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Experimental Gerontology

Comparison of available equations to estimate sit-to-stand muscle power and their association with gait speed and frailty in older people: Practical applications for the 5-rep sit-to-stand test

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ABSTRACT

Objectives: This study aimed i) to compare relative sit-to-stand power (STS_{rel}) values yielded by the different equations reported in the literature; ii) to examine the associations between STS_{rel}, derived from the equations, and age, sex, frailty and habitual gait speed (HGS); and iii) to compare the ability of the different STS_{rel} equations to detect frailty and low HGS in older adults.

Methods: 1568 participants (>65 years) were included. STS_{rel} was calculated according to four validated equations. Frailty was assessed using the Frailty Trait Scale and HGS as the time to complete 3 m. ANOVA tests, regression analyses and receiver operator characteristic curves were used.

Results: There were significant differences among the STS_{rel} values yielded by all the equations, which were higher in men compared to women and negatively associated with age ($r = -0.21$ to -0.37). STS_{rel} was positively and negative associated to HGS and frailty, respectively, in both men ($r = 0.29$ to 0.36 and $r = -0.18$ to -0.45) and women ($r = 0.23$ to 0.45 and $r = -0.09$ to -0.57) regardless of the equation used. Area under the curve values varied between 0.68 and 0.80 for Alcazar's, 0.67–0.80 for Ruiz-Cárdenas's, 0.51–0.65 for Smith's, and 0.68–0.80 for Takai's equations. Low STS_{rel} indicated an increased probability of having both low HGS and frailty (OR [95%CI] = 1.6 to 4.5 [1.21 to 5.79]) for all equations with the exception of Smith's equations for frailty in women.

Conclusions: All the equations presented adequate criterion validity, however, the Alcazar's equation showed the highest level of clinical relevance according to its ability to identify older people with frailty and low HGS.

1. Introduction

Aging is associated with a reduction in the functional reserve of the neuromuscular system, resulting in impaired mechanical muscle performance that translates into a reduced functional capacity to perform activities of daily living (ADL) (Aagaard et al., 2010). Mechanical power has been demonstrated to decline more quickly, and at an earlier age, than other important attributes such as muscle mass and muscle strength (i.e. sarcopenia) (Lauretani et al., 2003; Skelton et al., 1994; Siglinsky et al., 2015; Klass et al., 2008; Suetta et al., 2019), and it is more strongly related to the performance of ADL (e.g. stair climbing and walking) (Bean et al., 2003). Specifically, as most ADL require older people to

support their own body mass, the normalization of lower body mechanical power to body mass (i.e. relative power) strengthens the relationship with physical performance (Skelton et al., 1994; Alcazar et al., 2018).

However, the assessment of mechanical power in the clinical setting may be limited by the requirement for expensive measuring instruments that may need periodic calibration and offline data analysis, preventing health professionals from evaluating mechanical power. In the past, several investigations have used sit-to-stand (STS) performance as an indirect measure of muscle strength or power in older adults (Jones et al., 1999; Hardy et al., 2010). In this sense, poorer STS performance was associated with falls (Buatois et al., 2008), disability (Makizako et al., 2017) and mortality (Cooper et al., 2010). STS performance is usually assessed as the time needed to complete a certain number of chair rises (e.g. 5 repetitions) (Bohannon et al., 2007) or the number of chair rises completed within a certain time period (e.g. 30 s) (Jones et al., 1999), with little space, material and time requirement. Although STS performance has been used as an assessment of strength and power, some researchers argue that it should not be considered a measure of older adults' muscle strength or power, but a measure of physical performance (similar to other functional measures such as gait speed or stair climbing performance) (Lindemann et al., 2007).

Several investigations have validated simple equations that transform STS performance into STS power (please for further details on the validity of the equations see (Alcazar et al., 2018; Ruiz-Cardenas et al., 2018; Smith et al., 2010; Takai et al., 2009)). STS power derived from validated equations has been shown to be associated with quadriceps femoris muscle cross-sectional area and maximum knee extension force (Takai et al., 2009), habitual (Alcazar et al., 2018; Bahat et al., 2020) and maximal physical performances (Alcazar et al., 2020; Baltasar-Fernandez et al., 2020), cognitive function and quality of life (Alcazar et al., 2018), disability in ADL (Bahat et al., 2020) and mortality (Alcazar et al., 2021). Thus, these equations provide a feasible and clinically relevant method to routinely assess muscle power in primary care setting and specialized centers.

STS assessment is not unusual in daily clinical practice (Takeda et al., 2020). For example, the 5-rep STS test is included within several geriatric tools addressing the assessment of physical performance (Guralnik et al., 1994), frailty (Bortone and Sardone, 2021) and sarcopenia (Cruz-Jentoft et al., 2019) in older people. Therefore, health professionals can assess muscle power using data derived from routine 5-rep STS testing. Of note, the STS power equations available in the literature may yield different muscle power results when used with 5-rep STS data and may also be related differently to other important outcomes for older people, such as physical performance and frailty. Nevertheless, no previous studies have addressed these limitations in the literature. Therefore, the main goals of the present study regarding the 5-rep STS test were: i) to compare relative STS power values yielded by the different equations reported in the literature; ii) to examine the associations between relative STS power, derived from the equations, and age, sex, frailty and habitual gait speed (HGS) in older adults; and iii) to compare the ability of the different relative STS power equations to detect frailty and low habitual gait speed in older adults.

