Threshold of Relative Muscle Power Required to Rise from a Chair and Mobility Limitations and Disability in Older Adults

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Abstract:

Purpose: Being able to rise from a chair is paramount for independent living and is strongly influenced by the ability of the lower limbs to exert mechanical power. This study assessed minimal thresholds of lower-limb relative muscle power required to perform the sit-to-stand (STS) task in older adults and its association with mobility limitations and disability.

Methods: A total of 11,583 older adults (age: 60–103 years old) participated in this investigation. The 5-rep and 30-s versions of the STS test were used to assess chair rising ability. Relative power was calculated by the STS muscle power test. The minimum thresholds of power required to perform the STS tests were derived from the minimum values (i.e. ‘floor’ effect) reported in the power tests through regression analyses. Mobility limitations and disability in activities of daily living (ADL) were recorded.

Results: For the average older man and woman, the thresholds to complete five STS repetitions were 1.1 and 1.0 W·kg⁻¹, respectively, while the thresholds to complete one STS repetition were 0.3 W·kg⁻¹ in both sexes. These thresholds increased linearly with height (5- and 1-rep, respectively: +0.13 and +0.03 W·kg⁻¹ per 10-cm increase; both $p < 0.001$), and did not differ by sex or testing condition (both $p \geq 0.259$). All participants with relative power below the 5-rep threshold presented mobility limitations and 51–56% of women and 36–49% of men also showed disability in ADL (all $\chi^2 \geq 290.4$; $p < 0.001$).

Conclusion: A minimum level of relative muscle power is required to rise from a chair independently, which depends on the individual height and is associated with increased mobility limitations and disability. This information will help interpret data yielded by the STS muscle power test and may contribute to the prevention and treatment of mobility limitations in older people.

Key words: sit-to-stand; chair rising; chair stand; frailty; disability; mobility limitations.

1. Introduction

Being able to rise from a chair is crucial for independent living and demands a certain amount of muscle strength and velocity to overcome gravity. Mechanical muscle power is defined as the rate at which mechanical work is done or the product of force and velocity. Muscle power is known to decline at a faster rate with aging compared to muscle mass and strength (1), and aerobic capacity (2), and to be more strongly associated with physical function in older adults (3, 4). In addition, relative muscle power (muscle power normalized to body mass, $\text{W}\cdot\text{kg}^{-1}$) is critical for maintaining adequate levels of physical function at older age (5-8) and declines dramatically after the age of 40 years in both men (1.3–3.1% per year) and women (1.4–2.3% per year) (9). Notably, the positive relationship between relative muscle power and physical performance has been reported to be curvilinear (10, 11), and thus the relevance of relative muscle power is greater in older adults with impaired physical performance.

Accordingly, it has been suggested that a minimum level of relative muscle power is required to perform basic activities of daily living independently (12). Rising from a chair is one of the most important requirements for an independent living (e.g. to be able to stand up from a chair, toilet or bed to engage in other activities) and the sit-to-stand (STS) test is recommended as an adequate tool to assess lower-limb physical performance among older adults in daily clinical practice (13, 14). The STS transfer is defined as moving the center of mass of the body upward, from a sitting to a standing position, without losing balance (15). This task requires muscles to generate forces around joints to accelerate the body's mass over a distance against gravity (i.e. it requires to do mechanical work), and the rate at which it is done (i.e. mechanical power) determines performance. However, some frequently used versions of this test (e.g. 5-rep

