Aging Clinical and Experimental Research (2025) 37:222
https://doi.org/10.1007/s40520-025-03120-6

RESEARCH

Operationalizing Short Physical Performance Battery (SPPB) with muscle strength and power: predicting adverse events in older adults from the *ilsirente* study

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Received: 28 November 2024 / Accepted: 21 June 2025
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Abstract

Background and aims The present study examined associations between Short Physical Performance Battery (SPPB) indexes operationalized according to lower limb muscle strength and power and the incidence of adverse events in older community-dwellers.

Methods This was a prospective cohort study of octogenarians who lived in the mountain community of the Sirente geographic area in Central Italy. Participants completed the SPPB under standardized conditions. Lower limb muscle power was estimated according to results from the 5-time sit-to-stand (5STS) test using validated equations. Then, four SPPB indexes were created by replacing 5STS test results with muscle power measures. Outcomes were assessed 24 months after baseline and included falls, fractures, and death.

Results Data of 255 older adults (mean age: 85.8 ± 4.8 years; women: 67.0%) were examined. Binary regression analysis indicated that conventional SPPB was significantly associated with the incidence of falls (Odds ratio [OR] = 0.841, [95% confidence interval [CI]] = 0.758, 0.934), fractures (OR = 0.837, 95%CI = 0.702, 0.998), and death (hazard ratio = 0.961, 95%CI = 0.934, 0.999). However, no significant results were found when SPPB was operationalized according to muscle power parameters. Area under the curve (AUC) results indicated that SPPB indexes had lower accuracy for distinguishing participants at higher risk of negative events.

Discussion and conclusions Results of the present study indicate that conventional SPPB, but not SPPB indexes operationalized according to lower limb muscle power, was significantly associated with the incidence of negative events in older adults. However, SPPB indexes were not good to identify older adults at higher risk of experiencing negative events.

Keywords Sarcopenia · Physical function · Physical performance · Falls · Fractures

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Introduction

Maintaining physical performance is vital for promoting successful aging, as it directly influences the ability to retain independence [1]. In contrast, detriments in physical function are linked to the development of chronic conditions and geriatric syndromes [2–4]. Additionally, reductions in physical performance are associated with a range of negative health outcomes, including falls, hospitalizations, institutionalization, and mortality [5, 6]. Hence, regularly monitoring changes in physical performance is essential for effectively managing older adults' health [3, 4].

The Short Physical Performance Battery (SPPB), introduced by Guralnik et al. [7] in 1994, provides an

Published online: 19 July 2025

easy-to-apply, efficient, and safe method for assessing lower limb function in older adults. The SPPB includes tests for balance, walking speed, and lower limb muscle strength, with each test scored from 0 to 4 points, leading to a maximum total score of 12. Higher scores reflect better physical function. Initially validated for predicting the risk of institutionalization and death [7], subsequent research has broadened its validity for prediction of other adverse events, such as falls [8], mobility disability [9], and cardiovascular events [10]. Furthermore, the SPPB is acknowledged as a reliable tool for monitoring sarcopenia [3] and frailty [11, 12].

Muscle strength is a key component of the SPPB, as it is considered a primary consequence of muscle aging [13–15] and has significant associations with adverse health outcomes [16–19]. However, muscle power— the ability to generate strength quickly—declines earlier and more significantly than muscle strength(20). Furthermore, investigations have found that muscle power might be a better predictor of physical independence, functional performance, mobility, and death than muscle strength [16, 20, 21]. Because impairments in muscle power might be a more relevant proxy of muscle failure [22] than those in muscle strength, it may be hypothesized that replacing muscle strength with muscle power in the SPPB might enhance its ability to predict negative outcomes.

Nevertheless, the operationalization of this hypothesis remains limited due to the current assessment methods available for evaluating muscle power. Most existing tools were originally developed for use in athletic settings and require complex equipment (e.g., computer-interfaced pneumatic resistance machines) [23]. These methods are often unsuitable for older populations due to high costs, the need for specialized personnel, and the potential risk of adverse events [23].

