 0.96±0.45 G2: 1.17±0.48
Izquierdo et al[72] Cross-sectional study	Elderly men, n=47 2 groups: G1: middle-aged men (n=26) G2: elderly men (n=21) Mean age: G1: 42 y (35-46 y) G2: 65 y (60 − 74 y) IQR converted to SD[§]: G1: 42.0±2.8 G2: 65.0±3.5 BMI (kg/m^2)[†]:	Ultrasound Unilateral quadriceps CSA (cm^2): G1: 48.2±1.3 G2: 42.1±2.2 z score: G1: −2.97±0.13 G2: −2.39±0.22	Resisted squat exercise Unilateral isometric knee extension 1RM (Nm): G1: 217.7±40.2 G2: 165.7±23.7 z score: G1: −0.63±0.93 G2: −1.57±0.58	Physical activity questionnaire (LTPA) Physical activity, energy expenditure (MET/d): G1: 1392±920 G2: 893±404 (MET/week)[##]: G1: 9744±6440 G2: 6251±2828 z score: G1: 3.12±0.95 G2: 0.87±0.61
	Hemodialysis patients, n=79 4 groups:	MRI Unilateral quadriceps CSA	Dynamometer Unilateral Isokinetic knee	Accelerometry Physical activity (arbitrary units):

(continued)

Table 2 (*Continued*)

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
Johansen et al[73] Cross-sectional study	G1: placebo (n=20) G2: injections (n=19) G3: exercise (n=20) G4: both (n=20) Mean age: G1: 56.8±13.8 y G2: 55.7±13.4 y G3: 54.4±13.6 y G4: 55.5±12.5 y BMI (kg/m^2): G1: 27.8±6.5 G2: 24.8±4.6 G3: 27.4±5.3 G4: 27.8±9.7	(cm^2): G1: 51.1±10.9 G2: 46.6±15.7 G3: 47.9±13.9 G4: 39.5±9.3 z score: G1: −0.74±0.70 G2: −1.04±1.01 G3: −0.95±0.83 G4: −1.49±0.60	extension 90 degrees/s (Nm): G1: 41.7±19.4 G2: 30.7±22.4 G3: 39.2±25.1 G4: 43.6±26.9 z score: G1: −2.47±0.45 G2: −2.72±0.52 G3: −2.53±0.58 G4: −2.42±0.62	G1: 41270±28049 G2: 51471±17420 G3: 50141±34652 G4: 47040±19323 z score: G1: −1.98±0.46 G2: −1.81±0.29 G3: −1.83±0.57 G4: −1.88±0.32
Kahraman et al[60] RCT	Hypertension patients, n=24 2 groups: G1: n=12 G2: n=12) Mean age: G1: 52.5 y (25.75-62.50 y) G2: 47.5 y (29.5-59.0 y) BMI (kg/m^2): G1: 26.5 (22.3-28.3) G2: 25.9 (22.3-28.3) Median (IQR) converted to mean ± SD[§]: Mean age: G1: 52.5±27.2 G2: 47.5±21.6 BMI (kg/m^2): G1: 26.5±4.5 G2: 25.9±4.4	Ultrasound Unilateral rectus femoris CSA (cm^2): G1: 6.9 (6.0-9.4) G2: 7.2 (6.2-9.0) Median (IQR) converted to mean ± SD[§]: G1: 6.9±2.5 G2: 7.2±2.1 z score: G1: 1.56±2.78 G2: 1.89±2.33	Dynamometer Unilateral isometric knee extension (kg): G1: 14.7 (11.4-17.3) G2: 13.2 (10.4-23.1) Median (IQR) converted to mean ± SD[§]: G1: 14.7±4.4 G2: 13.2±9.4 z score: G1: −2.08±0.40 G2: −2.21±0.85	IPAQ MVPA (min/wk): G1: 302.9±445.4 G2: 393.0±326.0 z score: G1: −0.17±0.79 G2: −0.05±0.56
Kennis et al[51] RCT	Healthy older men, n=72 3 groups: G1: n=20 G2: n=23 G3: n=29 Mean age: G1: 68.4±0.9 y G2: 67.6±0.7 y G3: 67.5±1.1 y	CT Unilateral upper leg muscle volume (cm^3): G1: 124.7±2.6 G2: 121.3±3.1 G3: 124.8±2.5 SEM converted to SD[**]: G1: 124.7±11.8 G2: 121.3±15.1	Dynamometer Unilateral isometric knee extension 90 degrees (Nm): G1: 165.5±7.6 G2: 166.8±7.4 G3: 168.8±8.8 SEM converted to SD[**]: G1: 165.5±33.8	Physical activity Questionnaire (Flemish physical activity computerized questionnaire) Physical activity level index (MET/wk): G1: 1.50±0.02 G2: 1.55±0.06 G3: 1.54±0.03 SEM converted to SD[**]:

(continued)

Table 2 (*Continued*)