STS test) have the limitation that some older adults may not be able to complete several successive STS repetitions (16). Actually, lower-limb muscle function demands during chair rising are close to the maximum capabilities of even healthy older adults (17). In addition, these demands may be different according to the anthropometric characteristics of the individuals due to the vertical distance to be covered from the sitting to the standing positions will be different (18). Therefore, chair rising failure will occur in older adults unable to reach their individually required levels of force produced over a certain distance in a reasonable amount of time (i.e. insufficient mechanical power) (18, 19). Of relevance, low STS muscle power is associated with low gait speed, frailty and poor cognitive performance (6, 8), and the inability to perform the STS test has been more strongly associated with the occurrence of fall-related injuries than low gait speed or poor balance among older adults (20). A previous study reported a relative strength threshold of $3.5 \text{ N}\cdot\text{kg}^{-1}$ to be associated with limitations in chair rise ability in older people (21). However, no previous studies have assessed the minimum levels of relative power required to rise from a chair. The identification of these thresholds may help recognize and treat older people at risk of losing their STS ability before this occurs. Therefore, the main goal of the present investigation was to identify the minimal thresholds of lower-limb relative muscle power required to perform the STS task without the use of hands in older adults based on data from a large European cohort. Our secondary goal was to assess the prevalence of mobility limitations and disability in activities of daily living in older people with relative muscle power below the minimal thresholds.

2. Methods

2.1 Study overview

This investigation incorporated data from older adults participating in different European cohorts and research studies that can be grouped in four nationalities: i) Spain: the Toledo Study for Healthy Aging (TSHA) (22), and the EXERNET Multi-center Study (23); ii) Portugal: the Portuguese Cohort (24); iii) Denmark: the Copenhagen Sarcopenia Study (25), and the Falls Cohort (26); and iv) Belgium: the Flemish Policy Research Centre on Sport Cohorts (27-29) and other interventional studies (30-33). All but the TSHA measured STS performance by means of the 30-s STS test, while the TSHA used the 5-rep STS test.

2.2 Participants

A total of 11,583 older adults (7,443 older women and 4,140 older men from 60 to 103 years old) were included in the present investigation. Height (m) and body mass (kg) were assessed by a stadiometer and scale device, and body mass index (BMI) was calculated ($\text{kg}\cdot\text{m}^{-2}$). Main characteristics of the study participants are reported in Table 1. All participants from the EXERNET Multi-center Study and cohorts from Portugal, Denmark and Belgium were able to walk independently (with or without aids), to perform the STS test (30-s version), and did not present dementia or acute neuromuscular or joint injury. Participants from the TSHA included both individuals able and unable to complete the STS task (5-rep version), but all of them were able to complete a battery of physical tests (among others: gait speed, knee extension strength and balance) and did not present any acute neuromuscular or joint injury (22). Therefore, it can be assumed that the inability of some TSHA participants to perform the 5-rep STS test was likely due to poor lower-limb muscle function. All participants gave their written informed consent and

all the procedures were performed in accordance with the Helsinki Declaration. The participating cohorts and studies were approved by their corresponding local ethical committees.

2.3 STS muscle power test

Muscle power was assessed by means of the STS muscle power test (6, 34). This validated procedure calculates muscle power produced during the ascending phase of the STS task using an equation based on biomechanical principles. The participants performed either 5 STS repetitions as fast as possible (TSHA's participants, n=1,801), or as many STS repetitions as possible in 30 s (all other participants, n=9,389). Both STS tests were performed using a standardized armless chair (chair height ranged from 0.43 to 0.45 m), starting from a sitting position with arm crossed over the chest. During the standing phase, participants were instructed to extend their hips and knees until reaching the full standing position, maintaining arms crossed over the chest. Strong verbal encouragement was given throughout the test and participants were allowed to try 1-2 times before the definitive measure was registered. The result derived from the traditional STS test (either time needed to complete 5 repetitions or number of repetitions performed in 30 s) was collected by the researchers of each specific cohort. Then, the same researcher analyzed the data from all the cohorts together, and calculated power with the validated equation, which also includes body mass and height, as well as chair height to calculate mechanical power (6, 34):

$$\text{STS power} = \frac{\text{body mass} \times 0.9 \times g \times (\text{height} \times 0.5 - \text{chair height})}{\left[\frac{\text{time}}{\text{number of reps}} \right] \times 0.5}$$

where body mass is indicated in m; g is equal to $9.81 \text{ m}\cdot\text{s}^{-2}$; body height and chair height are indicated in m; and time is indicated in s. Further details on the equation can be found elsewhere (6, 34). Then, relative STS muscle power ($\text{W}\cdot\text{kg}^{-1}$) was calculated as STS muscle power normalized to body mass.