More recently, a notable assessment method was proposed and validated, which estimates four key muscle power parameters using results from the five-times sit-to-stand (5STS) test combined with basic anthropometric data [24]. These equations have been linked to various health outcomes and may help predict adverse events [25–28]. Moreover, due to their simplicity and feasibility, normative values have been established in different populations [29–32].

Hence, the possibility of assessing muscle power through easily applicable and validated equations allowed us to explore whether integrating muscle power into the SPPB could enhance its predictive ability. To this end, the current study compared the capacity of various SPPB indexes—operationalized using either lower limb muscle strength or power—to predict falls, fractures, and death in older adults.

Methods

This prospective cohort study examined data from a population of octogenarians residing in a mountain community in Central Italy. Data for the present investigation were gathered from the Aging and Longevity Study in the Sirente Geographic Area (ilSIRENTE) database [33]. ilSIRENTE was a prospective cohort study conducted in the mountain community of the Sirente geographic area (L’Aquila, Abruzzo) in Central Italy. The community living in this area is distributed in 13 towns and villages, all located at altitudes between 800 and 1400 m above sea level and surrounded by mountains. The Sirente area is mostly rural, with agriculture representing the main activity. The ilSIRENTE study was designed by the Department of Geriatrics of the Università Cattolica del Sacro Cuore (Rome, Italy) and the teaching nursing home Opera Santa Maria della Pace (Fontecchio, L’Aquila, Italy) in partnership with local administrators and primary care physicians of the Sirente Mountain Community Municipalities.

The study was conducted according to the principles of the Declaration of Helsinki and was approved by the Ethics Committee of the Università Cattolica del Sacro Cuore (Rome, Italy). Before enrolment, all participants or their proxies, when necessary, provided signed informed consent.

Participants

In October 2003, a comprehensive list of residents in the Sirente area was obtained from the registry offices of all municipalities involved in the study. Registration in these municipal records is mandatory at birth or upon relocation, as it is required to access primary health care services. This requirement ensured complete population coverage. From this list, potential study participants were identified by selecting all individuals living in the Sirente area who were born before January 1st, 1924. Among the 514 individuals initially screened, 32 men and 53 women had either died or moved away prior to the baseline assessment. General practitioners presented the ilSIRENTE study protocol to their eligible patients and invited them to participate. Individuals who initially declined were contacted at least two additional times by the study personnel before being definitively classified as refusals.

Of the 429 eligible individuals, the refusal rate was low (16%), with no significant differences by age or sex. As a result, a total of 364 participants aged 80 years and older were enrolled in the ilSIRENTE study. For the present study, analyses were conducted in 255 individuals, after excluding those with substantial physical disability ($n=20$), dementia ($n=14$), incapacity to complete the physical performance

tests (n=27), or missing data for the variables of interest (n=48).

The presence of physical disability and dementia were identified using the Minimum Data Set - Home Care (MDS-HD). Specifically, individuals were classified as disable if they had total dependence or could not perform one of the ten basic activities of daily living (i.e., mobility in bed, transfer, locomotion in and outside home, dressing upper and lower body, eating, toilet use, personal hygiene, and bathing) described in the session H, item 2. The presence of dementia was reported by a family member or caregiver during the interview, item 1 of section J, and confirmed by a physician.

Data collection

Baseline assessments began in December 2003 and were completed in September 2004. Clinical interviews and functional assessments were conducted at the study clinics in each town. Those who could not reach the study clinic because of physical or cognitive problems or transportation issues were assessed in their own homes. Follow-up visits to assess the incidence of falls and fractures were conducted 24 months after the baseline assessment, while deaths were recorded annually over a 10-year period via telephone contact. Information about medical history, medications, and lifestyle habits (e.g., smoking, alcohol consumption, physical activity) was collected using validated questionnaires [33]. All study procedures were conducted by trained personnel including specialized physicians, nurses, physiotherapists, medical residents, and medical students of the Department of Geriatrics of the Università Cattolica del Sacro Cuore, the teaching nursing home Opera Santa Maria della Pace, and primary care physicians. The principal investigator of the ilSIRENTE study (F.L.) is the custodian of the database.