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
	SEM converted to SD**: G1: 68.4±4.2 G2: 67.6±3.4 G3: 67.5±6.1 BMI (kg/m^2)†:	G3: 124.8±13.3 z score: G1: −0.92±0.25 G2: −0.99±0.32 G3: −0.92±0.28	G2: 166.8±35.6 G3: 168.7±47.2 z score: G1: −1.57±0.82 G2: −1.57±0.87 G3: −1.50±1.15	G1: 1.45±0.09 G2: 1.55±0.29 G3: 1.54±0.16 MET-min/wk***: G1: 609.0±37.8 G2: 651.0±121.8 G3: 646.8±67.2 z score: G1: −0.35±0.01 G2: −0.34±0.03 G3: −0.34±0.01
Kent-Braun et al[74] Cross-sectional study	Healthy adults, n=48 4 groups: G1: young women (n=12) G2: older women (n=12) G3: young men (n=12) G4: older men (n=12) Mean age: G1 and G3 (young): 32±1 y G2 and G4 (older): 72±1 y BMI (kg/m^2)†:	MRI Unilateral dorsiflexor muscles CSA (cm^2): G1 (n=11): 8.7±0.4 G2 (n=10): 7.7±0.5 G3 (n=12): 13.0±0.7 G4 (n=12): 10.3±0.6 SEM converted to SD**: G1: 8.7±1.4 G2: 13.0±2.4 G3: 7.7±1.7 G4 = 10.3±2.1 z score†:	Isometric force transducer Unilateral isometric ankle dorsiflexion 120 degrees (N): G1: 136±15 G2: 149±16 G3: 262±19 G4: 197±22 SEM converted to SD**: G1: 136.0±51.9 G2: 262.0±65.8 G3: 149.0±55.4 G4: 197.0±76.2 z score: G1: −0.73±1.25 G2: 0.76±1.35 G3: 0.45±1.42 G4: 0.54±1.73	Accelerometer Physical activity, arbitrary units/d: G1 and G3 (young [n=21]): 164153±14471, G2 and G4 (older [n=21]): 137757±12314 z score: G1: 0.05±0.25 G2: −0.39±0.22
Kukuljan et al[52] RCT	Healthy men, n=180 4 groups: G1: n=45 G2: n=46 G3: n=45 G4: n=44 Mean age: G1: 61.7±7.6 y G2: 60.7±7.1 y G3: 61.7±7.7 y G4: 59.9±7.4 y BMI (kg/m^2):	CT Unilateral midfemur muscle CSA (cm^2): G1: 145.9±17.6 G2: 151.9±18.3 G3: 143.9±17.4 G4: 148.5±20.0 z score: G1: 0.06±0.87 G2: 0.36±0.90 G3: −0.03±0.86 G4: −0.34±0.95	Leg press exercise Bilateral lower limb strength 1RM (kg): G1: 63.4±18.0 G2: 64.7±16.5 G3: 71.4±13.7 G4: 74.4±18.1 z score: G1: −2.18±0.22 G2: −2.16±0.20 G3: −2.08±0.17 G4: −2.05±0.22	Adapted physical activity questionnaire Moderate physical activity (MPA) (hr/wk): G1: 3.7±3.9, G2: 3.6±3.4, G3: 3.3±3.8, G4 = 3.4±4.1 [5]MPA (min/wk): G1: 222±234 G2: 216±216 G3: 198±228 G4: 204±246 z score:

(continued)

Table 2 (*Continued*)

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
	G1: 27.4±3.7 G2: 28.1±3.3 G3: 27.7±3.3 G4: 26.7±2.9			G1: −0.24±0.26 G2: 0.77±−3.27 G3: 0.21±−1.39 G4: −0.26±0.28
Leenders et al[53] RCT	Healthy elderly adults, n=53 4 groups: G1: n=12 G2: n=12 G3: n=14 G4: n=15 Mean age: G1: 69±1 y G2: 72±2 y G3: 70±1 y G4: 70±1 y BMI (kg/m^2): G1: 25.0±0.4 G2: 24.2±0.7 G3: 26.7±0.6 G4: 27.2±0.7 SEM converted to SD[**]: Mean age: G1: 69.0±3.5 G2: 72.0±6.9 G3: 70.0±3.7 G4 = 70.0±3.9 BMI (kg/m^2): G1: 25.0±3.3 G2: 24.2±5.9 G3: 26.7±5.1 G4: 27.2±5.9	CT scan Unilateral quadriceps CSA (cm^2): G1: 47.0±7.9 G2: 46.0±10.0 G3: 67.0±7.5 G4: 71.0±10.9 SEM converted to SD[**]: G1: 47.0±27.4 G2: 46.0±34.6 G3: 67.0±28.1 G4: 71.0±42.2 z score: G1: −0.06±3.39 G2: −0.13±4.45 G3: 0.75±2.89 G4: 1.16±4.35	Leg extension exercise Bilateral knee extension 1RM 90 degrees (kg): G1: 61.0±31.2 G2: 62.0±31.2 G3: 89.0±41.2 G4: 92.0±42.6 SEM converted to SD[**]: G1: 61.0±108.1 G2: 62.0±108.1 G3: 89.0±154.2 G4: 92.0±164.9 z score: G1: 2.81±9.24 G2: 2.89±9.24 G3: 3.71±13.18 G4: 3.97±14.11	Habitual physical activity record Physical activity mean energy expenditure (MET-h/d): G1: 1.4±0.5 G2: 1.5±0.4 G3: 1.5±0.7 G4: 1.5±0.4 SEM converted to SD[**]: G1: 1.4±0.5 G2: 1.5±0.4 G3: 1.5±0.7 G4: 1.5±0.7 (MET-min/wk)[†††]: G1: 604.8±218.3 G2: 625.8±160.0 G3: 621.6±298.6 G4: 630.0±292.8 z score: G1: −0.15±0.05 G2: −0.15±0.03 G3: −0.34±0.06 G4: −0.34±0.06
Leskinen et al[92] Longitudinal study	Healthy adults, n=32 2 groups: G1: inactive (n=16) G2: active (n=16) Mean age: G1: 60±6 y G2: 60±6 y BMI (kg/m^2): G1: 26.7±3.5 G2: 24.8±2.6	MRI Unilateral midthigh CSA (cm^2): G1: 196.2±33.5 G2: 183.7±22.6 z score: G1: 1.70±6.87 G2: −0.86±4.63	Dynamometer Unilateral isometric knee extension (N): G1: 425.8±87.3 G2: 507.8±121.4 N converted to kgs[||||]: G1: 43.4±8.9 G2: 51.8±12.4 z score:	Physical activity recall via interview Physical activity (MET-h/d): G1: 1.6±1.4 G2: 8.4±4.1 (MET-min/wk)[†††]: G1: 672±588 G2: 3528±1722 z score: G1: −0.24±0.13

(*continued*)

Table 2 (*Continued*)