2.3.1 Determination of relative muscle power thresholds

The present study included a large number of participants representing a wide range of older adults and physical characteristics ranging from institutionalized to well-functioning individuals. This provided the advantage of exploring the range of values of relative STS muscle power that can be observed in older adults. Consequently, the lowest values of relative STS power observed in the participants represented the ‘floor’ effect of the test or the relative muscle power thresholds required to complete the tests. Of note, the (in)ability to rise from a chair has been reported to be dependent of the height of the individual in relation to the chair (the taller a person is, the more difficult it is to rise from a given chair) (18, 35, 36). Therefore, the effect of height was considered in the analysis. Briefly, the lowest height-adjusted values of relative muscle power observed in the participants that completed 5 and 1 STS repetitions were identified in order to determine the thresholds of relative power that would be necessary to perform 5 and 1 STS repetitions, respectively (please see Statistical analysis section for further details).

2.4 Assessment of functional performance and disability in activities of daily living

Functional performance was assessed using various physical tests in the different cohorts/research studies: habitual gait speed (GS), maximal GS, the timed up-and-go (TUG) test, and the 6-min walking test (6-MWT). Gait velocity during each test was calculated as the ratio

between the walked distance and the recorded time ($\text{m}\cdot\text{s}^{-1}$). Older subjects with either habitual GS below $0.8 \text{ m}\cdot\text{s}^{-1}$ (37), maximal GS below $1.13 \text{ m}\cdot\text{s}^{-1}$ (38), TUG velocity below $0.43 \text{ m}\cdot\text{s}^{-1}$ (39) or 6-MWT velocity below $0.83 \text{ m}\cdot\text{s}^{-1}$ (40) were declared as having mobility limitations based on cut-off points found to be associated with either sarcopenia, fall status, hospitalization or mortality in their original studies.

In addition, disability in basic and instrumental activities of daily living (BADL: bathing, dressing, toileting, transferring, continence and feeding; and IADL: telephone use, shopping, cooking, housekeeping, laundry, transportation, responsibility on medications, and finances; respectively) was assessed in the participants of the TSHA by the Katz (score = 0–6) (41) and Lawton (score = 0–8 in women and 0–5 in men) (42) questionnaires, respectively. Moderate-to-severe disability in BADL was defined as having a Katz score ≤ 4 points (i.e. having limitations in at least 2 basic activities), while moderate-to-severe disability in IADL was defined as having a Lawton score ≤ 5 points in women and ≤ 3 points in men (i.e. having limitations in at least 3 instrumental activities, respectively).

2.5 Statistical analysis

Data are reported as mean $\pm$ standard deviation (SD) unless otherwise stated. The participants were divided into groups according to their height using deciles (from 1 to 10): TSHA's participants (performed 5-rep STS test), $\leq 1.43 \text{ m}$, $1.44\text{--}1.46 \text{ m}$, $1.47\text{--}1.49 \text{ m}$, $1.50\text{--}1.51 \text{ m}$, $1.52\text{--}1.54 \text{ m}$, $1.55\text{--}1.56 \text{ m}$, $1.57\text{--}1.59 \text{ m}$, $1.60\text{--}1.63 \text{ m}$, $1.64\text{--}1.67 \text{ m}$ and $\geq 1.68 \text{ m}$; and all other participants (performed 30-s STS test), $\leq 1.47 \text{ m}$, $1.48\text{--}1.49 \text{ m}$, $1.50\text{--}1.52 \text{ m}$, $1.53\text{--}1.55 \text{ m}$, $1.56\text{--}1.58 \text{ m}$, $1.59\text{--}1.60 \text{ m}$, $1.61\text{--}1.63 \text{ m}$, $1.64\text{--}1.67 \text{ m}$, $1.68\text{--}1.73 \text{ m}$ and $\geq 1.74 \text{ m}$. The minimum (i.e.

