Association of physical behaviours with sarcopenia in older adults: a systematic review and meta-analysis of observational studies

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Summary

Background Physical behaviours (ie, physical activity and sedentary behaviour) might have a role in the development of sarcopenia, although the evidence is unclear. We aimed to explore the association of total and intensity-specific levels of physical activity and sedentary behaviour with sarcopenia and its components (ie, muscle mass, muscle strength, and physical performance) in older adults.

Methods We conducted a systematic review and meta-analysis and searched MEDLINE (via PubMed), Scopus, and Web of Science from inception to July 26, 2022, for peer-reviewed, observational studies or baseline data from randomised clinical trials conducted in older adults (ie, individual age ≥60 years or mean age ≥65 years) and published in English that reported on the association of physical activity or sedentary behaviour or both with sarcopenia (or its determinants: muscle mass or strength, and physical performance). Physical activity and sedentary behaviour were measured by any method. The main outcome was sarcopenia, which could be diagnosed by any means. Estimates were extracted and pooled using Bayesian meta-analytic models and publication bias was assessed using the Egger's test. This study is registered with PROSPERO, CRD42022315865.

Findings We identified 15 766 records, of which 124 studies (230 174 older adults; 121 301 [52·7%] were female and 108 873 [47·3%] were male) were included in the systematic review. 86 studies were subsequently included in the meta-analysis. Higher levels of total physical activity were inversely associated with sarcopenia both cross-sectionally (21 studies, n=59 572; odds ratio 0·49, 95% credible interval 0·37–0·62) and longitudinally (four studies, n=7545; 0·51, 0·27–0·94). A protective association was also identified for moderate-to-vigorous physical activity in cross-sectional research (five studies, n=6787; 0·85, 0·71–0·99), whereas no association was identified for the remaining physical behaviours (ie, steps, light physical activity, or sedentary behaviour).

Interpretation Total and moderate-to-vigorous physical activity are inversely associated with sarcopenia. These findings might support the importance of moderate-to-vigorous, rather than light, intensity physical activity-based interventions to prevent sarcopenia.

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For the Spanish translation of the abstract see **Online** for appendix 1

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Introduction

Sarcopenia is characterised by an accelerated loss of muscle mass and function, and thus of physical performance, that affects approximately 10% of older adults, albeit with a large variation (8–51%) in the reported prevalences depending on factors such as the diagnostic method or the population studied.[1,2] Sarcopenia has a major role in ageing-related loss of functional ability and quality of life[3] and increases the risk of adverse outcomes, such as falls, disability, frailty, hospitalisation, and all-cause mortality.[4,5] Sarcopenia is considered to be a major public health issue[5] and is recognised as an independent condition by the International Classification of Diseases, Tenth Revision, Clinical Modification.[6] With no cure in the foreseeable future, there is a strong need to prevent or attenuate the progression of sarcopenia.[5,7]

Among several other factors (eg, genetics, diet, and pharmacological treatments), physical behaviours (ie, physical activity and sedentary behaviour) can have a role in the development of sarcopenia.[8] Previous meta-analytic evidence on the topic[9,10] is limited by the cross-sectional nature of most included studies and the generalised use of subjective tools (ie, questionnaires) to assess physical behaviours.[11] The ability to use objective physical activity quantification (also allowing for the determination of physical activity intensities; eg, the use of accelerometers that allow classification of time in physical activity into different intensities or identification of sedentary behaviours),[12] the increase in the number of studies analysing sedentary behaviour as the exposure of interest,[13] a growing consensus on sarcopenia operationalisation (ie, the methods by which sarcopenia

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Research in context

Evidence before this study

Physical behaviours (ie, physical activity and sedentary behaviour) might have a role in the development of sarcopenia in older people; however, evidence is inconclusive. We performed a systematic search on this topic in MEDLINE, Scopus, and Web of Science from inception to July 26, 2022, using terms related to the population of interest (ie, [“elderly” OR “older adult*” OR “old people”] AND [“sedentarism” OR “sedentary” OR “sitting” OR “inactivity” OR “physical activit*” OR “walking activit*”] AND [[“sarcopenia” OR “sarcopenic”] OR [“muscle mass” OR “appendicular lean mass” OR “skeletal muscle index” OR “lean mass” OR “appendicular skeletal muscle” OR “skeletal muscle mas” OR “appendicular skeletal muscle mass” OR “calf circumference”] OR [“physical performance” OR “gait speed” OR “gait velocity” OR “short physical performance battery” OR “ sppb” OR “timed up-and-go” OR “tug”] OR [“strength” OR “muscle strength” OR “grip strength” OR “handgrip strength” OR “chair stand”]]). Existing meta-analytic evidence on the topic suggests a protective effect of physical activity on sarcopenia but is limited by the cross-sectional nature of most included studies and the generalised use of subjective tools (ie, questionnaires) to assess physical behaviours. We observed an increasing number of longitudinal studies since 2017 using objective methods for physical behavior monitoring, which can provide more robust evidence on the topic.

Added value of this study

This systematic review with meta-analysis overcomes limitations of previous literature by incorporating longitudinal evidence based on objective assessment of physical behaviours and shows an inverse association between higher levels of total physical activity and sarcopenia both cross-sectionally and longitudinally. Intensity-specific analyses showed that higher levels of moderate-to-vigorous physical activity is more consistently associated with lower sarcopenia odds and its individual components, whereas light-intensity physical activity or sedentary behaviour were only marginally associated with sarcopenia.