2. Material and methods

2.1. Study design and participants

The *Toledo Study for Healthy Aging* is a population-based study that employed participants selected by a two-stage random sampling of people aged 65 and older included in the municipal census of the province of Toledo (Spain). The present study includes cross-sectional data collected from participants between 2011 and 2013. In total, 1568 older adults completed all the required testing and were included in the analysis (Table 1). All participants provided written informed consent and the study was performed in accordance with the Helsinki

Table 1
Main characteristics of the study participants.

Variable	Men (n = 721)			Women (n = 847)		
	Mean	±	SD	Mean	±	SD
Age (years)	75.5	±	6.0	75.8	±	6.1
Height (m)	1.64	±	0.07[a]	1.51	±	0.06
Femur length (m)	0.42	±	0.02[a]	0.39	±	0.02
Leg length (m)	0.79	±	0.04[a]	0.73	±	0.04
Weight (kg)	76.9	±	11.8[a]	69.3	±	12.1
BMI (kg·m^{-2})	28.7	±	4.0[a]	30.6	±	5.1
MMSE (points)	24.9	±	4.1[a]	24.1	±	4.1
Number of diseases (n)	2.7	±	1.2[a]	3.0	±	1.2
Number of medications (n)	4.7	±	2.8[a]	5.3	±	2.7
FTS (points)	33.8	±	13.5[a]	39.7	±	14.0
HGS (m·s^{-1})	0.9	±	0.3[a]	0.8	±	0.2
5-rep STS time (s)	13.9	±	3.8[a]	15.1	±	4.3
STS power calculations						
Alcazar's (W·kg^{-1})	2.6	±	0.7[a,*]	2.0	±	0.6[a,*]
Ruiz-Cárdenas's (W·kg^{-1})	7.2	±	1.0[a,*]	6.3	±	1.1[a,*]
Smith's [mean] (W·kg^{-1})	6.3	±	0.9[a,*]	5.6	±	1.1[a,*]
Smith's [peak] (W·kg^{-1})	7.8	±	1.3[a,*]	6.9	±	1.6[a,*]
Takai's (W·kg^{-1})	1.4	±	0.4[a,*]	1.1	±	0.3[a,*]

Note: SD: standard deviation; m; meters; kg: kilograms; n: number; s: seconds; W: watts; BMI: body mass index; MMSE: mini-mental state examination; FTS: frailty trait scale; HGS: habitual gait speed; STS: sit-to-stand.

[a] Statistically significant different compared to women.

[*] Statistically significant different compared to the rest of the equations (all *p* < 0.001).

Declaration and approved by the Clinical Research Ethics Committee of the Toledo Hospital, Spain.

2.2. Anthropometric measurements

Anthropometric measurements were obtained in each subject while wearing light clothing. Height was assessed on a stadiometer with a precision of 1 mm (Seca 711, Hamburg, Germany) while body mass was measured with a scale device with a precision of 100 g (Seca 711, Hamburg, Germany). Body mass index (BMI) was calculated as body mass divided by height^2 (kg·m^{-2}). The distances between the superior border of the greater trochanter and the inferior border of the i) lateral condyle of the femur and ii) malleolus lateralis were measured from whole body scans obtained by dual energy X-ray absorptiometry (DEXA) (Hologic, Serie Discovery QDR, Bedford, USA) and analyzed with specific image analysis software (ImageJ 1.52, National Institutes of Health, USA) because it is required to calculate relative STS power in the Ruiz-Cárdenas' and Takai's equations.

2.3. HGS and frailty

HGS was assessed over a 3-meter walking course. The time needed to complete the distance was recorded with a stopwatch to the nearest 0.01 s, and the best time of two attempts was chosen for further analysis. HGS measurements have been shown to have excellent test-retest reliability (ICC > 0.96) (Peters et al., 2013). Low HGS was defined as an HGS < 0.8 m·s^{-1} (Abellan van Kan et al., 2009; Studenski et al., 2011).

Frailty was assessed according to the Frailty Trait Scale (FTS), which evaluates 7 different dimensions (energy balance and nutrition, physical activity, nervous system, vascular system, weakness, endurance and slowness) providing a score between 0 and 100 points (Garcia-Garcia et al., 2014). Frailty was defined as an FTS score ≥ 50 points (Garcia-Garcia et al., 2014).

2.4. Five-repetition sit-to-stand power assessment

STS power was calculated using the 5-repetition STS test and various equations provided in the literature to calculate mechanical power in

older people. Briefly, the participants were encouraged to complete, as rapidly as possible, five timed STS repetitions on a 0.43 m chair with their arms crossed over the chest. They performed a first practice attempt followed by a minimum of two valid trials with 2 minute rest between trials. A third trial was performed by the participants who obtained a lower time in their 2nd attempt. Time to complete the STS test was recorded to the nearest 0.01 s using a stopwatch. Then, we used all equations reported in the literature that allowed at least the introduction of STS-derived data (time, repetitions, or both) to calculate muscle power, whether they were validated for the 5-rep STS test or not. STS power was estimated from the equations of Alcazar et al. (2018), Ruiz-Cardenas et al. (2018), Smith et al. (2010) and Takai et al. (2009) (Fig. 1). Briefly: i) Alcazar's equation uses STS performance (the time to complete five STS repetitions), participants' body masses and heights, and chair height, to compute mean absolute STS power (Alcazar et al., 2018); ii) Ruiz-Cárdenas's equation (Ruiz-Cardenas et al., 2018) requires the recording of STS performance [time between seat-off and the point when vertical force reaches body weight (which accounts for 37.5% of one STS repetition (Lindemann et al., 2003)), which was estimated from 5-rep STS performance] and participants' femur length to obtain mean relative STS power (Ruiz-Cardenas et al., 2018); iii) Smith's equations use STS performance [number of stands in 20s, which was estimated from 5-rep STS performance (20 s·n of STS repetitions·Five STS time^{-1})] and participants' body mass to calculate both mean and peak absolute STS power (Smith et al., 2010); and iv) Takai's equation requires STS performance (number of STS repetitions performed in a given time period), participants' body mass, leg length, and chair height to compute mean absolute STS power (Takai et al., 2009). Furthermore, power data obtained from the above-mentioned equations was normalized to body mass to obtain relative STS power, except for Ruiz-Cárdenas's equation that does not require this step.