Short physical performance battery indexes

The SPPB was performed under standardized conditions [7]. The battery involves three tests that evaluate lower-body function: a hierarchical test of standing balance, a 4-meter walk speed test, and a 5-time sit-to-stand (5STS) test. Each SPPB subtest is scored from 0 to 4, with 0 representing the inability to perform the test and a score of 4 representing the highest category of performance. For the balance tasks, participants were asked to stand with their feet side by side, followed by the semitandem (heel of one foot alongside the big toe of the other foot), and tandem (heel of one foot directly in front of and touching the other foot) positions for 10 s each. For the gait speed, a 4-m walk at participants' usual pace was timed. For the 5STS test, participants were requested to rise from a chair five times as fast as possible with their arms crossed in front of the body. A summary score was obtained by adding the scores of each individual SPPB component (range 0–12), with higher scores indicating better lower-body function.

Results of the 5STS test were used to estimated absolute (AMP), relative (RMP), allometric (ALMP), and specific muscle power (SMP) measures according to the validated equations proposed by Alcazar et al. [24]:

$$(1)\ \text{AMP (W)} = \frac{\text{Body weight (kg)} \times 0.9 \times g \times [\text{height (m)} \times 0.5 - \text{chair height (m)}]}{\left[\frac{\text{5STS test time (s)}}{\text{no. of STS repetitions}}\right] \times 0.5}$$

$$(2)\ \text{RMP (W/kg)} = \frac{\text{Absolute muscle power (W)}}{\text{Body weight (kg)}}$$

$$(3)\ \text{ALMP (W/m}^2\text{)} = \frac{\text{Absolute muscle power (W)}}{\text{Height (m}^2\text{)}}$$

$$(4)\ \text{SMP (W/kg)} = \frac{\text{Absolute muscle power (W)}}{\text{Appendicular skeletal muscle mass (kg)}}$$

Then, 5STS results of the conventional SPPB (SPPBc) were replaced with muscle power parameters using specific quartiles (supplementary material 1), allowing the development of four SPPB indexes: (i) AMP (SPPBamp), (ii) RMP (SPPBrmp), (iii) ALMP (SPPBalmp), and (iv) SMP (SPPBsmp).

Outcomes

Data regarding history of falls, as well as incident falls and fractures, were collected via face-to-face interviews by specialized physicians, nurses, physiotherapists, medical residents, primary care physicians, and medical students using item 1 of section J and item 5 of section K of the MDS−HC instrument [34]. At baseline, participants were asked to report any falls or fractures (e.g., hip, wrist, vertebral) that had occurred in the 90 days preceding data collection. The same methodology was applied at follow-up to evaluate the incidence of falls and fractures over a two-year period.

Survival status was obtained from participants' general practitioners and verified through the National Death Registry. Time to death was calculated from the date of the baseline visit to the recorded date of death. All deaths occurring within 10 years of enrollment were included in the analysis.

Covariates and adjustment variables

Body height and weight were measured through a stadiometer and an analog medical scale, respectively. The body mass index (BMI) was calculated as the ratio between body weight (kg) and the square of height (m^2). Calf circumference was taken on the dominant leg by measuring the largest girth (cm) between ankle and knee joints using an anthropometric tape while the participant was in a seated position. Values were rounded to the nearest 0.1 cm. Appendicular

skeletal muscle mass (ASM) was estimated based on the equation developed by the COCONUT Study Group [35]:

(5) ASM = −10.427 + (calf circumference (cm) × 0.768) − (age × 0.029) + (sex (male = 1, female = 0)) × 7.523.

where sex = 1 for men, sex = 0 for women.

