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original article

Performance comparison of resistance-trained subjects by different methods of adjusting for body mass

Comparação do desempenho de praticantes de exercícios resistidos por diferentes métodos de ajuste pela massa corporal

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Abstract – The aim of this study was to compare the performance (1RM) of resistance-trained subjects, using different methods of adjusting for body mass (BM): ratio standard, theoretical allometric exponent (0.67), and specific allometric exponents. The study included 11 male and 11 female healthy non-athletes (mean age = 22 years) engaged in regular resistance training for at least 6 months. Bench press (BP), 45° leg press (LP) and arm curl (AC) exercises were performed, and the participants were ranked (in descending order) according to each method. The specific allometric exponents for each exercise were: for men – BP (0.73), LP (0.35), and AC (0.71); and for women – BP (1.22), LP (1.02), and AC (0.85). The Kruskal-Wallis test revealed no differences between the rankings. However, visual inspection indicated that the participants were often classified differently in relation to performance by the methods used. Furthermore, no adjusted strength score was equal to the absolute strength values (1RM). The results suggest that there is a range of values in which the differences between exponents do not reflect different rankings (below 0.07 points) and a range in which rankings can be fundamentally different (above 0.14 points). This may be important in long-term selection of universally accepted allometric exponents, considering the range of values found in different studies. The standardization of exponents may allow the use of allometry as an additional tool in the prescription of resistance training.

Key words: Anthropometry; Muscle strength; Resistance training.

Resumo – *O objetivo do presente estudo foi comparar o desempenho (1RM) de praticantes de exercícios resistidos (ER), a partir de diferentes métodos de ajuste pela massa corporal (MC): ratio standard, expoente alométrico teórico (0,67) e expoentes alométricos específicos. Participaram do estudo 11 homens e 11 mulheres saudáveis, não-atletas, com média de idade de 22 anos, praticantes de ER há pelo menos seis meses. Foram utilizados os exercícios supino reto (SR), leg press 45º (LP) e rosca direta (RD), sendo realizado um ranqueamento (classificação decrescente) dos indivíduos de acordo com cada método. Os expoentes alométricos específicos para cada exercício encontrados foram, para homens 0,73 (SR), 0,35 (LP) e 0,71 (RD) e para mulheres 1,22 (SR), LP 1,02 (LP) e 0,85 (RD). O teste de postos de Kruskal-Wallis não detectou diferença entre os ranqueamentos. No entanto, a inspeção visual indicou que os métodos quase sempre classificavam de maneira diferente os indivíduos em relação ao desempenho. Além disso, nenhum ranqueamento de força corrigida foi igual ao da força absoluta (1RM). Os resultados sugerem que há uma faixa de valores na qual as diferenças entre os expoentes não refletem ranqueamentos distintos (abaixo de 0,07 pontos) e uma faixa em que os ranqueamentos podem ser essencialmente diferentes (acima de 0,14 pontos). Isso pode ser importante na seleção em longo prazo de expoentes alométricos que sejam universalmente aceitos, tendo em vista a variação dos valores apresentados em diferentes estudos. A padronização de expoentes pode permitir o uso da alometria como ferramenta adicional na prescrição do ER.*

Palavras-chave: *Antropometria; Força muscular; Treinamento de resistência.*

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INTRODUCTION

The measurement of muscle strength is fundamental in sports, as well as in prevention and rehabilitation. Both training plans and the preparation of diagnoses and training protocols are often defined according to the results of muscle strength assessments[1,2].

Although evidence suggests that body mass (BM) and muscle strength (MS) are associated[3-7], the importance of adjusting or scaling MS levels to BM during assessments is often neglected when the purpose is to compare different individuals. If any kind of scaling is adopted[8,9],it is often limited to the use of the ratio standard (MS/BM)[10].

Other variables, such as the cross-sectional area (CSA) of muscles, may be biologically more closely correlated with MS[11-14], but reliable measurements of CSA are expensive and made using computed tomography[12] or magnetic resonance[14], which makes the use of BM more attractive.

Several natural phenomena, such as the ratio between MS and BM, follow the power law (($y=ax^b$), and a growing number of studies have been conducted to evaluate whether allometry may be satisfactorily used to compare the MS of individuals or groups. In short, allometric scaling is achieved by linearizing a power function using the least squares method (equation 2) and the natural logarithm (ln) of the dependent and independent variables, which are, in this case, MS and BM.

