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Original Article

A COMPARISON OF ABSOLUTE, RATIO STANDARD AND ALLOMETRIC APPROACHES FOR BENCH PRESS PERFORMANCE ASSESSMENT IN MEN OVER 60

COMPARAÇÃO DAS ABORDAGENS ABSOLUTA, RAZÃO PADRÃO E ALOMÉTRICA PARA A PERFORMANCE NO SUPINO EM HOMENS ACIMA DE 60 ANOS

Wladymir Külkamp [1], **Jairo Júnior** [1], *** Guilherme Freccia** [1], **Joana Muller** [1], **Kléber Santos** [1], and **Lorival Carminatti** [1]

[1] Santa Catarina State University, Florianópolis-SC, Brazil..

RESUMO

Sabe-se que a massa corporal afeta a força muscular e o resultado de alguns testes funcionais, de modo que pessoas mais pesadas e altas serão mais fortes que as mais leves e menores. A razão-padrão (RP) tem sido largamente utilizada para remover o efeito da massa corporal, apesar de críticas conhecidas há muito tempo devido sua inadequação. Alometria (ALO), do contrário, tem sido aplicada como um método eficiente para normalizar a força muscular. Como o supino é um exercício de força e condicionamento bem reconhecido para idosos, o objetivo deste estudo foi verificar a influência da massa corporal sobre a avaliação do desempenho de um grupo de idosos no supino, comparando as abordagens absoluta (AB), RP e ALO. Dezesseis idosos saudáveis (65,5±5,13 anos de idade; 75,42±9,78Kg; 1,73±5,98m; 25,11±2,71 kg/m^2; 24,76±4,10 %gordura) se voluntariaram para participar no estudo. A máxima carga dinâmica foi verificada pelos testes de 1 repetição máxima (1RM). Na comparação das médias, a diferença significante do 1RM entre os participantes leves (54,9±8,85Kg) e pesados (66,2±8,86Kg) foi identificada apenas na abordagem ABS (p<0,05; ES=0,57). A RP falhou em remover completamente o efeito da massa corporal, permitindo correlação entre a força muscular e a massa corporal normalizadas (r=0,23), ao contrário da ALO (r=0,23 e 0,06). O coeficiente de Kendall revelou ausência de concordância entre as abordagens quando comparadas as suas respectivas classificações ordinais (kw=0,003; p>0,05). Em linha com pesquisas anteriores, ALO tem se mostrado como o único método viável para remover adequadamente o efeito da MC e para oferecer escores de desempenho mais apropriados para homens idosos, como os avaliados por este estudo.

Palavras-chave: Alometria; Razão-padrão; Escalonamento; Força Muscular; Supino

ABSTRACT

Body mass is known to affect muscle strength and the outcome of some functional tests, so that heavier and taller people will be stronger than lighter and smaller ones. Ratio standard (RS) has been widely used to remove the body mass effect, despite long date criticism due to its inadequacy. Allometry (ALLO), in turn, has been applied as an efficient method for normalizing muscular strength. As the bench press (BP) is a well-recognized strength and conditioning exercise for older adults, the aim of the present study was to verify the influence of body mass on the performance assessment of a group of older men in the BP, by comparing the absolute, RS and ALLO approaches. Sixteen healthy old men (65.5±5.13 years old; 75.42±9.78Kg; 1.73±5.98m; 25.11±2.71 kg/m2; 24.76±4.10 %fat) volunteered to participate in the study. Maximum dynamic load was verified by individual one-repetition maximum (1-RM) tests. Comparisons of means revealed that significant 1-RM difference between lighter (54.9±8.85Kg) and heavier (66.2±8.86Kg) participants was identified only in absolute approach (p<0.05; ES=0.57). RS failed in completely remove the body mass effect, allowing correlation between normalized muscular strength and BM (r=0.23), in contraire of ALLO (r=0.03 and 0.06). Kendall's concordance coefficient revealed an absolute lack of agreement between approaches when compared their respective ordinal classifications (kw=0.003; p>0.05). In line with previous research, ALLO has shown to be the only suitable method to remove adequately the body mass effect and to provide appropriated performance scores for the older men evaluated in this study.