Implications of all the available evidence

Higher levels of total physical activity (particularly that of higher intensity) might have a protective role against sarcopenia development at older ages. Our findings suggest that public health recommendations and interventions should focus their efforts towards total and moderate-to-vigorous (rather than light) physical activity targets as a means of promoting healthy ageing.

can be diagnosed),[14] and the availability of longitudinal data might help to overcome these limitations.[15] These factors can also assist in the development of interventions aimed to prevent sarcopenia[16] or its deleterious consequences.[17]

We aimed to establish the association of physical activity and sedentary behaviour with sarcopenia and various individual components that are used to define this condition (ie, muscle mass, muscle strength, and physical performance) in older adults.

Methods

Search strategy and selection criteria

We conducted a systematic review and meta-analysis of studies on the association of physical activity and sedentary behaviour with sarcopenia. JLS-S and LH searched MEDLINE (via PubMed), Web of Science, and Scopus from inception to July 26, 2022 (appendix 2 pp 183–85). Given the absence of medical subject headings linked to some of the core elements of our systematic review (eg, muscle mass and physical activity) we decided to use free-text search terms: (“elderly” OR “older adult*” OR “old people”) AND (“sedentarism” OR “sedentary” OR “sitting” OR “inactivity” OR “physical activit*” OR “walking activit*”) AND ((“sarcopenia” OR “sarcopenic”) OR (“muscle mass” OR “appendicular lean mass” OR “skeletal muscle index” OR “lean mass” OR “appendicular skeletal muscle” OR “skeletal muscle mass” OR “appendicular skeletal muscle mass” OR “calf circumference”) OR (“physical performance” OR “gait speed” OR “gait velocity” OR “short physical performance battery” OR “ sppb” OR “timed up-and-go” OR “tug”) OR (“strength” OR “muscle strength” OR “grip strength” OR “handgrip strength” OR “chair stand”)). We sought to retrieve summary-level estimates from studies. The title and abstract of potentially eligible studies were independently screened for suitability by two reviewers (JLS-S and LH). If deemed eligible, the full text was assessed, with disagreements resolved by an additional reviewer (PLV). Reference lists of included studies and relevant systematic reviews[10,11] on the topic were also manually screened for potentially eligible articles. Records were organised and managed with Mendeley (version 1.19.8; Elsevier, Amsterdam, Netherlands) and Rayyan.[18] We included studies that were peer-reviewed; were written in English; had a prospective or retrospective cohort, cross-sectional, or randomised clinical trial design for which baseline data of interest could be retrieved; included only participants aged 60 years or older as part of individual study criteria or alternatively, where younger participants were included, had a mean participant age of 65 years or older; and reported the association of physical activity or sedentary behaviour or both (assessed by any means) with sarcopenia (diagnosed by any means). We also included studies analysing the association of physical activity or sedentary behaviour with any individual component of sarcopenia: muscle mass, muscle strength, or physical performance according to the European Working Group on Sarcopenia in Older People (EWGSOP)[19,20] or the Asian Working

See Online for appendix 2

Group on Sarcopenia (AWGS).[21,22] For the meta-analysis, we included studies that reported associations between physical behaviours and sarcopenia by means of Pearson's *r*, β coefficients, or odds ratios (ORs). The protocol is available online.[23]

Data analysis

The following data from each of the included studies were independently extracted by two authors (JLS-S and LH): first author, year of publication, sample size, population characteristics, sampling design, method for physical activity or sedentary behaviour assessment, model and brand of accelerometer or pedometer device (if applicable), worn location of device (if applicable), minimum wear duration, and valid days required for inclusion in analysis for objective assessment of physical activity or sedentary behaviour (if applicable), measures used to characterise physical activity or sedentary behaviour, definition of sarcopenia or measurements of its different components, mean or median value of physical activity or sedentary behaviour metrics and sarcopenia components, main analysis performed to explore the associations of interest, covariate structure, effect sizes, and level of significance. The physical behaviour-related measures considered were sedentary behaviour, number of steps, light physical activity (including non-sedentary time), moderate-to-vigorous physical activity (and the sum of both moderate and vigorous physical activity), and total physical activity, classifying the participants as active or inactive on the basis of the classification proposed in the original studies or considering the outermost categories (eg, inactive for quartile 1 of total physical activity and active for quartile 4 of total physical activity) when more than two groups were reported. Summary data were tabulated in a Microsoft Excel spreadsheet, for which the template was approved after discussion between three authors (JLS-S, LH, and PLV).

Study quality was independently assessed by two authors (JLS-S and LH) using the Newcastle-Ottawa Scale for longitudinal studies and its adapted version for cross-sectional studies (appendix 2 pp 186–87).[24] A maximum score of 7 stars can be achieved for cross-sectional studies and a maximum score of 9 stars can be achieved for longitudinal studies. Thus, study quality was considered high if reaching at least 4 stars for cross-sectional studies or at least 5 stars for longitudinal studies. Otherwise, studies were considered to be of low quality.[24]

Following previously described procedures,[25,26] the level of evidence for each individual association assessed was rated considering the percentage of estimations reporting a significant positive or negative association (ie, no association if ≤33% of estimations reported a significant association, inconsistent or uncertain association if 34–59% of estimations reported a significant association, or positive or negative association if ≥60% of estimations reported a significant association); the quality of the studies (based on the Newcastle-Ottawa Scale); and the consistence across the studies (appendix 2 p 188).