Allometry, a relatively easy method, also has a strong theoretical basis and has gained credibility in the academic and scientific fields[5,16-19]. However, most studies have only applied allometry to athlete performances[7,20] and have neglected the reality of non-athletes, particularly those that practice resistance training (RT).

Some authors suggest that, based on the geometric similarity theory, an exponent of 0.67 should be used whenever a specific allometric exponent cannot be defined[5,21,22]. However, geometric similarity is not found in practice, at least not in the relation between body circumferences and BM[23].

The comparison of non-athlete performance may seem trivial. However, the study of methods for more accurate comparisons of MS between different groups and individuals, particularly non-athletes, may help to establish normative values that take into considerations the different individual physical and functional differences.

This study compared the performance (muscle strength [MS]) of resistance-trained (RT) individuals according to body mass (BM) using different scaling methods: ratio standard, theoretical allometric exponent (0.67) and specific allometric exponents.

METHODS

Subjects

Eleven male and 11 female non-athletes that had been practicing resistance training (RT) for at leas six months were included in the study (Table 2).

Their training protocol consisted of eight to ten resistance exercises involving the main muscle groups three times a week, with two to three sets of 8 to 12 repetitions. Only individuals with some experience in one-repetition maximum (1RM) tests were evaluated.

Exclusion criteria were any physical impairment that would prevent or make test performance unsafe and use of drugs that might affect performance.

All participants read and signed an informed consent term. All procedures were approved by the Ethics Committee for Research with Human Beings of Universidade do Estado de Santa Catarina under number 143/2009.

Procedures

All 1RM tests were preceded by general and specific warm-up exercises. Evaluations were made using the bench press (BP), 45-degree leg press (LP) and the arm curl (AC) tests, in this order, to avoid the consecutive performance of any two exercises using the upper limbs. The definition of 1RM was the load for which individuals could only make one repetition without any significant change in their performance technique and including all the movement range (except LP, which was limited to 90-degree knee flexion).

Some studies suggest that at least three sessions are necessary for the familiarization with the 1RM test protocols[24], but others showed that one testing day is enough to ensure result reliability when individuals already practice bodybuilding[25]. Moreover, although 1RM using the three tests should ideally be performed on different days, other studies also had participants perform them on the same occasion[25,26] without any negative effects on their conclusions.

In our study, performance in the 1RM tests should be interpreted, although not directly, as an expression of BM (kg).

Statistical analysis

The Shapiro-Wilk test was used to test the normal distribution of the anthropometric variables and MS. The SPSS 17.0 was used for statistical analyses, and the level of significance was set at 5%.

Construction of allometric models

The possibility of adopting allometric scaling due to the lack of linearity in the relation between MS and BM was confirmed using the exceptional circumstance expression (EC) defined by Tanner (equation 1), which is true when the division of the variation coefficients (vc) of the variables is equal to the Pearson correlation coefficient (r) between them[10].

$$BMvc/MSvc = r \qquad \text{(equation 1)}$$

Log-linear regressions were established for each specific situation (equation 2) based on the natural logarithms (ln) of BM and MS (1RM load in kg) in each situation, and all the allometric exponents (b) were defined within a 95% confidence interval (CI).

$$\ln MS = (\ln a) + (b * \ln BM) \quad \text{(equation 2)}$$

Regression diagnoses

To evaluate the quality of allometric scaling, diagnostic criteria of the regressions were used to define the fit of the models. This set of criteria was introduced by Batterham and George[16] and adopted by others, such as Vanderburgh and Doman[17], Cleather[18], Pua[27] and Zoeller et al.[19].

Rank comparison

Each method generated a ranking according to participant performance and classified ranks in descending order, from stronger to weakest. The reference rank, defined according to absolute force values (1RM), was the basis to maintain participant rank and compare changes in ranking (change of position of same participant in different ranks) and, consequently, the difference between methods. Differences were detected using the Kruskal-Wallis test and the visual inspection of ranks, and the criterion for the latter was that the change of at least one position would define difference. Participant classification according to the different methods (ranking) was defined by calculating the individual force index, as illustrated in Figure 1.

Body mass = 80 kg
Absolute muscle force = 100 kg

↓

ratio standard: IF = 100/80 = 1,25

theoretical exponent: IF = $100/(80^{0,67})$ = 5,3

specific expoente: IF = $100/(80^{0,35})$ = 21,6

IF = force index

Figure 1. Example of force index calculation for an individual performing leg press test

RESULTS

The variables that describe the sample and the results of the exceptional circumstance (EC) equation are shown in Table 1.