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
			G1: 0.56±0.76 G2: 1.27±1.06	G2: 0.38±0.37
MacMillan et al[93] Longitudinal study	Male adults with COPD, n=15 2 groups: G1: n=8 G2: n=7 Mean age: G1: 68±2 y G2: 63±2 y SEM converted to SD[**]: Mean age: G1: 68.0±5.7 y G2: 63.0±5.3 y BMI (kg/m^2)[†]:	DEXA Unliteral thigh muscle mass (kg): G1: 69.3±2.60% G2: 75.1±3.80% z score[†]:	Dynamometer Unilateral isometric knee extension 60 degrees (Nm): G1: 130±12 G2: 150±10 SEM converted to SD[**]: G1: 130.0±33.9 G2: 150.0±26.5 z score: G1: −1.13±1.06 G2: −0.50±0.83	Accelerometer (steps/d): G1: 3372±861 G2: 4271±655 SEM converted to SD[**]: G1: 3372.0±204.7 G2: 4271.0±179.2 z score: G1: −1.47±0.06 G2: −1.26±0.04
Maden-Wilkinson et al[85] Cross-sectional study	Healthy men, n=682 2 groups: G1: untrained (n=52) G2: long-term trained (n=16) Mean age: G1: 25.1±2.3 y G2: 21.6±2.0 y BMI (kg/m2)[†]:	MRI Unilateral quadriceps CSA (cm^2): G1: 86.2±11.2 G2: 135.0±15.0 z score: G1: −1.35±0.82 G2: 2.21±1.09	Dynamometer Unilateral isometric knee extension 115 degrees (Nm): G1: 245±43 G2: 388±70 z score: G1: −0.27±0.59 G2: 1.68±0.96	IPAQ Physical activity (MET-min/wk): G1: 2286±1312 G2: 5383±1495 z score: G1: −0.19±0.40 G2: 0.76±0.46
Manini et al[54] RCT	Sedentary women, n=27 2 groups: G1: diet restrict (n=14) G2: education (n=13) Mean age: Total: 63.8±6.0 y G1: 63.6±4.7 y G2: 64.0±7.3 y BMI (kg/m^2): Total: 36.1±5.6 G1: 36.1±2.9 G2: 35.9±7.7	MRI Unilateral thigh muscle volume (cm^3): G1: 244.0±49.3 G2: 236.4±49.3 z score[†]:	Dynamometer Unilateral isokinetic knee extension 60 degrees/s (Nm): G1: 89.9±25.5 G2: 105.5±22.2 z score: G1L −1.83±0.91 G2: −1.27±0.79	Pedometer Physical activity (steps/d): Total baseline: 4096±2080 z score: G1: −0.39±0.49
Marcus et al[55] RCT	Postmenopausal women, n=16 2 groups: G1: eccentric training (n=10)	DEXA Unilateral leg lean mass (kg): G1: 7.3±0.5 G2: 8.5±1.1	Dynamometer Unilateral isometric knee extension 90 degrees (kg): G1: 31.8±7.4 G2: 39.0±17.7	Pedometer Physical activity (steps/d): G1: 5949±2170 G2: 7873±778 z score:

(continued)

Table 2 (*Continued*)

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
	G2: control (n=6) Mean age: G1: 56.3±6.4 y G2: 53.2±6.5 y BMI (kg/m^2): G1: 28.5±3.7 G2: 32.2±4.0	z score: G1: −2.34±0.25 G2: −1.74±0.55	z score: G1: 0.19±0.87 G2: 1.04±2.08	G1: −0.16±0.42 G2: −1.56±2.37
Minegishi et al[56] RCT	Healthy adults, n=22 2 groups: G1: placebo (n=11) G2: milk intake (n=11) Age range: 60-74 y BMI (kg/m^2): G1: 22.9±0.5 G2: 22.9±0.7	MRI Unilateral quadriceps CSA (cm^2): G1: 87.8±3.4 G2: 84.4±4.1 SEM converted to SD**: G1: 87.8±11.3 G2: 84.4±13.6 z score: G1: 2.77±1.31 G2: 2.38±1.58	Force measurement system for one leg Unilateral isometric knee extension 90 degrees (kg): G1: 28.2±2.0 G2: 27.9±2.5 SEM converted to SD**: G1: 28.2±6.6 G2: 27.9±8.3 z score: G1: −0.74±0.57 G2: −0.77±0.71	Pedometer Physical activity (steps/d): G1: 7013±445 G2: 7845±739 SEM converted to SD**: G1: 7013.0±1475.9 G2: 7845.0±2450.9 z score: G1: −0.16±0.35 G2: 0.04±0.58
Moro et al[94] Longitudinal study	Healthy adults, n=19 1 group: G1: n=19 Mean age: G1: 71±4 y BMI (kg/m^2): G1: 27.8±3.0	DEXA Bilateral leg lean mass (kg): G1: 16.2±0.8 SEM converted to SD**: G1: 16.2±3.5 z score: G1: 1.72±1.20	Dynamometer Unilateral isokinetic knee extension 60 degrees/s (kg): G1: 91.7±3.0 SEM converted to SD**: G1: 91.7±13.1 z score: G1: −0.71±0.34	Accelerometer Physical activity (steps/d): G1: 4700±2051 z score: G1: −0.70±0.48
Morse et al (2004)[75] Cross-sectional Study	Healthy men, n=35 2 groups: G1: young men (n=14) G2: elderly men (n=21) Mean age: G1: 24.7±4.7 y G2: 73.7±3.6 y BMI (kg/m^2)[†]:	MRI Unilateral lower leg muscle volume (cm^3): G1: 9.4 (0.5•10^{-4}) G2: 7.5 (0.2•10^{-4}) z score[†]:	Dynamometer Unilateral isometric planterflexion 20 degrees (Nm): G1: 173.4±8.1 G2: 105.6±4.3 z score: G1: −2.48±0.12 G2: −2.80±0.07	Accelerometer (G1 [n=10]; G2 [n=22]) Moderate MET-min/d: G1: 41.6±15.1 G2: 33.5±21.1 Vigorous MET-min/d: G1: 2.4±1.9 G2: 0.1±0.3 MET-min/d: G1: 44.0±15.2 G2: 33.6±21.1 MET-min/week[‡‡‡]: G1: 307.7±106.5