Keywords: Allometry; Ratio Standard; Scaling; Muscle Strength; Bench Press

Introduction

Regular resistance training (RT) positively affects muscular strength improvement or maintenance in older adults[1]. This physical capacity is critical to multiple health outcomes, as lower levels of muscular strength have recently been linked to a higher risk of all-cause mortality[2]. Traditionally, strength training for older adults has been prescribed based on percentages of their one-repetition maximum (1RM) or a continuum of repetitions as well[3]. In addition, reference values for certain resistance exercises are available for evaluating performance in older adults[4], which serve as a parameter for identifying the degree of strength deficiency in this population. Therefore, an appropriate assessment of muscular strength is pivotal in ensuring reliable prediction of aging-related health outcomes[5,6], since misinterpretation could lead to an inadequate prescription.

Muscular strength stands for a sum of morphological (e.g., muscle size, density, and fiber type) and neural (e.g., motor units' recruitment and synchronization, firing frequency) characteristics[7]. Concerning morphology, it has long been known that muscle cross-sectional area (MCSA) is strongly and positively associated with strength levels[8]. Thus, it is expected that an individual with more muscle mass will produce more strength, including older adults[9]. That could also be extended to the relationship between body size dimensions (e.g., body mass; body height) and muscular strength values, in which the heavier and taller people will likely be stronger[10]. For that reason, it is advisable to use a normalized values of strength instead of the absolute approach in assessments. Although BH has been recently highlighted as a valid alternative[10], the most common body dimension used to normalize muscular strength is body mass, specially under dynamic exercises[11–13]. For older adults, the association between body mass and muscular strength is also expected[5], even if we take into account the natural MCSA progressive losses related to aging[14].

A muscular strength normalizing method known as Ratio Standard (RS) has been widely used by investigators and trainers[15,16], which comprises the direct ratio between muscular strength and body mass. Nonetheless, RS has received some criticism over the years[17], mainly because it assumes a linear relationship between body mass and muscular strength (intercept = 0), distorting the phenomenon in a real life setting. In addition, the use of RS may favor the performance of lighter lifters. As an alternative, allometric modelling (ALLO) is a method that takes on a non-linear relationship between body mass and muscular strength and can be mathematically defined by a power function (equation 1), where normalized performance corresponds to strength divided per body mass raised to a power exponent[18].

Although muscular strength performance is more precisely normalized by fat free mass or MCSA[19], allometry based on body mass is a practical, low cost, and valid method that has been successfully applied for normalizing strength in isometric[5,20] and dynamic exercises[12,18]. Among older adults, allometric modelling has been mainly applied for normalizing hand grip strength[21–23]. Although the bench press (BP) is a widely used strength and conditioning exercise for older adults[24], the allometric the allometric approach has only been applied for athletes[12] or young adults[11]. Thus, it seems to be important to investigate the effectiveness of allometry to remove the body mass effect on muscle strength of older men, as well as to verify the implications in classifying their performance when disregarding this effect.

Hence, the aim of the current study was to verify the influence of body mass on the performance assessment of a group of older men in the BP exercise, by comparing the absolute approach, RS, and ALLO approaches. We have hypothesized that the performance classifications would be different and that ALLO would provide adequate removal of the body mass effect, unlike the RS approach.

Methods

Participants and study design

Sixteen healthy older men (65.5±5.13 years old; 75.42±9.78Kg; 1.73±5.98m; 25.11±2.71 kg/m^2; 24.76±4.10 %fat) had participated in resistance training for at least one year (max 3 years) prior to data collection. Volunteers were selected from gyms in the city of Florianópolis (Santa Catarina, Brazil) and were free from physical or functional limitations to lift maximal loads. The study was conducted in accordance with the Declaration of Helsinki, and all participants signed an informed consent form. The study protocol was approved by the Committee for Ethics in Research on Human Beings of the State University of Santa Catarina (Register No. 25932519.3.0000.0118).