Construction of allometric models

According to Box 1, EC was not found in any of the tests, which confirmed the linearity of the relation between MS and BM and made it possible to use allometry as the scaling method.

Atkins[21] studied allometry in a group of rugby players and also used EC to justify the use of nonlinear equations for the relation between BM and handgrip strength.

The equations derived from allometric scaling of 1RM performance of men and women separately in the different RT tests, as well as the specific exponents derived, are shown in Table 1.

Box 1. Sample characteristics and evaluation of EC as defined by Tanner

	Men (n=11)			Women (n=11)		
	Mean	sd		Mean	sd	
Age (years)	22.09	3.24		22.82	2.99	
Body mass (kg)	69.91	8.14		55.92	5.94	
Height (m)	1.75	0.09		1.65	0.09	
Bench press (kg)	78.44	19.71		31.67	8.64	
45-degree leg press (kg)	272.28	38.77		184.73	36.56	
Arm curl (kg)	40.34	8.98		18.73	2.37	
EC Evaluation						
	BMvc/MSvc	r	EC	BMvc/MSvc	r	EC
Bench press	0.46	0.43	No	0.39	0.48	No
45-degree leg press	0.76	0.28	No	0.54	0.55	No
Arm curl	0.52	0.44	No	0.84	0.69	No

BMvc = body mass variation coefficient; MScv = muscle strength variation coefficient; r = Pearson correlation between BM and MS; EC = exceptional circumstance, defined by Tanner; sd = standard deviation

Table 1. Log-linear regressions of each specific situation

Test	S	Log-linear regression	SEE	R^2 (adjust.R^2)	b	CI
BP	M	lnY=(0.7305lnX)+1.2331	0.26	0.101(0.001)	0.73	-0.91 – 2.37
LP	M	lnY=(0.3518lnX)+4.099	0.14	0.078(-0.054)	0.35	-0.73 – 1.43
AC	M	lnY=(0.7105lnX)+0.6613	0.22	0.137(0.041)	0.71	-0.63 – 2.05
BP	W	lnY=(1.2208lnX)+1.4851	0.24	0.241(0.157)	1.22	-0.41 – 2.85
LP	W	lnY=(1.0220lnX)+1.0944	0.17	0.324(0.249)	1.02	-0.09 – 2.14
AC	W	lnY=(0.8544lnX)+0.5109	0.09	0.510(0.455)	0.85	0.22 – 1.49

S = sex; M = men; W = women; BP = bench press; LP = 45-degree leg press; AC = arm curl; ln = natural logarithm; CI = 95% confidence interval; SEE – standard error of estimate.

Regression diagnoses

The analysis of normal distribution of residuals revealed that residuals did not have a Gaussian distribution only in the bench press test in the group of men. In all other regressions, distribution was normal (Table 2).

The analysis of homoscedasticity showed that all regressions provided good fit, as significant values of the correlation between residuals and lnMS were not found in any of them, which ruled out the possibility of a systematic linear behavior. In addition, visual inspection of the graphs revealed that there was also no systematic nonlinear behavior that might be defined, for example, by a polynomial function (Table 2).

The analysis of the last and main criterion, which evaluated the capacity of allometric scaling to provide force indices independent from BM, revealed that all log-linear regressions were satisfactory models because there was no significant linear correlation between allometrically scaled force and BM (Table 2).

Table 2. Regression diagnoses

Test	Sex	Residual distribution	Homoscedasticity r	Homoscedasticity VIR	Pearson coefficient r (1RMcorr/BM)	Ad. Scl.
BP	M	0.845(p=0.06)	0.132(p=0.70)	RB	0.071(p=0.83)	Adequate
LP	M	0.866(p=0.11)	0.040(p=0.91)	RB	0.010(p=0.98)	Adequate
AC	M	0.894(p=0.16)	-0.001(p=0.99)	RB	0.062(p=0.86)	Adequate
BP	W	0.971(p=0.89)	0.002(p=0.99)	RB	0.040(p=0.91)	Adequate
LP	W	0.932(p=0.43)	0.013(p=0.97)	RB	0.020(p=0.95)	Adequate
AC	W	0.914(p=0.27)	0.017(p=0.96)	RB	-0.024(p=0.94)	Adequate

Ad. Scl. = adequacy of allometric scaling; VIR = visual inspection of residuals; BP = bench press; LP = 45-degree leg press; AC = arm curl; RB = random behavior; M = men; W = women; r = Pearson correlation coefficient; BM = Body mass; 1RMcorr = corrected allometric force

Rank comparison

Statistical analyses failed to detect differences between ranks in each situation although there were visible changes in positions, which raised questions about the sensitivity of the test in this type of comparison. Therefore, visual inspection was performed according to the criterion of change in at least one position to define difference.