2.5. Statistical analysis

Data are presented as mean ± standard deviation (SD) unless otherwise stated. Normality was confirmed by Shapiro-Wilk tests. Relative STS power values yielded by each equation were compared using two-way ANOVA tests with a within-subject factor (equation) and a between-subject factor (sex). Pairwise comparisons were adjusted using Bonferroni's correction. The relationship of relative STS power (estimated from the equations of Alcazar, Ruiz-Cárdenas, Smith and Takai) with age, HGS and frailty were assessed through regression analyses. Linear and quadratic regression models were compared based on the coefficient of determination (R^2) change to determine the most suitable regression model, and Pearson's correlation (r) values were reported. Receiver operator characteristics (ROC) curves were performed to assess the ability of relative STS power values estimated from

the equations to separately identify those participants with low HGS and frailty. Area under the curve (AUC) values and 95% confidence intervals (CI) were obtained. Optimal cut-off values were identified as those yielding the best trade-off (product) between sensitivity and specificity for the identification of participants who had low HGS and those who were frail, separately. Logistic regression analyses adjusted for sex, age, educational level, cognitive function (Folstein et al., 1975), number of diseases and number of medications were used to assess the impact of the equation-specific cut-off values for low relative STS power on low HGS and frailty, and odds ratios (OR) and 95% CI were obtained. Finally, the pooled effect of low relative STS power on low HGS and frailty was calculated. Statistical analyses were performed using SPSS v25 (SPSS Inc., Chicago, Illinois) and the level of significance was set at α = 0.05.

3. Results

The main characteristics of the study participants are shown in Table 1. All participants had at least one disease and were taking at least one medication. According to MMSE score, a total of 75 (10.4%) men and 123 (14.5%) women presented mild cognitive impairment while no participants presented severe cognitive impairment.

3.1. Differences in relative muscle power among equations and association with age and sex

Values of relative STS power obtained from the different equations for the 5-rep STS test are shown in Table 1. There were significant differences among the average values of relative STS power yielded by all the equations tested (all $p < 0.001$). Furthermore, all the equations showed higher relative STS power values in men compared to women (all $p < 0.001$), which were also significantly and negatively associated with age (for men and women, respectively; Alcazar's: $r = -0.24$ and -0.30; Ruiz-Cárdenas's: $r = -0.22$ and -0.27; Smith's: $r = -0.28$ and -0.37; Takai's: $r = -0.21$ and -0.26; all $p < 0.001$).

3.2. Clinical relevance of the different equations

Higher relative STS power was associated with higher HGS in both men ($r = 0.29$ to 0.36) and women ($r = 0.23$ to 0.45) regardless of the equation used ($p < 0.05$) (Fig. 2). Specifically, there was a moderate quadratic relationship for relative STS power derived from Alcazar's and Takai's equations, while the relationship was moderate and linear for Ruiz-Cárdenas's and small and linear for Smith's equations.

Additionally, higher relative STS power was associated with lower FTS frailty in men ($r = 0.18$ to 0.45) and women ($r = 0.09$ to 0.57), with distinct relationships derived from either Alcazar's, Ruiz-Cárdenas's,

Author	Equation	Validation instrument / outcome	Predictive value	Mean error
Alcazar et al. 2018	$\text{Mean STS power (W)} = \dfrac{Body\ mass \times 0.9 \times g \times [Height \times 0.5 - Chair\ Height]}{\left(\frac{Five\ STS\ time}{n\ of\ STS\ repetitions}\right) \times 0.5}$	Linear position transducer (leg press) [8]	$r = 0.72$	Δ = - 6.9 W
		Nottingham power rig [20]	$r = 0.75$	Δ = + 7.9 W
		Force platform + video analysis (5-rep STS test) [21]	$r = 0.95$	Δ = + 6.4 W
Ruiz-Cárdenas et al. 2018	$\text{Mean relative STS power (W·kg}^{-1}) = 2.773 - 6.228 \times One\ stand\ time_a + 18.224 \times d\ ^*$ $^a One\ stand\ time = \left(\frac{Five\ STS\ time}{n\ of\ STS\ repetitions}\right) \times 0.5 \times 0.375$	Force platform + video analysis (one stand) [16]	$r = 0.85$	Δ = + 0.08 W·kg^{-1}
Smith et al. 2010	$\text{Mean STS power (W)} = -504.845 + 10.793 \times Body\ mass + 21.603 \times n\ stands\ in\ 20s\ ^a$ $\text{Peak STS power (W)} = -715.218 + 13.915 \times Body\ mass + 33.425 \times n\ stands\ in\ 20s\ ^a$ $^a n\ stands\ in\ 20s = \frac{20\ s \times n\ of\ STS\ repetitions}{Five\ STS\ time}$	Force platform + high-speed motion analysis (30-s STS test) [17]	$r = 0.89$	Δ = + 4 W
			$r = 0.90$	Δ = 0 W
Takai et al. 2009	$\text{Mean STS power (W)} = \dfrac{Body\ mass \times g \times n\ of\ STS\ repetitions \times [d^{\#} - Chair\ Height]}{Five\ STS\ time}$	Quadriceps cross sectional area (MRI) [18]	$r = 0.80$	N/A
		Knee extension torque (myometer) [18]	$r = 0.73$	