This is a cross-sectional study with older men to verify the body mass effect on bench press performance, which was assessed by three methods: absolute, RS, and ALLO. The participants' classification was ordered from the stronger individual to the weaker one, in accordance with each method's score provided. This classification difference was verified by means of change in ranks (i.e., classification), with its adequacy based on the absence of correlation between the performance scores and the body mass values. Bench press was chosen considering its wide applications in resistance training, as well as regarding the technical level of execution.

Procedures

All volunteers performed anthropometric measurements and anamnesis in an initial session. To measure body mass (digital scale; 0.1kg accuracy), all participants were assessed wearing light clothes and barefoot.

Five-minute cycle ergometer (~70 rpm; light load) and shoulder mobility exercises with elastic straps were performed before the 1-RM test as a standardized warm-up protocol. Participants performed a set of five repetitions with barbells (no extra load) and then an additional set of 10-12 repetitions with a total of 18 kg.

Bench press 1-RM assessment

Maximum dynamic load was verified by individual one-repetition maximum (1-RM) test, considered a gold standard—a valid and safe method[25]. All tests were performed on a Smith Machine (Matrix, Johnson Health Technologies, USA, Aura Series Smith Machine G3-PL62), with a horizontal bench positioned just below the bar. Participants were asked to keep their head and back pressed against the bench. They were also instructed to fully extend their elbows when pushing the bar vertically in the concentric phase.

To determine subjects' 1-RM load, a trial-and-error procedure was used, within a maximum of five attempts, following the protocol suggested by Weir and coworkers[26]. The initial load applied was determined based on the movement velocity (speed<0.3 m/s), estimated by the My Lift® app, installed on a smartphone. The resistance was progressively increased by 2.5 kg to 5 kg until subjects were not able to perform more than one repetition. The final weight successfully lifted was recorded as the absolute 1-RM. 24-48 hours after the test, a new 1-RM assessment was performed to ensure the reliability of the measure (R^2 = 0.992; ICC = 0.998), with the highest 1-RM value of each participant being used for further analysis.

Movement velocity was also used as an additional validity criterion for the 1-RM test. Only actual loads of 1RM lifted at speeds of less than 0.2 m/s were considered[27]. Standardized verbal commands were given to participants in each trial to ensure adequate encouragement.

Data analysis

Performance classification

Subjects' individual performance was determined according to scores obtained from each reference method. In the absolute approach, the absolute load (kg) lifted was considered as the performance score itself (equation 2). In the RS method, 1-RM load was divided by the individual body mass, and the result was considered the performance score (equation 3).

In the ALLO approach, the score was defined by dividing 1-RM load by the individual body mass raised to a power exponent "b" (equation 4).

ABS = 1RM (equation 2)
RS = 1RM / BODY MASS (equation 3)
ALLO = 1RM / (BODY MASS)^b (equation 4)

Once there are different values suggested as allometric exponents for the bench press (none of them verified for the elderly), both the exponents most cited, b=0.56 [12,28] and b=0.67 [Geometric Similarity theory [18,29]] were used besides the sample-specific calculated exponent. This procedure is detailed in the 'allometric modeling' section below. The existence of a difference between the classifications was verified by means of (a) Kendall's agreement coefficient (kw~0; p>0.05) taking all methods simultaneously, and (b) Kendall's correlation (kt>0, p<0.05), considering only allometric models, also based on subsequent graphical analysis.