Box 2 shows the ranks in the three RT tests, the positions defined according to absolute force and the force allometrically adjusted to a specific exponent, to a theoretical exponent (0.67) and to the ratio standard. The last two columns of each table show the changes in each position: the first shows the difference found between the specific exponent and the theoretical exponent; and the second, the different between the specific exponent and the ratio standard. These differences were expressed as absolute values; values equal to zero indicate no change in positions; positive and negative values indicate the number of ascending and descending positions in comparison with the reference rank (specific allometric exponent).

Box 2. Rank differences of force corrected according to specific exponent, theoretical exponent (0.67) and ratio standard in each test

Bench press, men						Bench press, women				
R1 AbF	R2 0.73	R3 0.67	R4 1(ratio)	DifA	DifB	R2 1.22	R3 0.67	R4 1(ratio)	DifA	DifB
1º	1º	1º	1º	0	0	2º	1º	2º	1	0
2º	2º	2º	3º	0	-1	3º	3º	3º	0	0
3º	5º	5º	5º	0	0	1º	2º	1º	-1	0
4º	3º	3º	2º	0	1	4º	4º	4º	0	0
5º	4º	4º	4º	0	0	5º	5º	5º	0	0
6º	8º	8º	9º	0	-1	6º	6º	6º	0	0
7º	7º	7º	7º	0	0	7º	7º	7º	0	0
8º	9º	9º	8º	0	1	8º	8º	8º	0	0
9º	6º	6º	6º	0	0	10º	9º	10º	1	0
10º	10º	10º	10º	0	0	11º	11º	11º	0	0
11º	11º	11º	11º	0	0	9º	10º	9º	-1	0
45-degree leg press, men						45 -degree leg press, women				
R1 AbF	R2 0.35	R3 0.67	R4 1(ratio)	DifA	DifB	R2 1.02	R3 0.67	R4 1(ratio)	DifA	DifB

1º	1º	1º	1º	0	0	3º	4º	3º	-1	0
2º	2º	4º	4º	-2	-2	4º	5º	4º	-1	0
3º	4º	3º	3º	1	1	2º	2º	2º	0	0
4º	3º	2º	2º	1	1	1º	1º	1º	0	0
5º	7º	9º	9º	-2	-2	6º	9º	6º	-3	0
6º	8º	7º	8º	1	0	8º	10º	8º	-2	0
7º	6º	6º	6º	0	0	9º	8º	9º	1	0
8º	5º	5º	5º	0	0	5º	3º	5º	2	0
9º	9º	8º	7º	1	2	11º	11º	11º	0	0
10º	-	-	-	-	-	10º	7º	10º	3	0
11º	-	-	-	-	-	7º	6º	7º	1	0
Arm curl, men						Arm curl, women				
R1 AbF	R2 0.71	R3 0.67	R4 1(ratio)	DifA	DifB	R2 0.85	R3 0.67	R4 1(ratio)	DifA	DifB
1º	2º	2º	3º	0	-1	2º	2º	3º	0	-1
2º	1º	1º	1º	0	0	3º	3º	4º	0	-1
3º	4º	4º	5º	0	-1	1º	1º	1º	0	0
4º	3º	3º	2º	0	1	5º	5º	5º	0	0
5º	5º	5º	6º	0	-1	7º	7º	8º	0	-1
6º	7º	7º	8º	0	-1	10º	9º	11º	1	-1
7º	6º	6º	4º	0	2	4º	4º	2º	0	2
8º	8º	8º	7º	0	1	6º	6º	6º	0	0
9º	9º	9º	9º	0	0	9º	8º	9º	1	0
10º	11º	11º	11º	0	0	8º	10º	7º	-2	1
11º	10º	10º	10º	0	0	11º	11º	10º	0	1

R1 AbF = absolute force rank; R2 = specific exponent rank; R3 = theoretical exponent rank; R4 = ratio standard rank; DifA = difference of positions (R2 – R3); DifB = difference of positions (R2 – R4)

DISCUSSION

This study used different BM adjustment methods to compare ranks according to performance in 1RM tests of individuals that practiced resistance training.