(continued)

Table 2 (*Continued*)

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
				G2: 235.3±147.5 *z* score: G1: −0.13±0.01 G2: −0.14±0.01
Nakao et al[76] Cross-sectional study	Healthy adult women, n=30 1 group: G1: n=30 Mean age: G1: 73.6±5.5 y BMI (kg/m^2): G1: 22.5±2.9	Body composition impedance method Unilateral thigh muscle mass (kg): G1: 7.4±1.0 *z* score: G1: −1.15±0.50	Dynamometer Unilateral knee extension 90 degrees (N): G1: 308.9±81.0 N converted to kgs[‖‖]: G1: 31.5±8.3 *z* score: G1: −1.45±0.49	Pedometer Physical activity (steps/d): G1: 6055.4±2509.1 *z* score: G1: 0.07±0.59
Nunes et al[77] Cross-sectional study	Physically active females, n=54 2 groups, based on PFP: G1: PFP (n=27) G2: healthy (n=27) Mean age: G1: 24.3±4.0 y G2: 23.2±2.8 y BMI (kg/m^2)[†]:	Ultrasound Unilateral gluteus maximus thickness (cm): G1: 2.4±0.3 G2: 2.5±0.4 *z* score[†]:	Dynamometer Unilateral isometric hip extension 30 degrees (normalized torque %): G1: 174.4±40.8 G2: 204.5±37.0 Converted to Nm[§§§]: G1: 102.6±3.1 G2: 122.7±2.3 *z* score: G1: −1.18±0.08 G2: −0.69±0.06	IPAQ MET-min/wk: G1: 3248.4±2445.5 G2: 3191.6±1923.3 *z* score: G1: 0.46±0.75 G2: 0.45±0.59
Patel et al[78] Cross-sectional study	Patients with COPD, n=109 2 groups, based on SPPB score: G1: SPPB >10 (n=77) G2: SPPB <10 (n=32) Mean age: G1: 64±10 y G2: 68±7 y BMI (kg/m^2): G1: 26.1±6.0 G2: 26.6±7.0	Predicted rectus femoris CSA equation Bilateral rectus femoris CSA (mm^2): G1: 570±161 G2: 429±157 CSA (cm^2)[¶¶]: G1: 57.0±16.1 G2: 43.0±15.7 *z* score: G1: 0.72±1.35 G2: −0.46±1.32	Knee extension exercise Unilateral isometric knee extension 90 degrees (kg): G1: 33±9 G2: 24±7 *z* score: G1: −0.33±0.77 G2: −1.10±0.60	Accelerometer Physical activity (steps/d): G1: 5088 (2626-7163) G2: 2539 (1927-5103) Median (IQR) converted to mean ± SD[§]: G1: 4951.6±3427.7 G2: 3234.1±2464.7 *z* score: G1: −0.80±0.67 G2: −1.14±0.48
Perkin et al[79] Cross-sectional study	Healthy adults, n=80 2 groups: G1: older (n=50) G2: younger (n=20) Mean age:	Ultrasound Unilateral vastus lateralis thickness (mm): G1: 18±4 G2: 22±4	Dynamometer Unilateral isometric knee extension and flexion 90 degrees (N): G1: 1074±310	Accelerometer MVPA min/d: G1: 103±49 G2: 49±29 MVPA min/wk[*]:

(*continued*)

Table 2 (*Continued*)

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
	G1: 70±4 y G2: 25±4 y BMI (kg/m^2): G1: 24.3±3.4 G2: 22.6±2.8	Thickness (cm)[¶]: G1: 2.0±0.4 G2: 2.2±0.4 z score: G1: −0.40±1.55 G2: 1.15±1.55	G2: 1615±433 N converted to Kg[‖‖]: G1: 109.5±31.6 G2: 164.7±44.2 z score: G1: 1.47±1.25 G2: 0.85±1.12	G1: 721±343 G2: 343±203 z score: G1: 1.13±2.42 G2: 0.48±0.96
Reinders et al[80] Cross-sectional study	Older adults with heart disease, n=836 1 group: G1: n=836 Mean age: G1: 76.7±5.6 y BMI (kg/m^2): G1: 27.1±4.1	CT Unilateral midthigh CSA (cm^2): G1: 112.0±25.6 z score: G1: −0.73±0.79	Dynamometer Unilateral isometric knee extension 60 degrees (N): G1: 329±117 z score: G1: 2.31±2.27	Adapted physical activity questionnaire Moderate to vigorous physical (MVPA h/wk): G1: 1.4±2.3 MVPA min/wk[‖]: G1: 81.0±139.8 z score: G1: −0.59±9.02
Rodrigues et al[88] Cross-sectional study	Female adults with RA, n=48 3 groups: G1: n=16 G2: n=16 G3: n=16) Mean age: G1: 58.0±6.6 y G2: 59.6±3.9 y G3: 58.1±5.9 y BMI (kg/m^2): G1: 24.7±4.7 G2: 27.4±4.0 G3: 26.9±3.7	CT Unilateral quadriceps CSA (mm^2)[§§]: G1: 4500±800 G2: 4400±500 G3: 4800±1000 CSA (cm^2)[¶¶]: G1: 45.0±8.0 G2: 44.0±5.0 G3: 48.0±10.0 z score: G1: −0.82±1.0 G2: −0.95±0.62 G3: −0.45±-1.25	Leg extension exercise Unilateral isokinetic knee extension 1RM (kg): G1: 35.2±12.4 G2: 30.6±10.2 G3: 33.9±12.9 z score: G1: 0.59±1.46 G2: 0.05±1.20 G3: 0.44±1.52	Accelerometer MVPA (min/d): G1: 16.4±14.1 G2: 16.8±13.8 G3: 21.4±15.2 MVPA (min/wk)[*]: G1: 114.8±98.7 G2: 117.6±96.6 G3: 149.8±106.4 z score: G1: 0.79±0.94 G2: 0.81±0.92 G3: 1.12±1.01
Sakkas et al[81] Cross-sectional study	Diabetes patients, n=58 2 groups: G1: nondiabetes (n=33) G2: diabetes (n=25) Mean age: G1: 52±14 y G2: 58±12 y BMI (kg/m^2): G1: 25.8±5.7 G2: 26.1±5.6	MRI Unilateral thigh muscles CSA (cm^2): G1: 103.8±29.0 G2: 91.3±19.1 z score: G1: −1.03±0.97 G2: −1.44±0.64	Dynamometer Unilateral isokinetic knee extension at 90 degrees/s (kg): G1: 45.0±25.1 G2: 29.2±12.4 z score: G1: −2.39±0.58 G2: −2.76±0.29	Accelerometer Physical activity (arbitrary units): (median with 25th and 75th percentile) G1: 62.6 (43.7, 111.6) G2: 38.5 (22.5, 67.8) Median (IQR) converted to mean ± SD[§]: G1: 73.3±52.6 G2: 43.3±35.6 z score:

(continued)

Table 2 (*Continued*)

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
				G1: −1.45±0.87 G2: −1.94±0.59
Schofield et al[82] Cross-sectional study	Pathological and healthy population, n=40 2 groups: G1: cancer survivors (n=20) G2: controls (n=20) Mean age: G1: 63.2±8.9 y G2: 63.0±9.1 y BMI (kg/m^2)[†]:	pQCT Unilateral tibial area (mm^2): G1: 665.0±92.5 G2: 632.5±64.6 z score[†]:	Leg extension exercise Unilateral isokinetic knee extension 1RM (kg): G1: 24.1±6.8 G2: 26.8±9.6 z score: G1: −0.35±0.58 G2: −0.12±0.82	Accelerometer MVPA (min/d): G1: 17.6±34.5 G2: 24.7±26.9 MVPA (min/wk)[*]: G1: 123.5±241.2 G2: 172.9±188.1 z score: G1: 1.26±3.10 G2: 1.90±2.42
Tay et al[86] Cross-sectional study	Obese older adults, n=163 2 groups: G1: male (n=61) G2: female (n=102) Mean age: G1: 70±5 y G2: 70±5 y BMI (kg/m^2): G1: 33.7±3.2 G2: 33.6±3.0	MRI Bilateral thigh muscle volume (cm^3): G1 (n=61): 422.4±56.8 G2 (n=101): 287.5±42.3 z score: G1: −1.59±0.58 G2: −1.91±0.66	Leg extension exercise Bilateral isometric knee extension 1RM (kg): G1 (n=61): 95.2±34.5 G2 (n=101): 57.8±22.4 Unilateral isometric knee extension 1RM (kg)[#]: G1: 47.6±17.3 G2: 28.9±11.2 z score: G1: 0.65±1.60 G2: 0.09±1.31	Accelerometer MVPA (min/d): G1 (n=53): 18.3±14.4 G2 (n=90): 7.2±8.2 MVPA (min/wk)[*]: G1: 128.1±100.8 G2: 50.4±57.4 z score: G1: 0.08±0.16 G2: 0.0±−0.18
Weeks et al[83] Cross-sectional study	Healthy adults, n=52 2 groups: G1: women (n=26) G2: men (n=26) Mean age: G1: 33.7±12.6 y G2: 33.9±11.5 y BMI (kg/m^2): G1: 26.7±9.1 G2: 27.8±5.3	DEXA Unilateral lower limb lean mass (kg): G1: 8.2±2.1 G2: 11.4±2.1 z score: G1: −1.80±0.84 G2: −2.43±0.70	Dynamometer Unilateral isokinetic knee extension 60 degrees/s (Nm): G1: 133.3±32.4 G2: 211.4±53.7 z score: G1: −0.51±1.41 G2: −0.03±2.44	Adapted physical activity questionnaire Energy expenditure (MET-min/wk): G1: 10087±10887 G2: 10533±9098 z score: G1: 4.86±5.97 G2: 4.64±4.99
Westerberg et al[57] RCT	Pathological population, n=11 1 group: G1: n=11 Mean age: G1: 60±18 y BMI (kg/m^2)[†]:	Ultrasound Unilateral rectus femoris muscle thickness (mm): G1: 19.6±5.6 Thickness (cm) [¶]: G1: 2.0±0.6	Dynamometer Unilateral isometric knee extension (kg): G1: 25.2±4.4 z score: G1: −1.00±0.42	Accelerometer steps/d: G1: 8801 (6746-9723) IQR converted to SD[§]: G1: 8801.0±744.3 z score: G1: 0.20±−0.32

(continued)

Table 2 (*Continued*)

Study and Type	Participants/Groups	Muscle Size	Muscle Strength	Physical Activity
		z score: G1: 3.21±3.33		
Young et al[84] Cross-sectional study	Healthy adults, n=42 1 group: G1: n=42 Mean age: G1: 24.9±11.4 y BMI (kg/m^2): G1: 23.3±3.0	Ultrasound Unilateral rectus femoris thickness (cm): G1: 1.5±0.3 *z* score[†]:	Ergometer (Biodex) Unilateral isometric knee extension 60 degrees (Nm): G1: 173.4±35.4 *z* score: G1: −0.05±0.65	IPAQ Physical activity level Total MET (MET-min/wk): G1: 3065.4±2094.6 *z* score: G1: 0.22±0.64
Zhu et al[58] RCT	Older adults, n=196 2 groups: G1: protein intake (n=101) G2: placebo group (n=95) Mean age: G1: 74.2±2.8 y G2: 74.3±2.6 y BMI (kg/m^2): G1: 26.1±3.8 G2: 27.2±4.0	DEXA Bilateral lower limb lean muscle mass (kg): G1: 12.4±1.9 G2: 12.7±1.9 *z* score: G1: 0.41±0.66 G2: 0.52±0.66	Strain gauge Unilateral knee extension (kg): G1: 15.4±5.3, G2: 16.1±7.2 *z* score: G1: −1.84±0.45 G2: −1.78±0.62	IPAQ Physical activity, MET task-min/wk: G1: 453±390 G2: 398±376 *z* score: G1: −0.23±0.09 G2: −0.24±0.09

NOTE. Data presented as originally reported, recalculated to standard units (when required) and *z* scores calculated using normative data (see supplemental table S3, available online only at http://www.archives-pmr.org/) (mean ± SD).