Fig. 1. Calculation of STS power according to the Alcazar's, Ruiz-Cárdenas's, Smith's and Takai's equations. Note: g, gravity (i.e. 9.81 m·s^{-2}). n of STS repetitions, number of sit-to-stand repetitions. * distance between the superior border of the greater trochantes and the lateral condyle of the femur. n stands in 20 s, number of stands performed in 20 s. # Distance between the superior border of the greater trochanter and the malleolus lateralis. MRI: magnetic resonance imaging. Alcazar et al. (2018). Alcazar et al. (2020). Baltasar-Fernandez et al. (2020).
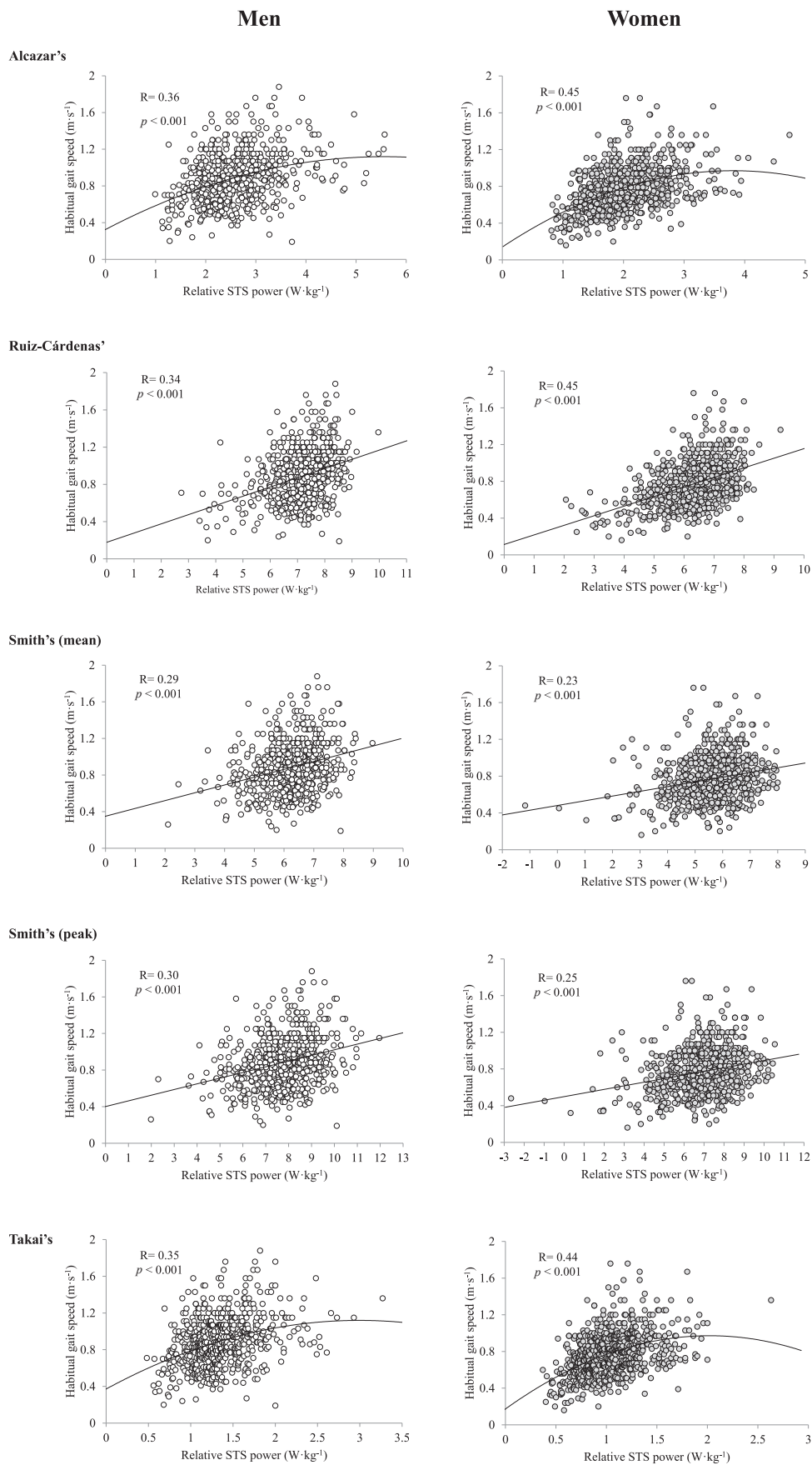
Fig. 2. Relationship between relative STS power calculated from Alcazar's, Ruiz-Cárdenas's, Smith's (mean values), Smith's (peak values) and Takai's equations and HGS in men and women.

Smith's (mean, only in men; and peak), and Takai's equations in both sexes ($p < 0.05$) (Fig. 3). In contrast, no relationship with frailty was found for the Smith's (mean) equation in older women. These relationships were moderate and quadratic for the Alcazar's, Ruiz-Cárdenas's and Takai's equations, while they were small and linear for Smith's equations.