Allometric modelling

Determination of the specific allometric exponent ("b") was performed from the linearization of the power function (equation 1), based on the natural logarithms (ln) of the body mass and 1-RM of each of the elderly participants. The value of "b" is determined based on the slope coefficient of the line corresponding to the resulting log-linear equation (equation 5).

ln (1RM) = ln a + b ln (body mass) (equation 5)

The quality of the allometric modeling was verified based on diagnostic regression criteria. These criteria considered normality, homoscedasticity (homogeneous variance), and the self-correlation of residuals [22,30]. The normality of the residual distribution was tested by the Shapiro-Wilk test (p>0.05); self-correlation by the Durbin-Watson test (critical values between the "dU" and "4-dU"); and homoscedasticity, which was verified by visual inspection of residues and by the Pesarán-Pesarán test (r ~ 0; p>0.05).

Body mass effect and classification performance and quality

body mass effect removal from performance was considered the main criterion to determine the quality of the classification provided by each method. The correlation (Pearson's r) between the methods' scores and the participants' body mass was verified and should be very close to zero (r ~ 0) to indicate its adequacy [20,31,32]. Correlations greater than 0.10 were assumed to indicate the failure of the method in removing the body mass effect, meaning a small but not trivial effect size [33,34]. In addition, the participants were divided into two groups based on body mass values: the heavier (GH) and lighter (GL) individuals. These groups were compared in accordance with the performance scores' classification method. Both scaling approaches, ratio standard and Allometry, arranged participants in the same way, grouping the same seven individuals in each of the groups.

Anthropometric and MS data normal distribution was confirmed by the Shapiro-Wilk test (p>0.05), which enables the parametric tests, where means and standard deviation (SD) are presented. Independent sample "t" tests were used to compare the performance means between the GH and GL groups. The effect size (ES) was presented as Cohen's "r" [33], where r < 0.1 means trivial effect; 0.1 ≤ r < 0.3 means small effect, 0.3 ≤ r < 0.5 means medium effect; and r > 0.5 means large effect [33,34]. A conversion from t-value to r-value method was used to standardize the effect size in the mean comparison tests. All statistical tests were performed with IBM SPSS Statistics ver. 23.0 (IBM Co., Armonk, NY, USA). The post hoc statistical power analysis was performed by the G*power 3.1 software and values above 0.8 were found. Sample size, ES, types of tests, and the value of assumed alpha (α = 5%) were imputed in the calculations.

Results

Allometric modeling provided a specific exponent equal to 0.66 for the older men in this study (Fig. 1a), which is practically the same value of "b" used by the Geometric Similarity Theory [18,29]. Thus, further analysis and classifications based on allometry were performed using only the exponents 0.56 and 0.67. Modelling fit (adequacy) was confirmed based on the assumed diagnostic regression criteria, with normally distributed residuals ($p > 0.05$), homoscedastic ($r = 0$; $p > 0.05$), and self-correlation exempted (dw ~ 2). Body fat likely did not disturb the relationship between body mass and muscular strength as subjects' body mass index (body mass) mean value (25.4±2.8 kg/m2) as well their fat percentage mean value (24.76±4.10 %) were according to expected values [35].

To verify the appropriateness of the alternative body height for muscular strength normalizing, additional allometric modelling was applied. As presented in Fig. 1b, body height was not a valid alternative to normalize subjects' performance. The log-linear relationship revealed no correlation between variables (r=0.02), meaning no effect of body height in muscular strength in this sample.