Abbreviations: CHAMPS, community healthy activities model program for seniors; COPD, chronic obstructive pulmonary disease; CT, computed tomography; DEXA, dual-energy x-ray absorptiometry; IQR, interquartile range; LTPA, leisure-time physical activity; MET, metabolic equivalent; MET-min, metabolic equivalent x minutes/week; MPA, moderate physical activity; PFP, patellofemoral pain; pQCT, quantitative computed tomography; RA, rheumatoid arthritis; RCT, randomized controlled trial; SPPB, short physical performance battery; TDEE, total daily energy expenditure.

[*] min/d to min/wk.
[†] Insufficient data available for calculation.
[‡] Foot-pounds to Nm.
[§] Median (IQR) to mean ± SD.
[‖] h/wk to min/wk.
[¶] Muscle thickness, mm to cm.
[#] Bilateral limb value from unilateral limb value.
[**] SEM to SD.
[††] MJ to kcal.
[‡‡] kcal/d to kcal/wk.
[§§] Value estimated from graph.
[‖‖] N to kg.
[¶¶] CSA, mm^2 to cm^2.
[##] MET/d to MET/wk.
[***] MET/wk to MET-min/wk.
[†††] MET-h/d to MET-min/wk.
[‡‡‡] MET-min/d to MET-min/wk.
[§§§] Torque normalized to body mass, % to Nm.

Most of the included studies described all items included in the methodological quality checklist (supplemental table S6, available online only at http://www.archives-pmr.org/). All studies clearly described 4 of the 6 items relating to reporting bias. Twenty-four provided adequate estimates of random variability and 36 clearly stated actual probability values for main outcomes. With regard to external validity, 44 studies included participants that were deemed representative of the entire population. All included studies showed a high level of internal validity and 45 studies were sufficiently powered to detect clinically important effects.

Results of weighted linear regression analyses

Data from 77 data points (33 studies) confirmed a moderate correlation (r=0.26, P<.01) between lower limb muscle strength and lower limb muscle size.

Objective physical activity

Thirty-four data points were included in the correlation of objective physical activity with muscle size (n=1626) because there were no normative data for the specific outcomes for 5 studies.[57,71,75,82,93] Across all ages, there was a moderate positive correlation (r=0.30) between objective measures of physical activity (mean z score: −0.33±0.72) and muscle size (0.43±0.74) (table 3, fig 2A). For the sensitivity analysis between objective measures of physical activity and muscle size, correlations ranged between perfect (younger population with only 2 data points) and a small negative correlation (middle age population).

There were 43 data points included in the correlation of objective physical activity and muscle strength (n=1869) because normative data for the specific outcome were not available for 1 study.[87] There was a small positive correlation (r=0.24) between objective measures of physical activity (mean z score: −0.19±0.71) and muscle strength (−0.63±0.92) for all ages (fig 2B). For the sensitivity analysis between objective measures of physical activity and muscle strength, correlations ranged between a strong negative (younger population) and a very strong correlation (middle age population).

Subjective physical activity

Forty-six data points were included in the correlation of subjective physical activity with muscle size (n=3243) because normative data for the specific outcomes were not available for 6 studies.[65,67,68,77,84,91] Across all ages, there was a strong negative correlation (r=−0.59) between subjective measures of physical activity (mean z score: 0.36±1.16) and muscle size (−0.53±1.40) (fig 3A). For the sensitivity analysis between subjective measures of physical activity and muscle size, correlations ranged from a small positive (younger population) to a strong negative correlation (older population).

There were 51 data points included in the correlation of subjective physical activity and muscle strength (n=3882) because normative data for the specific outcomes were not available for 2 studies.[67,87] Across all ages, there was a moderate negative correlation (r=−0.48) between subjective measures of physical activity (mean z score: 0.34±0.56) and muscle strength (−0.07±1.97) for all ages (fig 3B). For the sensitivity analysis between subjective measures of physical activity and muscle strength, correlations ranged from a small positive (younger population) to a strong negative correlation (middle age population).

Discussion

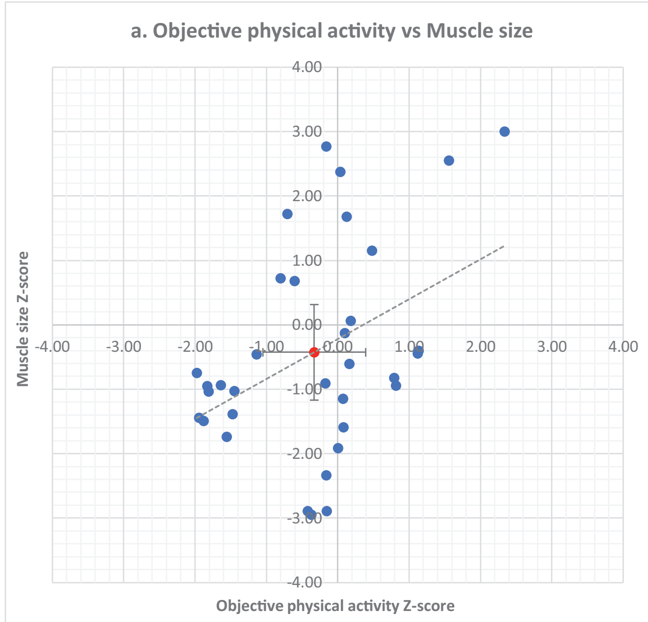
This review identified a moderate association between muscle size and muscle strength. Furthermore, a moderate association was also identified between objective measures of physical activity and both lower limb muscle size and strength. In contrast, subjective measures of physical activity were generally negatively correlated with both muscle size and muscle strength, particularly in older populations.