Bayesian random-effects meta-analyses were performed to explore the association of physical activity or sedentary behaviour variables with sarcopenia and its different components. We used a Bayesian approach because it allows direct modelling of the uncertainty of the estimate of between-study heterogeneity (τ or its variance, τ^2). This method produces full posterior distributions for meta-analysis parameters, such as the pooled effect and between-study heterogeneity. Additionally, the Bayesian approach is superior to frequentist approaches in estimating pooled effects, especially when the number of included studies is small.[27]

Before computing the pooled estimates, individual study data were transformed to ensure comparability using standard methods.[28,29] For the analysis of sarcopenia as a dichotomous outcome, ORs were transformed into logOR. Once the meta-analyses were conducted, the expectations of the posterior distributions of the effect estimates (ie, pooled logOR, study-specific intercepts, and between-study SD) and their associated uncertainty (95% credible interval [CrI]) were computed and transformed back to the original OR units. For the analysis of sarcopenia determinants (ie, muscle mass, muscle strength, and physical performance) individual-study estimates were converted to Pearson's correlation coefficients (*r* and 95% CrI) according to their corresponding formulas.[30–32] Within the Bayesian framework, the 95% CrI entails that the true estimate would lie within the interval given the observed data. For practical purposes, we considered an association to be significant when 0 was not included in the 95% CrI for *r* and 1 was not included in the 95% CrI for the OR.[33]

When a study presented statistics by subgroups (eg, men and women), we followed the Cochrane methodological recommendations to combine them into a single group.[34] We also conducted a meta-regression to explore the effect moderation of both age and sex (ie, proportion of women) in the total association between physical activity and sarcopenia. The presence of publication bias was assessed using the Egger's test. Sensitivity analyses were carried out, when feasible, on the basis of participants' characteristics (limited to populations without sarcopenia) and the methods used for exposure ascertainment (limited to studies using objective measures for sedentary behaviour or physical activity assessment) or outcome diagnosis (limited to studies defining sarcopenia according to EWGSOP, AWGS, or the Foundation for the National Institutes of Health recommendations). Additionally, sensitivity analyses were conducted by excluding influential studies that might lead to excess heterogeneity. To ease the clinical interpretation of our results, OR values were re-expressed as absolute risk reductions (ie, number of people per 1000 population who would not present with sarcopenia if they were exposed to

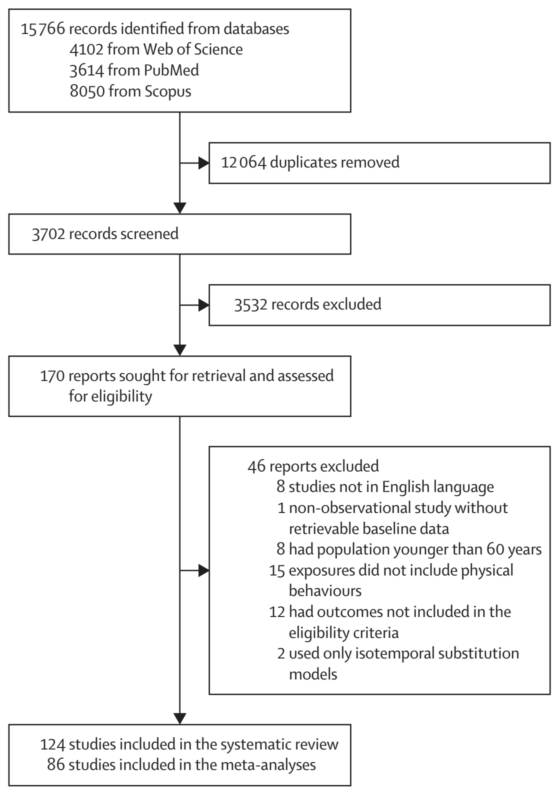

Figure 1: **PRISMA flow diagram of the inclusion process**

physical activity) across three prespecified evidence-based assumed comparator risks.[2] Details regarding data handling procedures and model implementation are shown in appendix 2 (pp 189–90).

Two researchers (JLS-S and PLV) independently used the Grading of Recommendations Assessment, Development and Evaluation (GRADE) to measure the certainty of the evidence for each meta-analysis (appendix 2 pp 191–92). In cases of disagreement, a third author (JSM) was consulted. We adhered to the protocols described in the updated GRADE handbook, and our interpretation and communication of results align with the recommendations of the GRADE working group.

All analyses were conducted using R, version 4.0.3. The review protocol was registered with PROSPERO, CRD42022315865, and the study is reported according to the PRISMA guidelines.[35]

Role of the funding source

There was no funding source for this study.

Results

We identified 15766 records, of which 3702 were screened. A total of 124 studies (appendix 2 pp 5–22) were included in the systematic review and 86 were included in the meta-analysis (figure 1). The details of the GRADE assessment are shown in appendix 2 (pp 2–4).

The included studies encompassed a total of 230 174 participants, ranging from 22 to 21 644 individuals per study (121 301 [52·7%] were female and 108 873 [47·3%] were male; mean age range 63–100 years; appendix 2 pp 5–22). 99 (79·8%) of 124 studies focused on community-dwelling older adults. The remaining studies reported on specific subgroups of older people: the oldest-old (ie, aged >80–85 years; n=5), older adults at risk of mobility disability (n=2), hospitalised individuals or individuals living in institutions (n=6), those attending a primary care centre (n=2), and those with specific health conditions (n=10; appendix 2 pp 5–22). 120 of 124 studies were conducted with single-country cohorts, and four studies used multicountry samples (appendix 2 pp 5–22). 110 (88·7%) studies used only a cross-sectional design, 10 (8·1%) studies used only a longitudinal design, and four (3·2%) studies used both a cross-sectional and a longitudinal design (appendix 2 pp 5–22). 98 (79·0%) studies were of high quality (appendix 2 pp 22–28).