‘floor’) values of relative STS power observed in each decile group of height were assessed in i) the participants performing the 5-rep STS test, ii) the participants performing five repetitions in the 30-s STS test, and iii) the participants performing one repetition in the 30-s STS test. (This is illustrated in the different subpanels of Figure 2.) Then, regression analyses were performed to evaluate the effect of height and sex on the reported relative muscle power thresholds, and coefficient of determination (R^2), standard error of the estimate (SEE) and F values were reported. In addition, the threshold values of relative muscle power and the regression equations obtained from the 5-rep and 30-s versions of the STS test were compared and mean differences with 95% confidence intervals (CI) were reported. Finally, the prevalence of mobility limitations was assessed in the participants that conducted 30-s STS testing and compared between those individuals with relative power values above and below the thresholds required to complete five STS repetitions using Chi-Square (χ^2) tests and Bonferroni’s corrections for multiple comparisons. Statistical analyses were performed using SPSS v20 (SPSS Inc., Chicago, Illinois) and the level of significance was set at $\alpha=0.05$.

3. Results

The (in)ability of the study participants to perform the STS test is shown in Figure 1. In the TSHA’s participants, 26% of older women and 13% of older men were unable to complete the 5-rep version of the STS test. Among the participants of the other cohorts, 2% of older women and men performed less than 5 repetitions in the 30-s version of the STS test. The minimum relative power value noted in each decile group of height is reported separately for the participants completing the 5-rep STS test, five repetitions in the 30-s STS test and one repetition in the 30-s STS test (Table 2).

The resulting thresholds of relative muscle power required to perform five repetitions in the 5-rep and 30-s versions of the STS test, and one repetition in the 30-s STS test are shown in Figure 2.

A significant linear relationship was found between the relative muscle power threshold required to complete five STS repetitions and height in the 5-rep ($R^2=0.998$; $SEE=0.008$; $F=3886.1$; $p<0.001$) and 30-s ($R^2=0.971$; $SEE=0.027$; $F=263.6$; $p<0.001$) versions of the STS test. Both relative muscle power thresholds increased significantly with height (5-rep: $\beta=1.432$ [1.379 to 1.485]; 30-s: $\beta=1.324$ [1.136 to 1.512]; both $p<0.001$) and were not affected by sex (both $F\leq 1.510$ and $p\geq 0.259$).

A significant linear relationship was also noted between the relative muscle power threshold needed to perform one STS repetition in the 30-s STS test and height ($R^2=0.990$; $SEE=0.003$; $F=782.3$; $p<0.001$). The threshold of relative muscle power increased significantly as a function of height ($\beta=0.294$ [0.269 to 0.318]; $p<0.001$). This relationship was not affected by sex ($F=0.403$; $p=0.546$).

Of note, no significant differences existed between the relative muscle power threshold required to perform five repetitions when derived from either the 5-rep or 30-s versions of the STS test (Differences: Constant term: $\beta = 0.136$ [-0.145 to 0.416]; Δ Slope term: $\beta = -0.109$ [-0.288 to 0.070]; both $p\geq 0.216$). Consequently the weighted mean of both equations were used for further analyses: constant term = -1.09 and slope term = 1.34. In contrast, significant differences

existed between the relative muscle power thresholds required to complete five vs. one repetition (Differences: Constant term: $\beta = 0.867$ [0.584 to 1.150]; Δ Slope term: $\beta = -1.071$ [-1.251 to -0.892]; both $p < 0.001$).