Muscle hypertrophy and increased strength are dependent on intensity of the physical activity.[95] Objective measures of physical activity are able to quantify this intensity[95] using devices, such as accelerometry, to record biomechanical aspects of physical activity in real time.[96] Consistent with previous reports,[96] accelerometers were the most commonly used method to assess objective physical activity in this review. Accelerometers have a low level of burden on the wearer and are capable of assessing the quantity and intensity of physical activity by recording movement along the vertical, anteroposterior, and mediolateral directions.[96] The ability to measure movement, produced by skeletal muscles, in 3 directions may explain the strength of relationship between objective measures of physical activity and both muscle size and strength. Additionally, data from objective measures of physical activity are direct reflections of physical activity being completed, and is therefore likely to lead to muscle hypertrophy or increased strength.[97] However, there are some limitations to the ability of accelerometers to accurately measure some types of physical activity

Table 3 Correlations between physical activity and measures of muscle size and strength across all age subgroups

Physical Activity Measure	Muscle Measure	Pearson Correlation for Age Group (No. of Data Points)			
		All ages	Younger (<35y)	Middle Aged (35-50y)	Older (>50y)
Objective	Size	0.30* (34)	†	−0.11 (11)	0.09* (21)
	Strength	0.24* (43)	−0.53* (5)	0.78* (11)	−0.08* (27)
Subjective	Size	−0.59* (46)	0.20* (7)	−0.51* (4)	−0.64* (35)
	Strength	−0.48* (51)	0.21* (13)	−0.70* (5)	0.13* (33)

* P<0.01.
† Two data points, positively correlated.



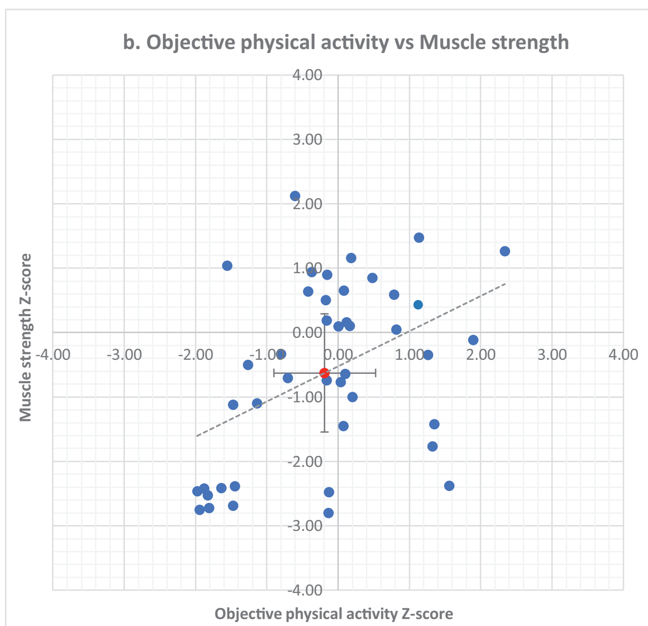


Fig 2 Correlations between z scores of pairs of outcome measures for objective measures of physical activity (mean ± SD of z scores in red).

such as walking up and down stairs or inclines, lifting or carrying objects over a distance, and cycling.[97] Pedometers were the only other objective measure used in this review, and this is consistent with previous reports of common use.[98] Although a limitation of measuring physical activity by counting steps is that it can only record movement above a set threshold and cannot distinguish between fast pace walking, running, or jumping,[96] pedometers still measure movement brought about by skeletal musculature of the lower limb. Within clinical settings, accelerometers and pedometers are most commonly used as objective measures of physical activity owing to their small size and relatively inexpensive cost.[96]

Estimation of physical activity using subjective measures may be particularly difficult for older individuals with a BMI classed in the overweight or obese category, as they perceive the amount of physical activity differently from the younger population, potentially owing to the inaccurate determination of relative intensity of the activities being completed.[45] Younger adults classified as "fit" report time completed in MVPA more accurately using the IPAQ.[45] In general, overreporting of activity is well documented in all age