Objective methods (ie, pedometers [four studies] or accelerometers [52 studies]) were used to assess sedentary behaviour in 31 studies and physical activity in 49 studies. Subjective methods (ie, interview [27 studies], questionnaire [21 studies], or a single question [19 studies]) were used to assess sedentary behaviour in 10 studies and physical activity in 68 studies. All studies expressed sedentary behaviour as total volume, whereas measures related to physical activity were expressed as engagement in exercise (n=3), number of steps per unit of time (n=17), volume of light physical activity (or active time, when moderate-to-vigorous physical activity was reported; n=19), moderate-to-vigorous physical activity (n=35), or total physical activity (n=65; appendix 2 pp 29–43, pp 44–63). Further details on the features of sedentary behaviour and physical activity assessment in the included studies are shown in appendix 2 (pp 29–43, pp 44–63).

Of the 42 studies reporting associations between physical behaviours and sarcopenia, 14 used the 2010 EWGSOP definition, five used the updated 2019 EWGSOP definition, three used the 2014 AWGS definition, and another three used the updated 2019 AWGS definition. Additionally, two studies adopted the Foundation for the National Institutes of Health definition, one study followed the definition proposed by the International Working Group on Sarcopenia, and one study used the Japan Society of Hepatology definition. Two studies specifically defined sarcopenia on the basis of low levels of handgrip strength according to sex-specific thresholds in the AWGS or Foundation for the National Institutes of Health recommendations, three studies defined sarcopenia on the basis of low muscle mass, two studies used a score of at least 4 on the Strength, Assistance in Walking, Rise from a Chair, Climb Stairs, and Falls scale, and six studies applied other definitions (appendix 2 pp 64–95).

Effect direction and p value (+ ▲, − ▼): p<0·0010; 0·0010≤p<0·010; 0·010≤p<0·050; 0·050≤p<0·10; 0·10≤p<0·25; p≥0·25	Sarcopenia definition, nature of exposure, and features of population	Sedentary behaviour*	Number of daily steps	Light physical activity†	Moderate-to-vigorous physical activity	Total physical activity‡
Aggio et al (2016)[36]	E1; objective; GP	▼ p≥0·25		▲ p≥0·25	▲ p≥0·25	
Bae and Kim (2017)[37]	Other; subjective; GP					▲ 0·010≤p<0·050
Curcio et al (2019)[38]	E1; subjective; GP					▲ 0·010≤p<0·050
da Silva et al (2017)[39]	Other; subjective; OO					▲ p≥0·25
Alexandre et al (2014)[40]	E1; subjective; GP					▲ 0·050≤p<0·10
Du et al (2022)[41]	E2; subjective; GP (male subpopulation)					▲ 0·10≤p<0·25
Du et al (2022)[41]	E2; subjective; GP (female subpopulation)					▲ 0·10≤p<0·25
Izawa et al (2017)[42]	E1; objective; PWD		▲ 0·010≤p<0·050			▲ 0·0010≤p<0·010
Kim et al (2013)[43]	Other; subjective; GP					▲ p<0·0010
Kitamura et al (2021)[44]	A1; objective; GP		▲ 0·0010≤p<0·010			
Ko et al (2021)[45]	A2; subjective; GP					▲ 0·0010≤p<0·010
Kurita et al (2022)[46]	E2; subjective; GP					▲ p<0·0010
Kwan et al (2022)[47]	S, objective; OO					▲ 0·010≤p<0·050
Landi et al (2012)[48]	E1; subjective; NH					▲ 0·10≤p<0·25
Lau et al (2005)[49]	Other; subjective; GP (male subpopulation)					▲ p≥0·25
Lau et al (2005)[49]	Other; subjective; GP (female subpopulation)					▲ p≥0·25
Lin et al (2013)[50]	E1; subjective; GP					▲ 0·10≤p<0·25
Martinez et al (2015)[51]	E1; subjective; H					▲ 0·010≤p<0·050
Meier and Lee (2020)[52]	E1; objective; GP	▼ p≥0·25	▲ 0·10≤p<0·25			
Mijnarends et al (2016)§[53]	E1; subjective; GP				▲ 0·0010≤p<0·010	
Murphy et al (2014)[54]	E1; subjective; GP					▲ 0·010≤p<0·050
Nguyen et al (2020)[55]	A2; subjective; GP					▲ p<0·0010
Nguyen et al (2020)[55]	F; subjective; GP					▲ p<0·0010
Ohashi et al (2018)[56]	J; subjective; PWD					▲ 0·0010≤p<0·010
Park et al (2010)[57]	Other; objective; GP		▲ 0·050≤p<0·10		▲ 0·0010≤p<0·010	
Park et al (2021)[58]	E1; subjective; GP					▲ p<0·0010
Reid et al (2018)[59]	E1; subjective; NH	▼ 0·10≤p<0·25				
Reid et al (2018)§[60]	E1; subjective; NH					
Rosique-Esteban et al (2019)[61]	E1; subjective; PWD	▼ 0·10≤p<0·25			▲ 0·0010≤p<0·010	▲ 0·0010≤p<0·010
Ryu et al (2013)[62]	Other; subjective; GP (male subpopulation)					▲ p<0·0010
Ryu et al (2013)[62]	Other; subjective; GP (female subpopulation)					▲ p≥0·25
Saadeddine et al (2021)[63]	Other; subjective; GP					▲ 0·0010≤p<0·010
Sánchez-Sánchez et al (2019)[64]	F; objective; GP	▼ p≥0·25		▲ p≥0·25	▲ 0·0010≤p<0·010	▲ p<0·0010
Sazlina et al (2020)[65]	A2; subjective; PWD					▲ 0·010≤p<0·050
Scott et al (2021)[66]	Other; objective; GP	▼ p≥0·25		▲ p≥0·25	▲ p<0·0010	
Seo and Lee (2022)[67]	Other¶; subjective; GP (male subpopulation)					▲ 0·010≤p<0·050
Seo and Lee (2022)[67]	Other¶; subjective; GP (female subpopulation)					▲ 0·050≤p<0·10
Seo and Lee (2022)[67]	Other‖; subjective; GP (male subpopulation)					▲ 0·050≤p<0·10
Seo and Lee (2022)[67]	Other‖; subjective; GP (female subpopulation)					▲ 0·0010≤p<0·010
Shephard et al (2013)[68]	Other; objective; GP (male subpopulation)		▲ 0·010≤p<0·050			▲ 0·010≤p<0·050
Shephard et al (2013)[68]	Other; objective; GP (female subpopulation)		▲ 0·010≤p<0·050			▲ 0·010≤p<0·050
Smith et al (2020)[69]	Other; subjective; GP	▼ 0·010≤p<0·050				
Sousa-Santos et al (2019)[70]	E2; subjective; GP					▲ 0·050≤p<0·10
Therakomen et al (2020)[71]	A1; subjective; GP					▲ 0·010≤p<0·050
Tramontano et al (2017)[72]	I; subjective; GP					▲ 0·010≤p<0·050
Tyrovolas et al (2016)[73]	E1; subjective; GP					▲ 0·010≤p<0·050
Tzeng et al (2020)[74]	Other; subjective; GP	▼ 0·010≤p<0·050			▲ p<0·0010	
Veen et al (2022)[75]	Other; objective; GP			▲ 0·010≤p<0·050	▲ p<0·0010	
Westbury et al (2018)[76]	E1; objective; GP			▲ 0·010≤p<0·050	▲ 0·050≤p<0·10	▲ 0·10≤p<0·25
Yang et al (2019)[77]	Other; subjective; GP (male subpopulation)					▲ 0·010≤p<0·050
Yang et al (2019)[77]	Other; subjective; GP (female subpopulation)					▲ p<0·0010
Yoo et al (2020)[78]	Other; subjective; GP					▲ 0·010≤p<0·050
Yuenyongchaiwat and Boonsinsukh (2020)[79]	E1; subjective; GP					▲ 0·010≤p<0·050