Physical activity levels were estimated based on self-report. Participants indicated their patterns of physical activity during middle-aged (40–60 years) and in the last year before interviewing according to the following options: (a) virtually no physical activity (bedridden or almost); (b) sitting most of the time, with brief periods of light walking or other light activities; (c) low-intensity activities (e.g., walking, dancing, fishing, hunting) at least 2–4 h a week; (d) moderate-intensity activities (e.g., running, uphill walking, swimming, gymnastics) at least 1–2 h a week or low-intensity activities more than 4 h a week; (e) moderate-intensity activities more than 3 h a week; (f) high-intensity activities most days of the week; and (g) walking more than 5 km a day at least 5 days per week. The concepts of low, moderate, and high intensity were explained to participants before data collection. Multimorbidity was operationalized as the presence of two or more of the following conditions: obesity, coronary heart disease, cerebrovascular disease, congestive heart failure, peripheral artery disease, hypertension, lung disease (chronic obstructive pulmonary disease, emphysema, or asthma), osteoarthritis, diabetes, dementia, Parkinson's disease, renal failure and cancer (non-melanoma skin cancer excluded). This operationalization has been widely used in the literature to define multimorbidity in older adults [36]. Clinical diagnoses were recorded using section J of the MDS−HC [34] based on self-report, information gathered from primary care physicians, performing physical examinations, and conducting comprehensive reviews of clinical documentation, including laboratory tests and imaging examinations. Current smoking was defined as the regular use of tobacco, with a minimum frequency of once per week, during the previous year. Participants' self-perception of their economic status was categorized as follows: (i) don't know, (ii) good, (iii) sufficient, (iv) bad. Marital status, formal education level, and time since last hospital stay were assessed using items 4 and 6 of section BB and item 4 of section C of the MDS−HC [34].

Statistical analysis

Continuous variables are expressed as mean ± standard deviation (SD), while categorical and ordinal variables are reported as absolute numbers and percentages. SPPB results in the Table 1 are expressed as median (min-max). Binary regressions were conducted to test the associations between SPPB indexes incident falls, fractures, and death. Cox proportional hazards analyses were used to identify predictors of survival. Time until death was used as the "time" variable. The final models were adjusted for age, sex, BMI, physical activity levels during middle-age and in the last year, smoking status, formal education, time since last hospital stay, marital status, self-perception of economic status, and multimorbidity. Receiver operating characteristic (ROC) curve analyses were used to evaluate the diagnostic accuracy of SPPB indexes through adjusted models. Area under the ROC curve (AUC) was categorized as acceptable (0.7–0.8), excellent (0.8–0.9) or outstanding (>0.9). For all tests, the level of significance was set at 5% ($p < 0.05$). All P-values were determined by two-tailed tests. The SPSS software (version 23.0, SPSS Inc., Chicago, IL, USA) was used for all analyses.

Results

Participants characteristics

Data of 255 older adults were examined. Participants had a mean age of 85.8 ± 4.8 years, and most were women (67.0%). Mean BMI values indicated that participants had normal weight. Average isometric handgrip strength and 5STS values were lower than cutoff points for sarcopenia, according to the European Working Group on Sarcopenia in Older People 2 (EWGSOP2) [3]. At baseline, 14 participants (5.5%) reported have had at least one episode of fall in the past 90 days before data collection. The incidence of falls and fractures during the follow-up was 7.9% and 2.4%, respectively.

Associations between SPPB indexes, falls, and fractures

Unadjusted and adjusted binary regression analysis to test the associations between SPPB and the incidence of falls and fractures are shown in Table 2. In the unadjusted model, SPPBc was significantly associated with the incidence of falls and fractures. Results remained similar after adjusting for covariates. No significant associations were observed between any SPPB index operationalized according to muscle power and the incidence of adverse events.

Associations between SPPB indexes and death

Unadjusted and adjusted COX regression results are shown in Table 3. In the unadjusted analysis, SPPBc, SPPBamp, SPPBrmp, SPPBalmp, and SPPBamp were significantly associated with mortality. When results were adjusted for covariates, only SPPBc remained significant.

Table 1 Main characteristics of study participants ($n=255$)