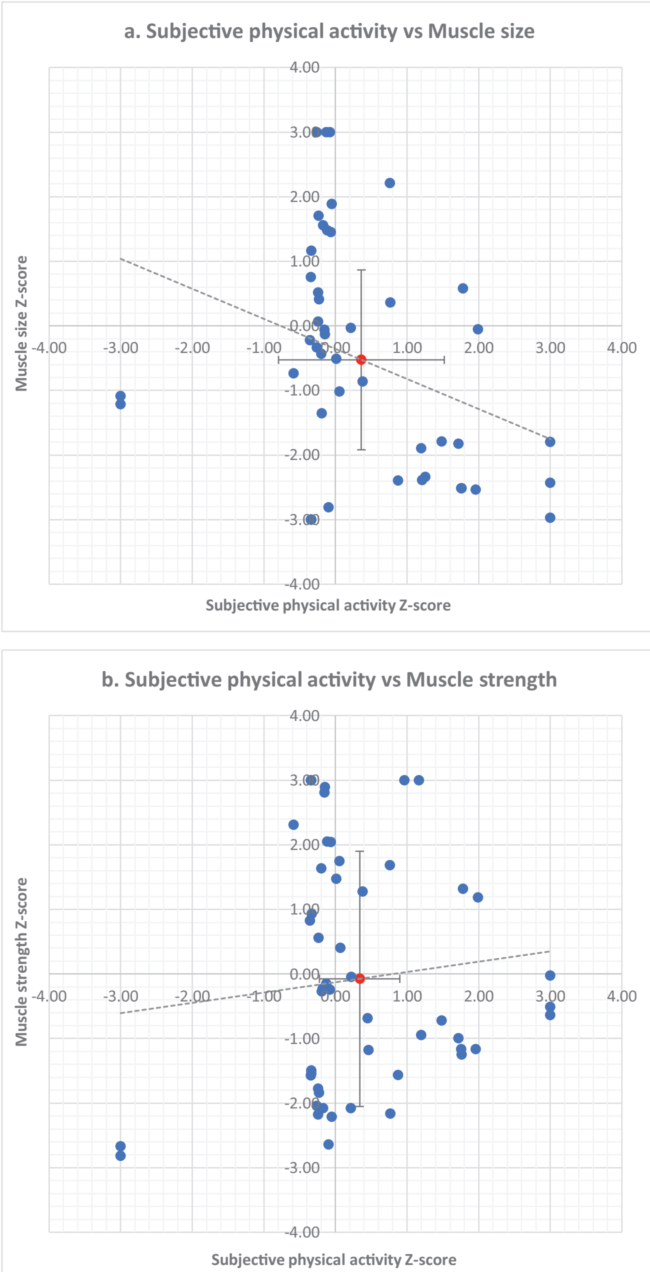


Fig 3 Correlations between z scores of pairs of outcome measures for subjective measures of physical activity (mean ± SD of z scores in red).

groups using subjective measures.[45] The mean age of the participants in the studies included within the subjective analysis was 58.8 years, with an average BMI of 26.8 (overweight). The age and BMI of the participants may help explain the negative relationship between reported measures of physical activity and muscle strength and size identified in this review. The sensitivity analysis in this review is consistent with previous reports of inaccurate estimation of physical activity using subjective measures in older populations.[45] There was generally a negative relationship between physical activity and muscle outcome measures for the older populations, but a positive relationship between subjective measures of physical activity and both muscle strength and size in the younger population.

Physical activity that includes resistance exercise is particularly associated with increases in muscle hypertrophy and strength, including in the elderly population.[99] In weightbearing activities (eg, walking or running) as measured by both subjective and objective physical activity in this study, bodyweight is the primary form of resistance. Although the subjective and objective physical activity tools used in the included studies were not designed to quantify resistance exercise per se, objective measures (eg, accelerometers) are used to quantify weightbearing activities (eg, walking and running) by monitoring movement of the body in multiple planes. Therefore, objective measures provide a measure of muscular activity against bodyweight as the primary form of resistance and this probably explains the moderate positive correlation with muscle size. The divergent relationships obtained for objective and subjective measures of physical activity with muscle size and strength is likely to reflect the lack of agreement that exists between subjective and objective measurements of physical activity. In support of this statement, the overreporting of activity is well documented in all age groups using subjective measures.

Genetic factors (eg, sex), endocrine status, and age affect muscle hypertrophy and strength gains.[100] One of the major factors that contributes to muscle size and strength is body size. To account for the variance in body size, both strength[101] and muscle size[8] data are often normalized to the individual's bodyweight. However, because body size data for individual participants in each included study were not available, these calculations could not be made for this review. Additionally, physical activity in most studies included in this review was only measured over a 1-week period, and changes in muscle size in particular can take up to 6 weeks to be observed.[13] These factors may help explain why objective measures of physical activity only accounted for a relatively low proportion of the variance in muscle size (9%) and strength (5%). Future studies should consider reliability of 1 week vs longer data collection periods for physical activity.

Study strengths

Several characteristics of this study were adopted to increase the overall power of the correlation analysis and therefore increase confidence in the outcomes of the study. The systematic search strategy resulted in inclusion of peer reviewed studies with original data for all 3 outcomes measures (physical activity, muscle size, muscle strength) across a large population sample (n=5893) and a wide range of age groups (18-78y). The inclusion of multiple subgroups from included studies and the ability to include data from multiple muscle groups through conversion to z scores increased the number of data points in each analysis. The separate analysis of objective and subjective measures of physical activity has identified the positive relationship between objective measures and muscle size and strength that might otherwise have been masked if these data were pooled. Finally, the weighting of the correlation on the sample size of subgroups means that the relationship between outcome variables reflects the participant numbers of subgroups. The majority of studies reported on most items relating to methodological quality indicating a relatively low risk of bias in the results of this meta-analysis. Although some studies did not report normality tests and actual probability values, they are less important to the findings of this review as only base line data were extracted for analysis.

Study limitations

Although restricting included studies to only those including measures of both muscle strength and size reduced the number of data points in these analyses, it was necessary to enable direct comparison between the associations between physical activity, muscle size, and strength using data from the same participants. The inability to account for other individual factors (eg, participant body size) might have also limited the findings of this review. The high number of calculations completed during data analysis to obtain *z* scores for each subgroup could also be seen as a limitation. However, most of the mean *z* scores were less than 1 standard deviation from zero and the mean standard deviation of the *z* scores approximated 1, indicating a relatively normal distribution of these calculated data. Additionally, normative data from large studies were used when possible in the calculation of all data and the factors to account for sex differences in outcome measures were checked for consistency against other large studies for each of physical activity,[102,103] muscle size,[27,29] and muscle strength.[37,39]

Conclusions

This study identified that objective measures of physical activity are moderately associated with lower limb muscle size and strength in a broad cross-section of the general population. Therefore, if clinicians and exercise professionals within rehabilitation settings are proposing to use measures of physical activity to predict improvements in muscle size and strength, this study suggested that only objective measures such as accelerometry should be used across the general population. It is possible that subjective measures of physical activity might be appropriate for individuals within a younger population.

Supplier

a. IBM SPSS Statistics for Windows, version 27.0; IBM Corp.

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