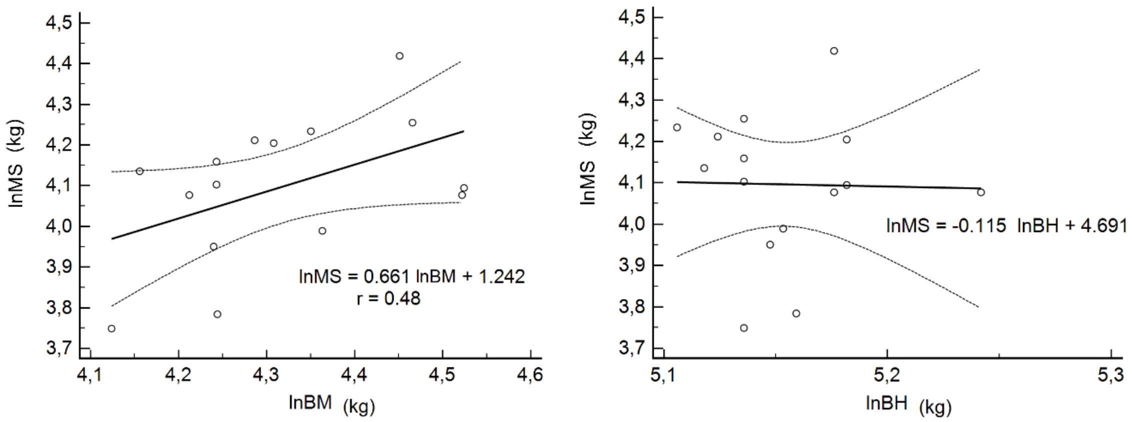

Figure 1. Log-linear relationship between muscle strength and body mass (left panel) and body height (right panel)
Notes: lnMS: log-linear Muscle Strength; lnBH: log-linear Body Height; lnBM: log-linear Body Mass
Source: authors

When all participants were analyzed as a unique group, only ALLO (both exponents) was efficient for adequately removing the body mass effect over performance, providing an absolute absence of correlation with muscular strength (r=0) (Figs. 2c and 2d). On the other hand, absolute approach (Fig. 2a) and RS (Fig. 2b) approaches failed to properly classify the participants, with a moderate (ES=0.45) and small (ES=0.28) body mass effect size, respectively.