3.3. Comparison of cut-off values among equations

A total of 248 (34.4%) men and 423 (49.9%) women had low HGS (i. e. <0.8 m·s^{-1}), while 98 (13.6%) men and 210 (24.8%) women were frail (i.e. FTS >50). ROC curves showing the ability of the different relative STS power equations to predict, separately, low HGS and frailty are displayed in Fig. 4A and B, respectively. Briefly, AUC values varied between 0.68 and 0.80 for Alcazar's, 0.67–0.80 for Ruiz-Cárdenas's, 0.51–0.65 for Smith's, and 0.68–0.80 for Takai's equations. In addition, the calculated relative STS power cut-off values for predicting, separately, low HGS and frailty, as well as the impact (OR [95% CI]) of having low relative STS power on low HGS and frailty are shown in Table 2 for the different equations. Low relative STS power according to either Alcazar's, Ruiz-Cárdenas's, Smith's or Takai's equations was significantly associated with low HGS in both women and men. In addition, low relative STS power according to either Alcazar's, Ruiz-Cárdenas's, Smith's (peak values) or Takai's equations was significantly associated with frailty in men (all $p < 0.001$), while relative STS power according to the Alcazar's, Ruiz-Cárdenas's and Takai's equations was associated with frailty in women (all $p < 0.001$). However, no association existed between Smith's low relative STS power and frailty in women (all $p > 0.05$). Fig. 5 shows the pooled effect of low relative STS power derived from the different equations on low HGS and frailty together.

4. Discussion

This study demonstrated that relative STS power estimated from Alcazar's, Ruiz-Cárdenas's, Smith's and Takai's equations differed significantly. In addition, regardless of the used equation: i) STS power was significantly higher in men compared to women; ii) there was a significant and negative association between age and STS power; and iii) lower STS power was associated with slower HGS. However, STS power data derived from all but the Smith's equation for women were significantly and negatively associated with frailty among older adults.

Although mechanical power of lower extremity muscles is recognized as a more clinically relevant measure than muscle strength and mass in older populations, perhaps, its assessment in the clinical setting has not been sufficiently promoted in the past due to a lack of feasible tests (Beaudart et al., 2019). Nevertheless, there are several equations that allow the transformation of STS performance into mechanical power. To our knowledge, the equations analyzed in this investigation are the only ones reported in the literature that allow STS power to be calculated after recording the time or number of STS repetitions and selected anthropometric data. In general, these equations may be categorized into two groups: (i) those based on mathematical models derived from regression analyses, and (ii) those based on biomechanical principles or models.

The Ruiz-Cárdenas's and Smith's equation are based on regression models. The validity of these equations may be limited to participants with similar characteristics (highly functioning community-dwelling older adults) to those included in their validation studies (Ruiz-Cardenas et al., 2018; Smith et al., 2010). The Ruiz-Cárdenas's equation has been previously twice validated against 3D motion capture camera and force plates in a total sample of 67 healthy individuals (21–91 years) (Ruiz-Cardenas et al., 2018; Orange et al., 2020) while the Smith's equation has been validated in a sample composed by 14 older adults (76.0 $\pm$ 7.2 years) (Smith et al., 2010) which may limit its external validity. In general, relative STS power values estimated from both

equations were significantly related to HGS and frailty, which denotes the functional relevance of these equations in older people even when these equations were not designed for the 5-repetition STS test. However, two older women (0.1%) presented negative values for relative STS power when Smith's equations were used. A previous report (Bassey et al., 1992) pointed out that a minimum of 0.6 W·kg^{-1} of lower-limb relative power would be required to perform ADL (e.g. chair rising), well below the minimum of 4.0 W·kg^{-1} estimated to be required when performing a single chair stand by Smith et al. (2010) using their equation. Of note, these two women who obtained negative power values were underweight and had poor STS performance, so these findings would question the validity of the Smith's equations when used in older individuals with these specific characteristics and reflect the "basement effect" reported by these researchers for individuals weighing less than 50 kg who could not complete more than one stand (Smith et al., 2010).

Rather than using regression modeling, Alcazar's and Takai's equations are based on biomechanical principles. These equations may potentially be adequate for a large proportion of the older population if the main biomechanical factors that influence mechanical power production during the chair rise movement are properly considered. Relative STS power obtained from these equations was significantly associated with HGS and frailty, and no negative values for relative STS powers were computed. In addition, unlike for Ruiz-Cárdenas's and Smith's equations, these relationships were curvilinear for Alcazar's and Takai's equations, which is expected for the relationship between muscle power and physical performance in older adults (Bean et al., 2003; Alcazar et al., 2018; Bean et al., 2002). Moreover, there were no participants with relative STS power values lower than 0.6 W·kg^{-1} when using Alcazar's equation, while 5 (0.7%) older men and 40 (4.7%) older women presented levels of relative STS power lower than 0.6 W·kg^{-1} when Takai's equation was applied. These artifacts derived from Takai's equation were likely caused by the fact that this equation did not differentiate between the concentric (ascending) and eccentric (descending) phases of the STS task. Thus, Takai's velocity is calculated as the ratio between the vertical distance covered solely during the ascending phase and the total duration of the ascending and descending phases together. This leads to an underestimation of velocity (and power) values when using Takai's equation. In contrast, Alcazar's equation applies a factor of 0.5 to the estimated duration of one complete STS repetition to calculate STS power solely during the ascending phase, which has been previously validated (Baltasar-Fernandez et al., 2020; Van Roie et al., 2019). In addition, among the strengths of Alcazar's equation is the fact that it does not require measurement of leg length and has been validated against three different previously validated instruments (linear position transducer, Nottingham power rig and force plate) in a total of 718 older adults aged 60–93 years with SPPB scores ranging from 4 to 12 (Alcazar et al., 2018; Alcazar et al., 2020; Baltasar-Fernandez et al., 2020).