Finally, among those TSHA's participants with relative muscle power above the 5-rep threshold, only 1.6% of women and 1.0% of men showed moderate-to-severe disability in BADL, and 5.7% of women and 6.3% of men exhibited moderate-to-severe disability in IADL. These prevalences increased significantly in those TSHA's participants with relative muscle power below the 5-rep threshold, who showed prevalences of 50.8% in women and 36.4% in men for disability in BADL ($\chi^2 = 538.1$ and 291.3 , respectively), and of 55.5% in women and 48.7% in men for disability in IADL ($\chi^2 = 425.5$ and 228.4 , respectively) (all $p < 0.001$) (Figure 3A and 3B). On the other hand, only 15.4% of older women and 13.4% of older men with levels of relative power above the required threshold to complete 5 STS repetitions presented mobility limitations, compared to a prevalence of 100% observed in older women and men with levels of relative power below the mentioned threshold (women: $\chi^2 = 290.4$; men: $\chi^2 = 740.2$; both $p < 0.001$) (Figure 3C).

4. Discussion

The main finding of the present study was that a minimal threshold of relative muscle power is required to independently rise from a chair. The result is based on data from a large European cohort including 11,583 older individuals (≥ 60 years old) ranging from frail institutionalized to healthy independently living. Importantly, the threshold of relative muscle power depended on number of chair rises (higher for performing five repetitions compared to one) and increased

linearly with body height. However, there was no difference between men and women after accounting for height. In addition, all the participants with relative muscle power below the threshold required to complete five STS repetitions presented mobility limitations, and approximately half of them presented some type of disability in activities of daily living.

Although it is well-known that muscle power is essential for physical function in older people, (43, 44), to the authors knowledge, no previous studies have investigated the minimum level of muscle power that is required to independently perform activities of daily living. Based on their observations, Bassey et al. (12) did speculate on a minimum of $0.6 \text{ W}\cdot\text{kg}^{-1}$ of relative unilateral leg muscle power that would be necessary for unassisted walking (12). Considering the bilateral deficit that has been reported in older adults (45), that value would reach about $1.0 \text{ W}\cdot\text{kg}^{-1}$ in terms of relative bilateral leg muscle power. This is very similar to the threshold of relative muscle power that is required to perform 5 STS repetitions for the average older man ($1.13 \text{ W}\cdot\text{kg}^{-1}$, height = 1.66 m) and woman ($0.97 \text{ W}\cdot\text{kg}^{-1}$; height = 1.54 m) in the present investigation. Notably, this sex difference is explained by differences in height. In line with these findings, Hughes and colleagues demonstrated that there was no difference in the required joint moments to rise from a chair between young and old subjects, when anthropometric characteristics were matched (18). Cut-off values for absolute unilateral leg extension power to predict a gait speed lower than $0.8 \text{ m}\cdot\text{s}^{-1}$ in older individuals have previously been reported (men: 101.0 W; women: 59.1 W), but cut-off values for relative muscle power were missing (37). Further, Makizako et al. have suggested a cut-off value of 10 s in the 5-rep STS test to predict the development of disability during a 2-year follow-up in older people (46). Importantly, however, STS-derived muscle power has been shown to be more strongly correlated with

physical and cognitive function compared to traditional timed STS performance (6, 34); and relative muscle power is more functionally relevant than absolute muscle power (5-7) given that most activities of daily living require the supporting of the subject's own body mass. These findings should be taken into account in future studies to provide more functionally relevant interventions for older populations.