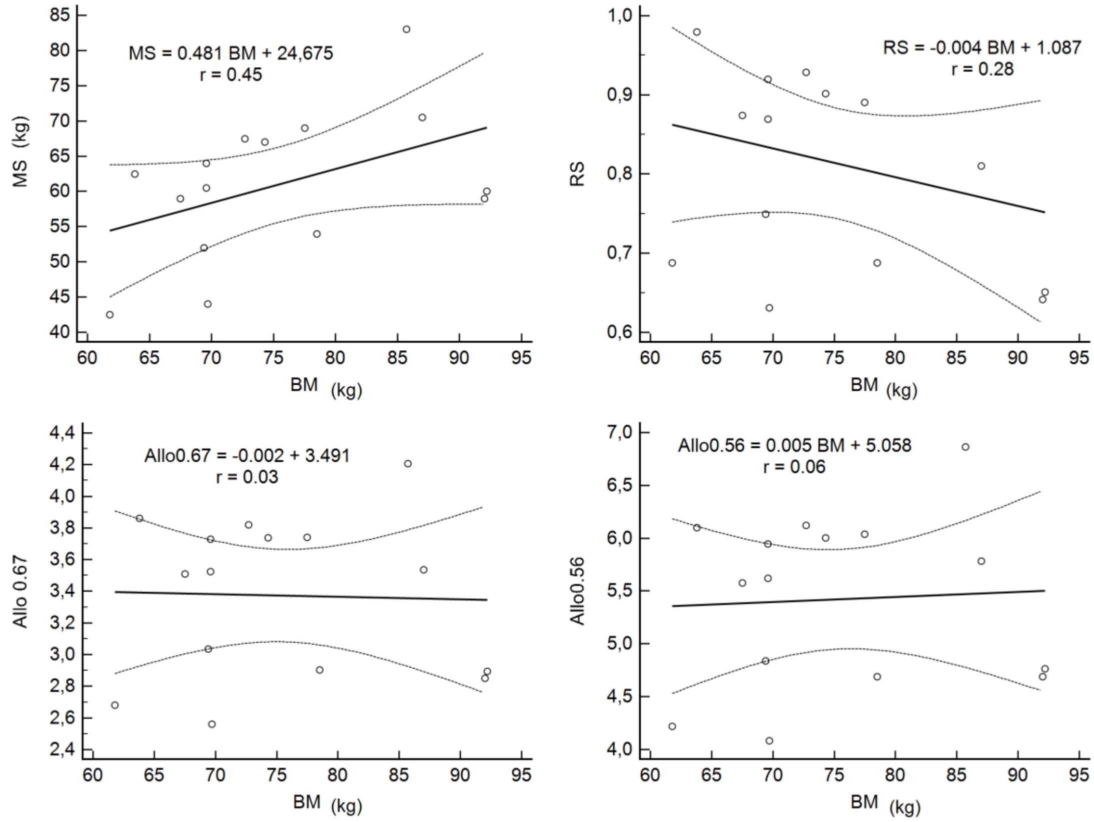

Figure 2. Relationship between absolute muscle strength and body mass (superior left panel); relationship between normalized muscle strength and body mass (superior right panel); relationship between allometrically scaled muscular strength and body mass with b=0.67 (inferior left panel); relationship between allometrically scaled muscular strength and body mass with b=0.56 (inferior right panel).

Notes: MS, Muscle Strength; BM, Body Mass; RS, Ratio Standard
Source: authors

Comparisons of means (Table 1) revealed that when participants were divided between lighter and heavier ones, a significant difference between groups was identified only in the absolute approach score ($p<0,05$; ES=0,57), opposite from RS and ALLO (both exponents). It is important to highlight that the effect size presented correspond to "t" values converted to "r" values, which do not actually account for the correlation between normalized muscular strength and body mass (main criterion of approaches' suitability).

Table 1. Mean comparisons of heavier and lighter subjects according to the methods

N=16	Score	SD	*P*	ES	95%CI
*BM**					
GH	82.5	7.74	0.00*	0.80	(76.0 - 88.9)
GL	67.3	3.25			(64.3 - 70.3)
*ABS**					
GH	66.2	8.86	0.03*	0.57	(58.8 - 73.6)
GL	54.9	8,85			(46.7 - 63.1)
RS					
GH	0.8	0.13	0.93	0.02	(0.7 - 0.9)
GL	0.8	0.13			(0.7 - 0.9)
ALLO					
(0.67)	3.5	0.51	0.49	0.19	(3.0 - 3.9)
GH	3.3	0,51			(2.8 - 3.7)
GL					
ALLO					
(0.56)	5.6	0.81	0.99	0.27	(4.9 - 6.2)
GH	5.2	0.82			(4.4 - 5.9)
GL					

Notes:BM: body mass; GH: heavier individuals; GL: lighter individuals; SD: standard deviation; ES: effect-size; ABS: absolute score; RS: ratio standard score; ALLO: allometric score
Source: authors

Figure 3 presents the classifications (ascending order) generated by the different approaches. The lines in Fig. 3a represent the changes in ranks, initially considering the classification by the absolute method. Only two participants maintained their rank considering all approaches. Kendall's concordance coefficient revealed an absolute lack of agreement between classifications when compared simultaneously (kw=0.003; p>0.05). When only classifications based on ALLO approaches (both exponents) were compared, Kendall's correlation coefficient indicated agreement between them (kt=0.96; p<0.05). The graph analysis of Fig. 3b indicates that only two participants had slightly changed their ranks according to both ALLO approaches, which suggests that both exponents in fact provide very similar classifications.