In terms of the clinical relevance of the studied equations, the low relative STS power derived from all equations was significantly associated with impaired physical function and frailty (except for the Smith's equation in women) in both older men and women. In this sense, the highest AUC values were seen for Alcazar's and Takai's equations regarding the ability to identify older men and women with low HGS (i. e. <0.8 m·s^{-1}) and frailty. Finally, when the negative effect of low relative STS power on physical function and frailty was pooled, Alcazar's equation showed the highest OR in older men (OR [95% CI] = 3.47 [2.51, 4.80]) and women (OR [95% CI] = 3.54 [2.69, 4.67]). Notably, previous reports indicated that relative STS power was more strongly associated with gait speed than traditional measures of STS performance, such as handgrip strength and power assessed with the Nottingham power rig (Alcazar et al., 2018; Alcazar et al., 2020). Also, the low relative STS power assessed by Alcazar's equation was reported to be more clinically relevant than sarcopenia in older people (Bahat et al., 2020; Losa-Reyna et al., 2020). This evidence on the clinical relevance of
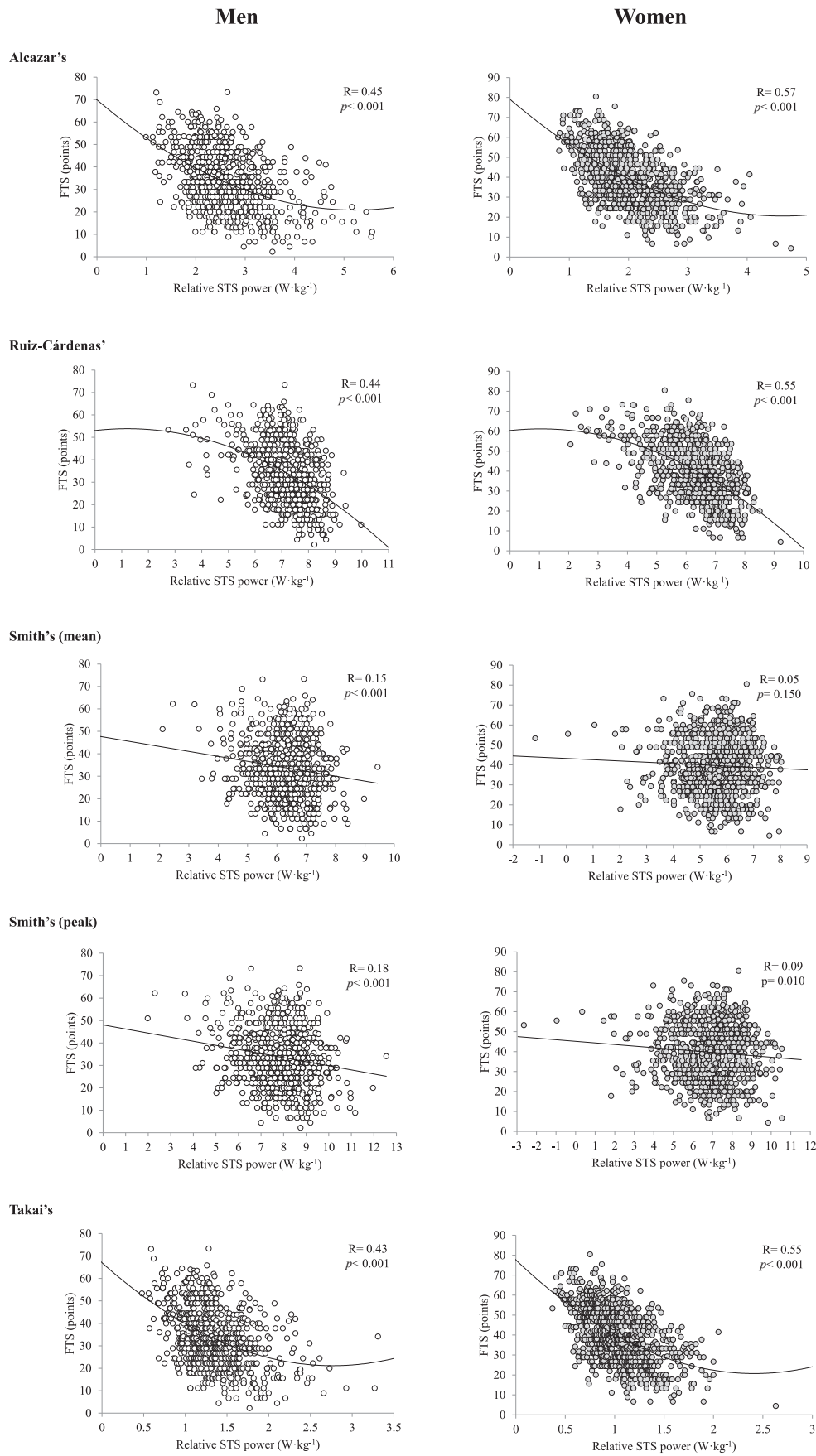
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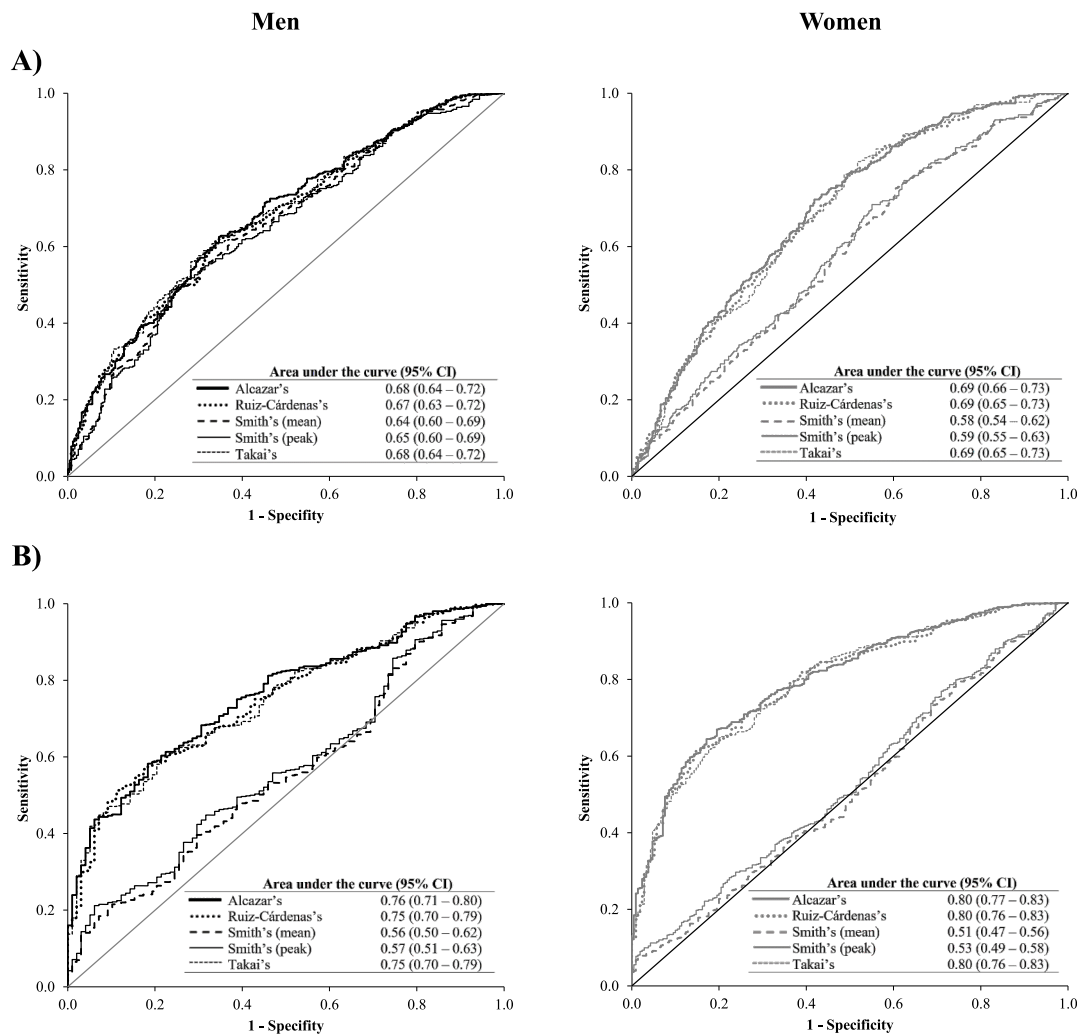
Fig. 4. Receiver operator characteristics curve plots compare how relative STS power calculated from the different equations allows the identification of older adults with low HGS (A) and frailty (B). The reference line is shown in grey for men and black for women.