Variables	Values
Age, years	84.2 ± 5.1
Female, %	63.1
BMI, kg/m^2	26.0 ± 4.1
SPPB*, score	7.0 (2–12)
5STS, s	15.5 ± 6.7
AMP, W	372.6 ± 119.0
RMP, W/kg	2.1 ± 0.8
ALMP, W/m^2	56.2 ± 22.7
SMP, kg	8.9 ± 5.1
ALM, kg	19.2 ± 5.1
Current smoking, %	6.6
Multimorbidity, %	66.1
Hypertension, %	51.4
Osteoarthritis, %	6.3
Diabetes, %	6.3
Osteoporosis, %	6.3
Cancer, %	3.9
Peripheral arterial disease, %	3.5
Ictus, %	1.2
Physically active during middle-age, %	97.8
Self-rated economic status, %	
a) Don't know	3.3
b) Good	7.7
c) Sufficient	84.3
d) Bad	3.6
Marital status, %	
a) Married	27.7
b) Never married	9.9
c) Widowed/Separated/Divorced	62.4
Difficult in the Instrumental Activities of Daily Living%	
a) Meal preparation	32.5
b) Ordinary housework	39.2
c) Managing finance	18.4
d) Managing medication	19.6
e) Phone use	13.3
f) Shopping	48.2
g) Transportation	65.1
Difficult in Basic Activities of Daily Living%	
a) Mobility in bed	0.3
b) Transfer	2.7
c) Locomotion in home	3.5
d) Locomotion outside of home	4.7
e) Dressing upper body	8.6
f) Dressing lower body	12.5
g) Eating	0.7
h) Toilet use	7.8
i) Personal hygiene	9.4
j) Bathing	29
Formal education, %	
a) No schooling	2.7
b) 8th grade/less	0.5
c) 9–11 grades	90.9
d) High school	2.5
e) Technical or trade school	1.9
f) Some college	1.1

Table 1 (continued)

Variables	Values
g) Bachelor's degree	0.3
h) Graduate degree	—
Time since last hospital stay, %	
a) No hospitalization in the last 180 days	83.8
b) Within last week	3.8
c) Within 8 to 14 days	1.6
d) Within 15 to 30 days	1.4
e) More than 30 days ago	9.3

5STS= 5-time sit-to-stand test; ALM= Appendicular lean mass; ALMP= Allometric muscle power; AMP= Absolute muscle power; BMI= Body mass index; RMP = Relative muscle power; SMP= Specific muscle power; SPPB= Short Physical Performance Battery. *Mean (min-max)

Table 2 Unadjusted and adjusted binary regression for the associations between SPPB and negative events

	Unadjusted			Adjusted		
	OR	95%CI	P-Value	OR	95%CI	P-Value
	Falls					
SPPBc	0.833	(0.761, 0.913)	0.001	0.841	(0.758, 0.934)	0.001
SPPBamp	0.891	(0.755, 1.051)	0.170	1.003	(0.809, 1.243)	0.981
SPPBrmp	0.879	(0.748, 1.033)	0.118	0.974	(0.792, 1.199)	0.806
SPPBalmp	0.891	(0.754, 1.053)	0.175	1.004	(0.809, 1.247)	0.970
SPPBsmp	0.917	(0.755, 1.085)	0.313	0.999	(0.812, 1.230)	0.994
	Fractures					
SPPBc	0.839	(0.724, 0.972)	0.020	0.837	(0.702, 0.998)	0.048
SPPBamp	1.020	(0.739, 1.408)	0.904	1.110	(0.722, 1.706)	0.633
SPPBrmp	0.960	(0.713, 1.292)	0.788	1.023	(0.689, 1.521)	0.909
SPPBalmp	1.044	(0.747, 1.459)	0.801	1.145	(0.727, 1.804)	0.559
SPPBsmp	1.012	(0.736, 1.393)	0.940	1.018	(0.698, 1.485)	0.925

5STS = 5-time sit-to-stand test; ALMP = Allometric muscle power; AMP = Absolute muscle power; C = Conventional; CI = Confidence interval; OR = Odds ratio; RMP = Relative muscle power; SMP = Specific muscle power; SPPB = Short Physical Performance Battery

Adjusted for age, sex, BMI, physical activity levels during middle-age and in the last year, smoking status, formal education, time since last hospital stay, marital status, self-perception of economic status, and multimorbidity

Table 3 Unadjusted and adjusted Cox regressions for the predictive capacity of SPPB indexes toward negative outcomes in women