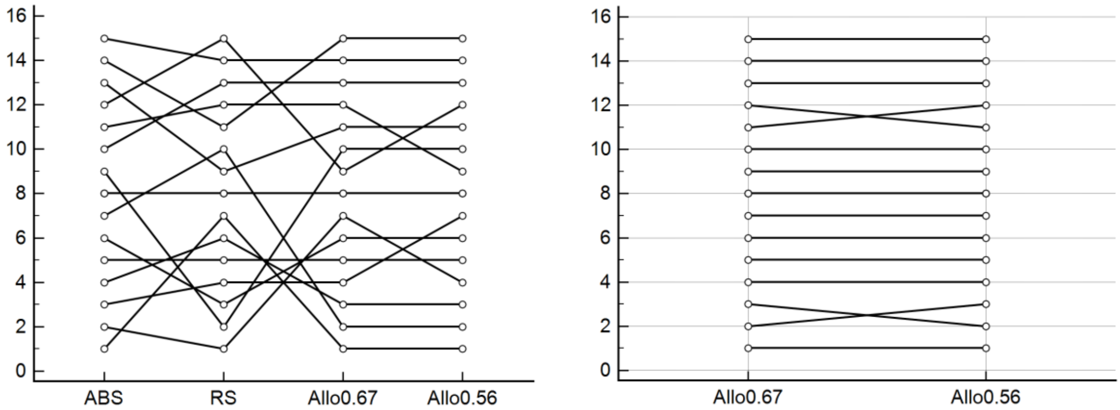

Figure 3. Ordinal classification (position ranking) from three different approaches (left panel); Ordinal classification considering only two magnitudes of "b" allometric exponents (right panel)

Notes: ABS= absolute; RS= ratio standard; Allo0.67 and Allo0.56: values of "b".
Source: Authors

Discussion

Our results showed that older adults' performance classification in the BP could be significantly altered if body mass effect is not properly removed. In the present study, most participants were differently ranked within each approach (Fig. 2a), providing different performance status interpretations according to the chosen method. As far as we know, this is the first study that assesses the effect of body mass on the performance of older adults in the BP using different approaches.

Both statistical criteria, by correlation (Fig. 2a) and by comparison of means (Table 1), confirmed the argument that greater muscular strength must be expected for heavier individuals [10] even among older adults, which contraindicates the use of the absolute approach for performance comparisons in BP for this population also. Although the RS method was apparently useful to ensure similar performance means by both lighter and heavier older adults (Table 1), the main statistical criterion adopted to assess the quality of the methods was the lack of correlation between normalized muscular strength (score) and body mass, where RS proved to be ineffective in removing the body mass effect (Fig. 2b). Despite the mentioned inadequacy, some investigators continue to suggest the use of the RS method for muscular strength normalizing [16].

Thus, allometric scaling was the only suitable method, among those evaluated, to provide performance assessment free of body mass confounding effect. On the contrary, the RS method favored the performance of the lighter people (Fig. 2b), and the absolute method, which favored the performance of the heavier ones (Fig. 2a). These results corroborate previous findings involving young adults or athletes [20], as well as older adults [22].

The sample's specific allometric exponent calculated from the body mass - muscular strength log-linear relationship coincided with the theoretical value of b=0.67 suggested by the Geometrical Similarity Theory [18,29]. According to this theory, assuming body segments as geometric shapes with constant density (e.g., squares and cubes), it is expected that the MS—which corresponds to the MSCA ('S') [8]—is proportional to the length ('L') measurements raised to the power 2 (muscular strength~S~L^2). The body mass, which is a measure of volume ('V'), would correspond to measures of 'L' raised to the power 3 (body mass~V~L^3). Thus, the muscular strength should be proportional to (body mass)$^{2/3}$ or (body mass)[0,67 18,29]. Previous studies have already reported similarities between the theoretical and calculated exponents [11,19,20,36], but none of those assessed older adults in a BP exercise.

Some researchers argue that, although body mass is expected to influence strength performance, the allometric exponent should not be 0.67. According to Nevill et al[29], adults are not geometrically similar; former athletes' and non-athletes' thigh MCSA for instance, might increase at a higher rate than its geometrical similarity predicted value, which implies an exponent lower than the theoretical. Even Jaric and colleagues[18], defenders of "theoretical b", underpin that the maximum muscular strength performed by specific muscle groups generally demonstrates "b" values closer to 0.5 or a little higher. In addition, other researchers suggest that allometric scaling is not an adequate method to remove the body mass effect, because it undervalues the performance of both heavier and lighter individuals, favoring those belonging to the intermediate category of body mass[30,31,36,37]. It should be noted that the studies involved only high-level weightlifters, which may explain the differences from our results. Moreover, when the allometric modeling accounts for the summed performance in different exercises (as performed in the cited studies), the resultant exponent distorts the natural allometric relationship between muscular strength and body mass in each kind of exercise differently[37]. Nevertheless, in the present study allometric scaling adequately removed the body mass effect upon older individuals' performance, meeting the same criteria used in the above-mentioned studies.