As expected, we found the threshold required to perform a single STS repetition (0.24 and 0.20 W·kg⁻¹ for the average older men and women, respectively) to be lower compared to 5 STS repetitions (1.13 and 0.97 W·kg⁻¹, respectively). However, it should be pointed out that the time required to complete 1 STS repetition was not directly measured, but obtained from a 30-s timed test, and thus the 1-rep threshold should be interpreted with caution. Indeed, it must be considered that the used equation (6, 34) estimates average muscle power produced over a certain period of time, and thus, whether the participants distributed their performed repetitions irregularly throughout the recorded time cannot be assessed. For instance, the participants may have completed 1 repetition during the first 10 s of the test and could have declared to be unable to complete any further repetitions. A maximum time to rise of 10 s has been regarded as an adequate cut-off point for declaring a chair rising as successful (47). A simulation in our participants (i.e. assuming all of them completed one repetition in 10 s) yielded that, considering their anthropometric characteristics, this rising time would correspond with a threshold of relative muscle power to perform a single STS repetition of 0.33 and 0.28 W·kg⁻¹ for the average older man and woman, respectively. Despite this, the findings reported in the current investigation can be of great value in practical contexts where STS tests are routinely performed, since both the 5-rep and 1-rep thresholds of relative power can help to determine and interpret

the functional status of the subjects and the consequences associated to mobility limitations and disability. It should be highlighted that the thresholds of relative muscle power needed to perform 5 STS repetitions were directly measured in the TSHA's participants, and cross-validated in the participants of the other cohorts involved in the present investigation. Furthermore, the latter thresholds were clearly associated with impaired physical performance and disability, given that all the participants with relative muscle power below the 5-rep threshold presented mobility limitations in gait-related activities, and half of them showed moderate-to-severe disability in activities of daily living.

The methodology used to assess muscle power in the current investigation might be considered a study limitation. Their strengths and limitations have been adequately addressed and acknowledged in detail elsewhere (6, 34, 48). Notably, the validity of the STS muscle power test as a measure of muscle power in older people has been demonstrated by several studies comparing this measure to muscle power obtained from an instrumented leg press (6), Nottingham power rig (34) and force plate (48). The clinical relevance of equation-derived relative STS muscle power has also been demonstrated to be slightly superior to that showed by sarcopenia (8, 49). The presence of chronic joint pain was not assessed in the participants of the current study, which may influence negatively in their performance during repetitive STS actions. However, it should be noted that the STS power test evaluates the ability of the participants to produce mechanical power, which can be affected by numerous negative conditions, such as joint pain, muscle dysfunction or poor coordination. Future studies should investigate the specific causes that lead some older adults to fall below the power thresholds here reported (e.g. chronic diseases, physical inactivity or aging *per se*); and the applicability of the

findings of the current study to other non-European samples needs to be clarified in future studies. Moreover, the thresholds of relative muscle power may vary slightly as a function of chair height, and thus the findings of the present study apply to the assessment of STS power using standard height chairs (0.43 to 0.45 m). The association between STS power and age was not assessed in the current manuscript, but a detailed sex-specific analysis on this aspect is warranted as part of a future investigation. Finally, it is worth mentioning that the (in)ability to rise from a chair can be improved after a resistance training intervention (50). Resistance training is well-known to improve relative muscle power among older people, and interventions tailoring the improvement of STS ability should include resistance exercises performed at maximal intended velocity (51). In addition, special attention should be paid to the hip- and knee-extensor muscles due to their contribution to the upward acceleration of the body's center of mass, and to the ankle muscles for their contribution to postural stabilization (52).

5. Conclusions

The ability to rise from a chair is crucial for independent living. In the present study, the minimum thresholds of relative muscle power required to perform one and five chair rises were derived from a large European cohort including 11,583 older adults from four European countries ranging from institutionalized frail to healthy independently living. Importantly, these thresholds were strongly influenced by the individual's anthropometric characteristics and were consistent when extracted from either the 5-rep or the 30-s versions of the STS test. Older people with relative power below the 5-rep power threshold presented mobility limitations, and half of them presented disability in activities of daily living. Hence, these findings will help to interpret data derived from the STS muscle power test and may contribute to the prevention and treatment of mobility limitations and disability in older people.

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Conflict of interest

The authors declare no conflicts of interests.