Figure 2: **Graphical summary of the associations between increases in different physical behaviours and sarcopenia**

Effect direction is indicated by upward (ie, beneficial effects for the patient) and downward (ie, detrimental effects for the patient) arrows. A1=Asian Working Group on Sarcopenia, 2014. A2=Asian Working Group on Sarcopenia, 2019. E1=European Working Group on Sarcopenia in Older People 2010. E2=European Working Group on Sarcopenia in Older People 2019. F=Foundations for the National Institute of Health. GP=general older adult population. H=hospitalised older adults. I=International Working Group on Sarcopenia. J=Japan Society of Hepatology. NH=nursing home residents. OO=oldest-old adults. PWD=population with disease. S=SARC-F Questionnaire: Strength, Assistance with Walking, Rise from a Chair, Climb Stairs and Falls. *Includes television viewing and sitting time. †Includes non-sedentary time when moderate-to-vigorous physical activity is measured. ‡Total physical activity includes counts per minute. §Longitudinal study. ¶Defined sarcopenia as low muscle mass. ||Defined sarcopenia as low muscle strength.

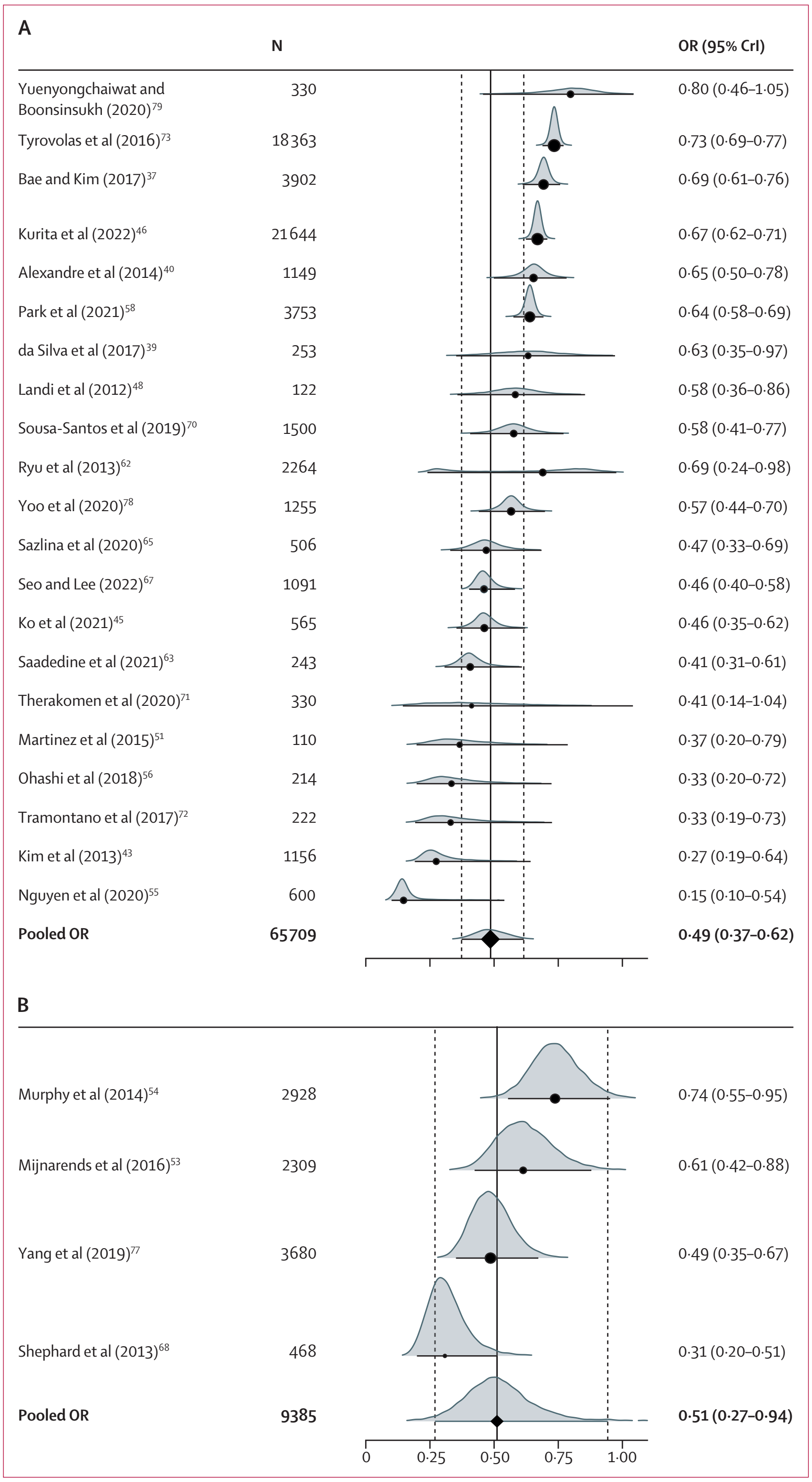

***Figure 3:* Forest plots of the associations between total physical activity levels and sarcopenia**
Cross-sectional (A) and longitudinal (B) associations between total physical activity levels (ie, most active *vs* least active) and sarcopenia. The solid line indicates the median pooled OR estimate. The dashed lines indicate the lower and upper bounds of the 95% CrI of the pooled estimates. CrI=credible interval. OR=odds ratio.

Muscle mass was estimated by means of dual-energy x-ray absorptiometry (n=16), bioimpedance (n=5), CT (n=1), or anthropometric measurements (n=1). Muscle strength was assessed with the handgrip test (n=42) or as time to complete the five-times sit to stand test (n=20). Physical performance was assessed through gait speed (n=39), the timed up-and-go test (n=19), or the Short Physical Performance Battery (n=17). A detailed description of the methods used to assess sarcopenia and its different components in the included studies is shown in appendix 2 (pp 64–95).

Associations between physical behaviours and sarcopenia were recorded (appendix 2 pp 96–161) as well as the associations of different physical behaviours with sarcopenia and its components (figure 2, appendix 2 pp 171–80).

An inverse association was seen between sarcopenia and the number of daily steps, with four of six estimations yielding significant results (figure 2) and all four coming from high-quality studies (appendix 2 pp 162–65). Similarly, moderate-to-vigorous physical activity showed significant inverse associations in seven of nine estimations (with six of the seven studies assessed as high quality). Total physical activity presented significant inverse associations with sarcopenia in 29 of 43 estimations (25 of 29 from high-quality studies). Furthermore, moderate-to-vigorous physical activity