Variables	Non-Adjusted Cox regression			Adjusted Cox regression		
	HR	P-value	CI (95%CI)	HR	P-value	CI (95%CI)
Death						
SPPBc	**0.882**	**0.001**	**0.857, 0.907**	**0.961**	**0.008**	**0.934, 0.999**
SPPBamp	**0.921**	**0.001**	**0.877, 0.969**	0.971	0.287	0.920, 1.025
SPPBrmp	**0.926**	**0.002**	**0.882, 0.973**	0.969	0.248	0.919, 1.022
SPPBalmp	**0.913**	**0.001**	**0.869, 0.960**	0.966	0.205	0.923, 1.019
SPPBsmp	**0.895**	**0.001**	**0.852, 0.941**	0.968	0.234	0.918, 1.021

Bold denotes significance

ALMP = Allometric muscle power; AMP = Absolute muscle power; C = Conventional; CI = Confidence interval HR = Hazard ratio; RMP = Relative muscle power; SMP = Specific muscle power; SPPB: Short Physical Performance Battery

Adjusted for age, sex, BMI, physical activity levels during middle-age and in the last year, smoking status, formal education, time since last hospital stay, marital status, self-perception of economic status, and multimorbidity

Ability to discriminate individuals at higher risk of negative events

ROC curve results are shown in Table 4. All AUC values were ≤0.7, indicating poor ability to discriminate participants at a higher risk of negative outcomes.

Discussion

The main findings of the present study indicate that SPPBc, but not SPPB indexes operationalized according to lower limb muscle power, was significantly associated with the incidence of negative events in older adults. Despite these significant associations, AUC results suggest that SPPB

Table 4 Predictive capacity of SPPB indexes adjusted for covariates toward negative outcomes

	AUC	95% CI	
Falls			
SPPBc	0.690	0.527	0.798
SPPBamp	0.688	0.614	0.762
SPPBrmp	0.690	0.617	0.763
SPPBalmp	0.691	0.544	0.774
SPPBsmp	0.650	0.585	0.817
Fractures			
SPPBc	0.680	0.329	0.884
SPPBamp	0.678	0.234	0.912
SPPBrmp	0.682	0.273	0.774
SPPBalmp	0.691	0.352	0.832
SPPBsmp	0.596	0.495	0.949
Death			
SPPBc	0.339	0.285	0.599
SPPBamp	0.372	0.250	0.782
SPPBrmp	0.339	0.215	0.463
SPPBalmp	0.317	0.051	0.583
SPPBsmp	0.501	0.427	0.574

ALMP = Allometric muscle power; AMP = Absolute muscle power; AUC = Area under the curve; C = Conventional; RMP = Relative muscle power; SMP = Specific muscle power; SPPB: Short Physical Performance Battery

indexes are not good to identify older adults at higher risk of experiencing negative events.

These findings are consistent with prior investigations that found significant associations between SPPBc and the occurrence of negative events in older adults [9, 37, 38]. Moreover, our results support international recommendations emphasizing the importance of SPPBc as a valuable tool for assessing physical performance in older adults, particularly in the context of frailty [11, 12] and sarcopenia [3].

We hypothesized that using muscle power instead of muscle strength could yield stronger associations between SPPB scores and adverse events in older adults. These assumptions are based on the fact that muscle power declines earlier and to a greater extension [39], along with being more strongly associated with health-related outcomes in comparison to muscle strength [16, 20, 21]. As such, we assumed that low muscle power could be a major product of muscle failure and neuromuscular detriments. However, our results indicate that SPPB indexes operationalized according to muscle power were not significantly associated with the occurrence of any the negative events considered.

Some potential explanations could be proposed for our findings. One possibility relies on the trajectories of muscle strength and power decline during aging. Indeed, compared to young adults, muscle power is expected to be reduced by up to 80% in octogenarians [16]. In contrast, declines in muscle strength at this stage of life typically reach 60% [16]. This scenario might indicate that muscle power declines substantially until the ninth decade of life, with marginal detriments in subsequent next years, whereas losses in muscle strength occur more gradually throughout the aging process. Under these circumstances, variations in muscle strength could be more heterogenous and representative of an individual's health status, thereby promoting stronger associations with adverse events.

An alternative or complementary explanation is based on the characteristics of our sample, given that participants of the ilSirente study are relatively homogenous regarding many features that might direct or indirectly influence neuromuscular function and, consequently, muscle power trajectories, including smoking, economy status, physical activity during middle-aged, education, and access to healthcare. A certain level of homogeneity was also observed for muscle power parameters compared to other investigations [31, 32].