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Figure 1. Percentage of older people unable to perform the 5-rep sit-to-stand (STS) test (*on the left*) and percentage of older people that performed less than five repetitions in the 30-s STS test (*on the right*).

Figure 2. Thresholds of relative muscle power required to perform five repetitions (*blue line*) in the 5-rep STS test, and five (*red line*) and one (*green line*) repetitions in the 30-s STS test in older men (*grey circles*) and women (*white diamonds*). The linear equations included in each corresponding panel represent the relation observed between relative muscle power threshold and height (h). Please note that data from all the participants that performed the 5-rep STS test are shown in the upper panel, data from all the participants performing at least five repetitions in the 30-s STS test are shown in the middle panel, and data from all the participants performing between one and four repetitions (both included) in the 30-s STS test are shown in the lower panel.

Figure 3. Prevalence of disability in (A) basic and (B) instrumental activities of daily living (BADL and IADL, respectively) and (C) prevalence of mobility limitations in the participants with relative muscle power above vs. below the threshold required to complete five STS repetitions.

Figure 1

Figure 2

Figure 3

Table 1. Main characteristics of the older (aged 60.0-103.0 years) female and male study participants.

	Spain (TSHA)	Spain (EMS)	Portugal	Denmark	Belgium
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
<i>Women (n)</i>	1282	2033	3164	405	559
Age (years)	78.9 ± 8.1	72.1 ± 5.3	75.4 ± 7.4	74.0 ± 8.2	68.1 ± 6.2
Body mass (kg)	68.3 ± 12.8	68.6 ± 10.6	67.1 ± 11.7	67.8 ± 12.4	69.1 ± 11.0
Height (m)	1.50 ± 0.06	1.53 ± 0.06	1.54 ± 0.07	1.63 ± 0.06	1.60 ± 0.06
BMI (kg·m ⁻²)	30.3 ± 5.4	29.4 ± 4.3	28.3 ± 4.5	25.6 ± 4.6	27.1 ± 4.3
<i>Men (n)</i>	981	629	1692	314	524
Age (years)	78.0 ± 7.8	72.1 ± 5.4	75.5 ± 7.5	72.4 ± 7.4	68.2 ± 6.0
Body mass (kg)	75.7 ± 12.4	77.5 ± 11.1	73.1 ± 12.3	83.8 ± 14.5	81.1 ± 10.8
Height (m)	1.63 ± 0.07	1.65 ± 0.07	1.63 ± 0.08	1.77 ± 0.07	1.72 ± 0.06
BMI (kg·m ⁻²)	28.4 ± 4.2	28.3 ± 3.5	27.6 ± 3.9	26.6 ± 4.1	27.3 ± 3.4

TSHA, Toledo Study for Healthy Aging. EMS, Exernet Multi-center Study. SD, standard deviation. BMI, body mass index.

Table 2. Minimum relative muscle power value and participant's height observed for each testing condition within each group of height.

	Group of height (Decile)									
	1	2	3	4	5	6	7	8	9	10
5-rep STS test ($\text{W} \cdot \text{kg}^{-1}$)	0.81	0.88	0.99	0.94	0.97	1.02	1.04	1.12	1.24	1.30
Height (m)	1.41	1.46	1.47	1.50	1.52	1.55	1.57	1.62	1.70	1.76
30-s STS test										
5 reps ($\text{W} \cdot \text{kg}^{-1}$)	0.74	0.90	0.93	0.96	0.97	1.01	1.07	1.09	1.21	1.23
Height (m)	1.36	1.48	1.50	1.55	1.56	1.59	1.63	1.64	1.68	1.74
1 rep ($\text{W} \cdot \text{kg}^{-1}$)	0.17	0.18	0.19	0.20	0.21	0.21	0.22	0.24	0.25	0.26
Height (m)	1.44	1.48	1.50	1.53	1.56	1.58	1.62	1.66	1.72	1.74
STS, sit-to-stand.										