was consistently associated with a higher gait speed in 12 of 17 estimations (with 11 of 12 from high-quality studies) and had a superior Short Physical Performance Battery score in six of seven estimations (with all six from high-quality studies). Additionally, moderate-to-vigorous physical activity was associated with better performance in the timed up-and-go test, as seen in six of nine estimations (five of six from high-quality studies). Conversely, total physical activity was consistently associated with a more favourable Short Physical Performance Battery score in six of seven estimations (four of six from high-quality studies). The remaining explored associations were either deemed insufficient or uncertain or showed no association (appendix pp 162–65).

In cross-sectional studies, increased total physical activity was linked to a reduced prevalence of sarcopenia. This result was observed in 21 studies (n=59 572), with a pooled OR for the most active versus the most inactive groups of 0·49 (95% CrI 0·37–0·62, figure 3A); moderate heterogeneity was noted (τ=0·47). However, potential publication bias was indicated (Egger's test p=0·037; appendix 2 p 2). Interpreting these results, there is an implied reduction of 25 (95% CrI 19–31) cases per 1000 individuals for an assumed control risk [ACR] of 5%, 111 (83–139) cases per 1000 individuals for an ACR of 25%, and 173 (118–228) cases per 1000 individuals for an ACR of 50%. Subanalyses pinpointed an inverse association between moderate-to-vigorous physical activity and sarcopenia prevalence (five studies, n=6787); an OR of 0·85 (95% CrI 0·71–0·99) was identified for moderate-to-vigorous physical activity increases of 30 min per day, and the heterogeneity was moderate (τ=0·11) with no evident publication bias (Egger's test p=0·050). By contrast, no clear association emerged for sedentary behaviour (six studies, n=6920), with an OR of 1·35 (95% CrI 0·91–2·04; τ=0·53) for sedentary behaviour increases of 30 min per day (appendix 2 p 2). Other physical activity indicators, such as light physical activity and daily steps, were either hindered by model convergence issues or not reported in a sufficient number of studies. For the associations between total physical activity and sarcopenia, a greater female proportion aligned with higher OR values for sarcopenia, whereas age did not show a distinct association (appendix 2 p 181).

A moderate association was observed between total physical activity and both muscle strength (but not mass) and physical performance (table). Subanalyses attending to specific physical behaviours showed a moderate association between moderate-to-vigorous physical activity and each of the three components of sarcopenia, whereas no consistent associations were identified for light physical activity, number of daily steps, or sedentary behaviour (table). No substantial heterogeneity (τ<0·50) or sign of publication bias (Egger's test p=0·050) was detected (table 1; appendix 2 pp 2–3).