Table 2
Optimal relative STS power cut-off values (W·kg^{-1}) for the different equations and their impact on low HGS and frailty.

	Men			Women		
	Cut-off value	OR (95% CI)[a]	p	Cut-off value	OR (95% CI)[a]	p
Low HGS						
Alcazar's	2.5	2.78 (1.90–4.07)	<0.001	1.9	2.08 (1.45–2.99)	<0.001
Ruiz-Cárdenas's	7.2	2.50 (1.70–3.66)	<0.001	6.2	1.96 (1.38–2.80)	<0.001
Smith's (mean)	6.4	2.50 (1.66–3.76)	<0.001	5.6	1.56 (1.07–2.28)	0.022
Smith's (peak)	8.0	2.65 (1.76–3.99)	<0.001	6.6	1.67 (1.13–2.49)	0.011
Takai's	1.3	2.62 (1.79–3.85)	<0.001	0.9	2.30 (2.55–3.40)	<0.001
Frailty						
Alcazar's	2.5	5.23 (2.83–9.63)	<0.001	1.9	5.54 (3.63–8.46)	<0.001
Ruiz-Cárdenas's	7.1	3.67 (2.15–6.24)	<0.001	6.2	5.40 (3.44–8.16)	<0.001
Smith's (mean)	6.4	1.37 (0.80–2.36)	0.252	5.7	0.88 (0.59–1.32)	0.525
Smith's (peak)	8.1	1.82 (1.04–3.19)	0.035	6.7	0.97 (0.64–1.48)	0.890
Takai's	1.3	5.50 (2.90–10.47)	<0.001	1.0	4.89 (3.20–7.46)	<0.001

Note: low HGS: low habitual gait speed; OR: odd ratio; CI: confidence interval.
[a] Adjusted for age, educational level, cognitive function, number of diseases and number of medications.

STS power adds to previous evidence relating muscle power to older people's functional ability (Bean et al., 2003; Bean et al., 2002; Bean et al., 2010), frailty (Bahat et al., 2020; Losa-Reyna et al., 2020) risk of hospitalization (Losa-Reyna and Alcazar, 2021) and all-cause mortality (Alcazar et al., 2021; Losa-Reyna and Alcazar, 2021).