Values of "b" ranging from 0.45 to 0.73 have been proposed for BP in the literature[11,12,38,39], which seems to demonstrate a sample-dependent effect on the exponent magnitude[32]. Although the determination of the most precise "b" value is not possible, the exponents available in literature converge in terms that the RS method is not adequate for BP performance assessment[10,17,18]. Furthermore, from a statistical point of view, there was no difference in the quality of the scaling provided by both evaluated "b" values (0.56 and 0.67), which suggests that most of the values found in the literature provide very similar normalizing. Graphical analysis of ranking positions also corroborates this argument (Fig. 3b).

Although lower values of "b" (e.g., b=0.40) have been reported for older adults' handgrip strength compared to young adults[19,21], BP had not yet been investigated. In fact, exercise mode seems to affect the magnitude of the allometric exponent value[12,30], which indicates that the exponents observed here should not be applied to assess older adults in exercises other than BP.

Our data also revealed other important results. Body height was found not to be an adequate predictor of BP performance of participants (r=0.02), contrary to two recently published studies[10,21,40], which highlighted body height as the most adequate body dimension for muscular strength normalization. This may have occurred due to two reasons. First, the difference between the types of exercise evaluated in the studies (handgrip strength vs. bench press). Second, our sample was homogeneous in terms of body height (~3%), but heterogeneous in terms of muscular strength (~17% of variation), leading to a likely sample-specific lower correlation. However, previous studies also stated that body mass instead of body height is a more appropriate body dimension for allometric modeling[19,28].

From a practical perspective, muscular strength performance must be classified with a proper body mass effect removal, providing more accurate decision making within training and rehabilitation prescription (kinesiotherapy). If strength normalization is inadequate, performance may be underestimated or overestimated depending on the method, biasing the training design. This issue has been previously reported evaluating elite football athletes' BP performance based on absolute, ratio, and allometric methods[12,13,38]. It was noted that only allometric modelling was able to provide mean normalized muscular strength that could be used to provide both underperformance and injury susceptibility guidance. Our results also corroborate the conclusions of Crewther et al[38] n the respect that both theoretical and derived exponents provide adequate strength normalization.

The sample size is the main limitation of the present study, which suggests caution when applying the normalized muscular strength means for inferences to this population. Still regarding the number of participants, we recognize that the calculated "b" could be sample-specific[10,32], even though its magnitude is dimensionally sound and its value is close to the value presented in previous research with non-athletes[11].

Conclusion

The type of method was found to influence BP performance assessment in men over 60 years old. As we expected, and in line with previous research, allometric scaling (ALLO) adequately removed the body mass effect and was the only suitable method to provide appropriate performance scores. On the contrary, RS favored the lighter individuals and absolute approach favored the heavier ones, so neither are indicated for interindividual comparisons. Although additional research is necessary, we suggest the use of exponents ranging from 0.56 to 0.67 for BP performance normalizing in men over age 60. This approach is especially recommended when comparing individuals with different magnitudes of body mass.

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ORCID:
Wladymir Külkamp: https://orcid.org/0000-0002-4113-5791
Guilherme Freccia: https://orcid.org/0000-0002-7393-9751
Joana Muller: https://orcid.org/0000-0002-6535-5115
Kléber Santos: https://orcid.org/0009-0003-7143-464X
Lorival Carminatti: https://orcid.org/0000-0002-5893-109X

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Correspondence address: Guilherme Weiss Freccia. Rua José Cândido da Silva, 85, Florianópolis-SC, CEP 88075-250.
E-mail: Guilherme.freccia@udesc.br