In longitudinal studies, the highest (compared with the lowest) total physical activity levels were inversely related to the risk of developing sarcopenia. This result was observed in four studies involving 7545 older adults, with a pooled OR of 0·51 (95% CrI 0·27–0·94; τ=0·52; figure 3B). Analyses for the longitudinal associations between physical behaviours other than total physical activity and sarcopenia could not be conducted due to an insufficient number of studies. Likewise, planned subanalyses when more than three studies were available focused on objective or subjective physical activity instruments were unfeasible because of the few studies available for performing the intended analyses.

Sensitivity analyses for both cross-sectional and longitudinal studies consistently corroborated the initial results (appendix 2 pp 166–70, 182).

Discussion

This study suggests that higher total physical activity is associated with a lower risk of sarcopenia in older adults, as supported by our meta-analytic evidence of both cross-sectional and longitudinal studies. The association seems to be more robust for moderate-to-vigorous physical activity (albeit analyses of the longitudinal data could not be conducted), but no evidence exists for associations with other physical behaviour indicators, such as light physical activity, number of steps, or sedentary behaviour.

Physical behaviours are deemed to be lifelong determinants of health.[80,81] Higher total physical activity levels have been identified as one of the most relevant factors for healthy ageing,[82] and some evidence suggests that reducing sedentary behaviour might also have a role.[83] However, the information available on the association between different physical behaviours and sarcopenia remains, to date, unclear. These findings not only update but also extend those derived from previous meta-analyses showing a protective association between physical activity and sarcopenia in older age.[9,10] Namely, our results support and expand on those by Steffl and colleagues,[9] who pooled seven cross-sectional studies exploring associations between total physical activity and sarcopenia. These authors reported a reduced odds of sarcopenia among active individuals, with a pooled OR of 0·45 (95% CI 0·37–0·55). This result is consistent in magnitude with the pooled estimate from our meta-analysis. Furthermore, our analysis indicated that total physical activity shows an inverse association with sarcopenia in both cross-sectional and longitudinal studies, emphasising the potential protective role of this physical behaviour.

A major novelty of our meta-analysis, compared with previous work, is the inclusion of studies that used objective, device-based measures of physical behaviours. This method offers a nuanced characterisation of the duration and intensity of sedentary behaviour or physical activity. The intensity of physical activity has been established as a pivotal modulator of its effects on health. Although there are documented benefits from reducing sedentary behaviour in favour of increasing light physical activity,[84–87] the literature clearly emphasises the more

	Number of studies (number of participants)	*r* (95% CrI)	τ (95% CrI)
Muscle mass			
Sedentary behaviour	10 (3831)	0·00 (–0·04 to 0·04)	0·02 (0·00 to 0·07)
Light physical activity	6 (5126)	0·07 (0·00 to 0·14)	0·05 (0·00 to 0·18)
Moderate-to-vigorous physical activity	7 (6204)	0·13 (0·03 to 0·24)	0·11 (0·03 to 0·25)
Total physical activity	7 (3827)	0·22 (–0·06 to 0·51)	0·35 (0·18 to 0·72)
Muscle strength			
Sedentary behaviour	22 (22 370)	0·03 (0·01 to 0·05)	0·02 (0·00 to 0·04)
Light physical activity	13 (8707)	0·04 (0·00 to 0·08)	0·03 (0·00 to 0·09)
Moderate-to-vigorous physical activity	16 (9086)	0·14 (0·00 to 0·29)	0·24 (0·15 to 0·38)
Total physical activity	15 (8060)	0·22 (0·09 to 0·34)	0·23 (0·15 to 0·36)
Steps	7 (2585)	0·01 (–0·15 to 0·16)	0·15 (0·03 to 0·38)
Physical performance			
Sedentary behaviour	23 (16 384)	0·04 (–0·05 to 0·14)	0·19 (0·13 to 0·0·29)
Light physical activity	13 (7205)	0·12 (–0·01 to 0·27)	0·25 (0·16 to 0·40)
Moderate-to-vigorous physical activity	20 (10 825)	0·11 (0·04 to 0·19)	0·15 (0·09 to 0·23)
Total physical activity	10 (26 529)	0·30 (0·10 to 0·50)	0·29 (0·17 to 0·51)
Steps	7 (2011)	0·02 (–0·14 to 0·19)	0·17 (0·05 to 0·42)

Given the heterogeneity observed in the exposures and outcomes (eg, different units for the measurement of the same outcome), the effect estimates reported in the original studies were converted to correlation coefficients (*r*) to allow pooling. τ values from 0·10 to 0·50 represent reasonable heterogeneity, values from 0·50 to 1·00 represent fairly high heterogeneity, and values over 1·00 represent fairly extreme heterogeneity. CrI=credible interval.

Table: **Cross-sectional associations between physical behaviours and muscle mass, muscle strength, and physical performance**

potent and consistent health advantages of moderate-to-vigorous physical activity.[88,89] In our study, we identified an inverse association between moderate-to-vigorous physical activity and sarcopenia in cross-sectional studies. Moreover, moderate-to-vigorous physical activity showed a protective association with the preservation of various individual determinants of sarcopenia. Our findings were corroborated, where feasible, by sensitivity analyses focused on studies with objective sedentary behaviour or physical activity assessments. Conversely, light physical activity did not show significant associations with sarcopenia, emphasising the potential significance of physical activity intensity in the prevention of sarcopenia.