Given its association with independence and ADL performance, and its more precipitous decline with age compared to strength and sarcopenia, mechanical power should be regarded as a standard outcome measure in the clinical management of aging. As demonstrated in the current investigation, the STS is a feasible technique for the assessment of relative muscle power in older people and needs minimal equipment and time (<2 min).
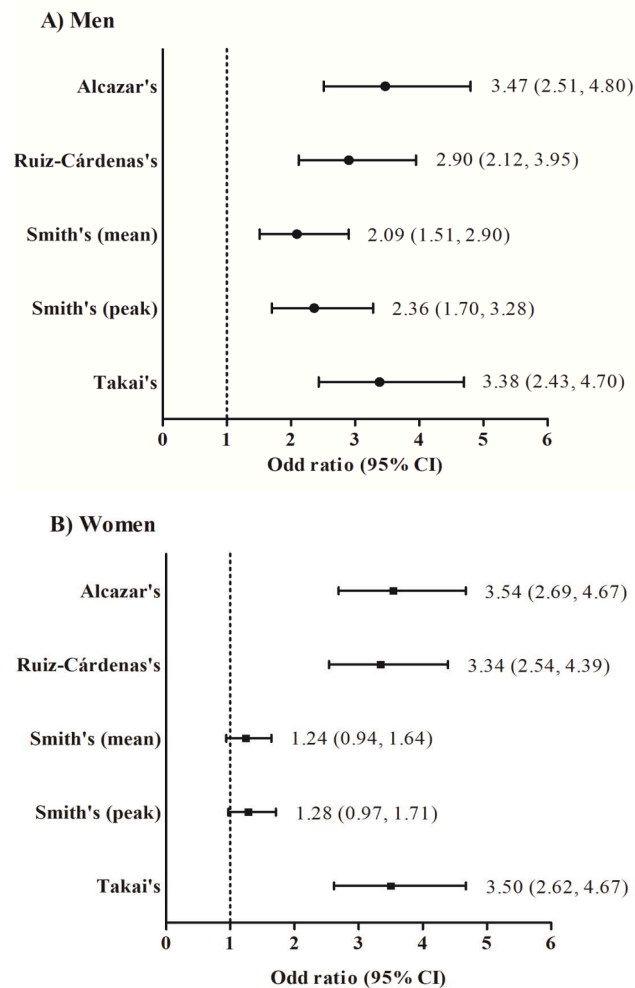
Fig. 5. Pooled effect (combined effect of having both low HGS and frailty) of having low relative STS power according to the equation used.

5. Study limitations

There are some limitations that should be considered when interpreting the present study findings. The time taken to stand up once from a chair and the number of stands performed in 20 s were estimated from the 5-repetition STS test to compute power using Ruiz-Cárdenas's and Smith's equations, respectively. For the Ruiz-Cárdenas's equation, relative STS power may have been underestimated in the current investigation; however, STS performance has been shown to decline only 10% after eight STS repetitions in older women (Lindemann et al., 2016). Since our participants only performed 5 STS repetitions, it is unlikely that this influenced STS power values derived from Ruiz-Cárdenas's equation. On the contrary, for the Smith equation, the calculated relative STS power may have been overestimated in the current study. However, evidence from studies using both the 5-repetition and 30-s versions of the STS test suggests that this overestimation would not be higher than 5–7% and would not affect the association with gait speed parameters (Zhang et al., 2018; Morita et al., 2018). Furthermore, the Ruiz-Cárdenas's equation was not originally validated using a stopwatch; rather it requires the use of a mobile device to record the STS test, a height-adjustable chair to set starting knee joint position at 90°, and to measure and introduce participant's femur length. Our study used a 0.43 m chair, then vertical displacement may not be matched to femur length in some participants. In any case, the main goal of the present investigation was to compare all available equations that may potentially be used to calculate muscle power from routine 5-rep STS testing (i.e. just using a stopwatch and a chair). This latter aspect justifies the inclusion of all the studied equations to provide an adequate recommendation regarding the preferential use of a specific equation for 5-rep STS data. On the other hand, our study also presented some strengths such as the inclusion of a large sample of older people, the very accurate anthropometric assessment thanks to the analysis of images obtained from the DEXA scans, as well as being the first study to compare the use of different validated equations and evaluate their impact on negative outcomes such as low HGS and frailty. However, further studies comparing the clinical relevance of equation-derived relative STS power values using different versions of the STS test (e.g., 10-rep, 20-s, 30-s or 1-min) may yield important findings for their application in the clinical setting.

6. Conclusion

In general, all the equations presented adequate criterion validity: i) relative STS power was higher in men compared to women and was negatively associated with age; ii) there was a positive and moderate association between relative STS power and HGS, and a negative and moderate association between relative STS power and frailty (except with the Smith's equations). However, for the assessment of muscle power during the 5-rep STS test, the equation provided by Alcazar et al. (2018) showed the highest level of clinical relevance assessed by its ability to identify older adults with impaired physical function and frailty and would be more appropriate in terms of feasibility in the clinical setting when compared to other equations.

CRediT authorship contribution statement

Ivan Baltasar-Fernandez: Data curation, Formal Analysis, Visualization, Writing- Original Draft. **Julian Alcazar**: Formal Analysis, Investigation, Writing- Review & editing. **Jose Losa-Reyna**: Data curation, Resources, Supervision, Writing- Review & editing. **Hector Soto**: Investigation, Writing- Review & editing. **Luis M Alegre**: Resources, Supervision, Writing- Review & editing. **Yohei Takai**: Writing- Review & editing. **Juan D Ruiz-Cárdenas**: Writing- Review & editing. **Joseph F Signorile**: Writing- Review & editing. **Leocadio Rodriguez-Mañas**: Conceptualization, Funding acquisition, Methodology, Project Administration. **Francisco J García- García**: Conceptualization, Funding acquisition, Methodology, Project Administration. **Ignacio Ara**: Funding acquisition, Resources, Supervision, Writing- Review & editing.

All authors have read and approved the final version of the manuscript and agree with its order of presentation.

Declaration of competing interest

The authors declare no conflict of interest.

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