An additional explanation lies in the method used to assess muscle power. In the present study, muscle power was estimated using validated equations based on 5STS performance and anthropometric parameters. Muscle power parameters estimated according to these equations have been significantly associated with many health-related parameters, including disability, hospitalization, and death [26, 28]40– [42]. Moreover, population-based normative values have been proposed to facilitate its clinical applications (37580323, 37986667, 34216098).

Nevertheless, not all studies confirmed associations between equation-based muscle power measures and health parameters [25, 42], and some authors argued that they involve important conceptual problems, mainly with the operationalization of concentric movements [43]. Furthermore, 5STS muscle power parameters and laboratory-based measures (i.e., linear encoder) seem to capture different aspects of muscle power [44, 45], which influences its

association with physical performance tests [44, 45]. As such, the possibility that different results could be obtained if muscle power was estimated using other instruments cannot be ruled out.

Despite the significant associations between SPPBc and negative outcomes, AUC results indicate that this measure is not good to distinguish individuals at higher risk of negative outcomes. These findings are at least partly supported by other investigations that found that SPPBc has only a low-to-moderate diagnostic value [46–48]. These discrepancies might be attributed to the different analytical purposes of the tests, given that binary regression estimates the probability of an outcome occurring based on predictor variables, whereas AUC evaluates the overall ability of a model to discriminate between two classes (e.g., event vs. no event) based on predicted probabilities.

A major limitation of the present study involves the fact that muscle power was estimated using equations. Although the muscle power equations were validated against gold standard measures [24], they shave been subject to criticism, particularly for assuming that only part of the body mass is accelerated during the concentric phase. However, generating mechanical power under these conditions should arguably consider changes in both kinetic and potential energy of the whole body. Concerns have also been raised regarding the conceptual clarity of how the concentric phase is defined within this context. As noted by Fabrica and Biancardi [43], both of these critiques center on aspects of the concentric phase, which is also the stage of the movement that likely demands greater balance control. In light of these issues, it may be necessary to revise the 5STS-based equations, either by incorporating the movement of the entire body into the model or by refining the formula through more detailed biomechanical investigation.

Other limitations of the present study need to be mentioned. First, the lack of data on the timing of falls and fractures hampered conducting survival analyses with these variables. Additionally, fall rates were not recorded over the two-year period. Secondly, ASM was estimated using calf circumference, rather than more accurate assessment tools. This method was chosen for its ability to assess participants both at the study sites and at home. Third, we did not have information on the cause of death. Fourth, the low incidence of falls and fractures prevented participants classification into subgroups (i.e., fallers and non-fallers). Fifth, our analysis did not account for the use of walking aids. Finally, we studied a cohort of relatively healthy, very old adults living in a mountain region, and caution should be taken when generalizing these findings to other populations.

Conclusions

Results of the present study indicate that SPPBc, but not SPPB indexes operationalized according to lower limb muscle power, was significantly associated with the incidence of negative events in older adults. However, AUC results indicate that SPPB indexes are not good to identify older adults at higher risk of experiencing negative events. Further research is warranted to explore whether the operationalization of SPPB using laboratory-based muscle power measures increases its ability to identify at-risk individuals.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s40520-025-03120-6.

Acknowledgments The APC was funded by the Italian Ministry of Health (Ricerca Corrente 2025).

Author contributions Conceptualization: HJCJ, AAB, AR, LRM, FL, EM; Methodology: HJCJ, AAB, AR, LRM, FL, EM; Formal analysis and investigation: HJCJ, AAB, AR, LRM, FL, EM; Writing - original draft preparation: HJCJ, AAB, AR, LRM, FL, EM; Writing - review and editing: HJCJ, AAB, EM; Funding acquisition: EM, FL.

Funding No funding was received for conducting this study.

Data availability The data are available upon request from Professor Landi.

Declarations

Ethics approval and consent to participate This study did not involve any animal subjects. The study was approved by the Ethics Committee of the Università Cattolica del Sacro Cuore (Rome, Italy).

Informed consent All participants or their proxies, when necessary, provided signed informed consent before enrolment.

Competing interests The authors declare no competing interests.

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