Although the mechanisms behind the potential of physical activity to prevent or attenuate sarcopenia are yet to be clearly elucidated, improvements in muscle fibre bioenergetics,[90] upregulation of antioxidant defence,[91,92] epigenetic changes,[93] preservation of proteostasis,[94] increased satellite-cell differentiation,[95] anti-inflammatory responses,[96] or improved capillarisation and motor unit remodelling[97–99] have been suggested, all of which are associated with an attenuation of age-related atrophy and apoptosis of muscle fibres.[100,101]

To our knowledge, our study is the first to use meta-analyses to investigate the association between sedentary behaviour and sarcopenia. Although individual studies have previously reported significant associations between sedentary behaviour and sarcopenia in non-adjusted analyses,[64,66] our findings suggest that sedentary behaviour is not consistently linked to sarcopenia, especially when accounting for physical activity.[61,64,102] Our findings echo those by Ramsey and colleagues, who did not detect an association between objectively assessed sedentary behaviour and muscle strength or power among older adults.[103] The apparent absence of association between these two variables might stem from the interplay between sedentary behaviour and physical activity.[104] Some research even suggests negligible health repercussions from high levels of sedentary behaviour in highly active individuals (ie, people who spend long periods of time sitting but also have high levels of physical activity).[105,106] Still, mechanisms often linked to excessive sedentary behaviour, such as insulin resistance and mitochondrial dysfunction,[104] are also seen as potential drivers for sarcopenia. A review by Raffin and colleagues[107] posits that prolonged sedentary behaviour can amplify some ageing hallmarks in muscle fibres,[108] leading to atrophy. These findings suggest a potential association between sedentary behaviour and sarcopenia. Future longitudinal research should use refined sedentary behaviour assessments[13,104] to examine this link and its independence from physical activity levels.

Our analysis hints that a deficit in high-intensity physical activity (ie, moderate-to-vigorous physical activity or vigorous physical activity), more than low light physical activity or high sedentary behaviour, might fuel sarcopenia onset. Consequently, and from a practical or clinical viewpoint, our results suggest that emphasis should be placed not only on amount of physical activity but also on physical activity intensity when prescribing or recommending physical activity to older adults at risk of sarcopenia, which can be attained in the form of either structured physical exercise or as non-structured leisure physical activity. Previous research has shown the effectiveness and safety of individualised physical activity interventions even among the frailest older adults, who retain superb ability to adapt to physical activity.[109,110] For example, in the multicountry SPRINTT trial, a simple multicomponent physical activity programme based on walking, resistance, balance, and flexibility exercises of moderate-to-high intensity was effective in the prevention of disability in older adults at risk of sarcopenia.[111]

Interestingly, a higher proportion of women within studies seemed to be associated with higher ORs for sarcopenia, which suggests a moderation of the effect by sex, aligning with Stefll and colleagues' study findings.[9] These authors reported a stronger protective effect of higher total physical activity against sarcopenia in men (OR 0·46, 95% CI 0·37–0·58) than in women (0·65, 0·52–0·81). Further research should establish sex-related disparities in the association between physical behaviours and sarcopenia and the reasons behind them.

To our knowledge, this is the first systematic review and meta-analysis to examine the associations between the different physical behaviours and their categories (ie, sedentary behaviour, total physical activity, and the range of physical activity intensities) and sarcopenia. Our results therefore offer a comprehensive perspective on the topic, enhancing the practical application of the evidence available compared with earlier studies. Additionally, key strengths of our study include the incorporation of longitudinal research and the use of device-based physical behaviour assessments. Moreover, evaluating the association of physical behaviours not only with sarcopenia but also with the different individual components of this condition further bolsters our findings. Finally, the use of a Bayesian framework in our meta-analyses enabled us to estimate pooled outcomes, between-study variance, and study uncertainty, even with few studies for some associations—a feat not achievable with frequentist methods.

Our study is not without limitations. Although we included objective measures of sedentary behaviour or physical activity, many studies relied on subjective tools for the measurement of physical activity. Additionally, the use of cutoff points from young adult cohorts to classify accelerometer-based physical activity intensities in older people might have clouded the association between physical activity and sarcopenia due to potential misclassification of physical activity.[112,113] Adopting specific cutoff points for older adults in future research[114] might thus refine our estimates. The diverse definitions of sarcopenia across studies present challenges, with some estimates unsuitable for meta-analysis due to these disparities. Nevertheless, our use of effect direction graphics and evaluation of evidence consistency allowed for qualitative interpretation when quantitative analysis was not feasible. Notably, despite inclusion of longitudinal data, most of our evidence derives from cross-sectional studies, carrying the inherent risk of reverse causation and thus yielding a low GRADE rating.

Although sedentary behaviour and light physical activity have minimal associations with sarcopenia in older people, moderate-to-vigorous physical activity (albeit with the evidence primarily supported by cross-sectional studies), and particularly total physical activity, appear to be protective against this condition. Thus, public health initiatives aiming at preventing sarcopenia should emphasise the importance of engaging older people in more intense physical activity. To truly grasp the role of physical behaviours in developing sarcopenia, however, future in-depth longitudinal studies, and notably randomised controlled trials, are needed.

Contributors

JLS-S, JSM, and PLV conceptualised the study. PLV, BdPC, and AL supervised the study. JLS-S, LH, DG-G, and PLV curated the data. PLV, DG-G, and BdPC analysed the data. DG-G produced the figures. JLS-S wrote the original draft of the manuscript. All authors contributed to the writing and revision of the manuscript. JLS-S, LH, and PLV accessed and verified all the underlying data. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Declaration of interests

We declare no competing interests.

Data sharing

The datasets analysed during this study are available from the corresponding author on reasonable request by email.

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