The theoretical allometric exponent (0.67), based on geometrical similarity, was included because it has been recommended for the general use in allometric scaling of force, particularly when it is not possible to derive a specific exponent[4,5,21,28]. The use of another common exponent for all the exercises was not feasible because most studies in the literature suggested different exponents, which made it difficult to choose one that might be a safe reference.

The ratio standard, included here despite the indisputable theoretical basis that confirms its inadequacy, provided a way to examine whether the exponents found in our study, particularly those close to 1, may lead, in practice, to any significant differences in ranks from the results obtained when the exponent is equal to 1.

As expected, the analysis of the differences in ranking generated by specific exponents and the ratio standard, shown in Table 3, did not reveal any evidence of differences in tests from which exponents greater than 1 were derived (BP and LP in the group of women). In addition, a difference of 0.15 points between the specific exponent of AC in the group of women and the ratio standard (1 – 0.85) ranked individuals differently.

Therefore, in the sample under study, there seemed to be a range of values for which the differences in exponents did not indicate different ranks (below 0.07 points) and a range in which ranks may be essentially different (above 0.14 points). This may be associated with the variation coefficient of the force values in the sample in each situation, in which the differences between individuals may be large enough to make the minimum exponent differences prevent differences in rankings. The existence of ranges that are sensitive to differences may raise questions about the validity of calculating means as a technique to estimate common exponents, as reported by Folland et al.[13] in their study about allometric scaling of isometric force and torque.

It is important to note that, although not the focus of this study, no method generated adjusted force rankings equal to the ranking defined by absolute force (Table 4), which supports the idea that performance in absolute values should be seen cautiously in the comparison of groups.

Vanderburgh et al.[29] compared the strength of men and women using traditional analysis of covariance and also found differences in the result of specific exponent and ratio standard scaling. After the calculation of mean values of corrected forces according to both methods, they concluded that the use of the ratio standard overestimates female force when compared with the specific allometric exponent and results in theoretically less acceptable differences.

Markovic and Jaric[28] used a single sample *t* test to investigate the differences between the 0.67 exponent and the exponents that they found in six types of dynamic tests, such as BP, squats and arm curls. They concluded that the theoretical exponent may be used to normalize force in all exercises because there is no statistical significance in the *t* test results ($p>0.05$). However, this result was presumed even though an exponent of 0.27 was found for the handgrip strength, which may raise questions about test sensitivity and the validity of this type of method.

Markovic and Sekulic[30] compared allometric modeling in groups of powerlifters and weightlifters to investigate whether the exponents that they found in each modality, for men and women, did not have any significant differences from the 0.67 exponent. They examined exponents within the confidence interval defined (95% CI) at the time when the log-linear regressions were built. Therefore, when the 0.67 exponent was within that CI, it was not classified as different from the specific exponents derived in their study.

In our study, the method adopted by Markovic and Seculic[30] could not be used because the low values of the coefficient of determination (R^2) of the log-linear regressions generated very large CI, which included negative and positive exponents (Table 2).

Visual examination of rankings has not been used for analyses in any other studies, and, therefore, comparisons with our study findings were not possible. However, this type of analysis precludes tests of statistical probability and may be easily replicated in future studies. Therefore, its merits may be assed by the interpretation of results alone. In addition, it raises questions about the validity of the indiscriminate use of the 0.67 exponent to adjust MS to BM, as suggested by several authors[4,5,21,28].

Although such detailed comparisons of force seem to be more important in weightlifting competitions, in which changes of one single position may result in prizes, the study of non-athlete rankings according to different exponents may help to build a more accurate model of allometric scaling for the prescription of RT to improve health. Rank comparisons may, in practice, fine-tune the definition of how much the absolute differences of exponents may be reflected in the discrimination of groups according to force (ranges sensitive to difference), which may lead to the adoption of a standard number selected from a restricted set of exponents.

One of the main limitations of this study was its small sample size, which, however, does not seem to have affected results, as it was possible to compare methods and detect differences between them. In addition, the purpose of this study was not to extrapolate results; rather, it aimed at contributing to the discussion about the need to use adequate strategies to adjust muscle strength to body mass.

CONCLUSION

The analysis of the difference between ranks defined by specific exponents, the theoretical exponent (0.670) and ratio standard revealed that, in most situations, there were non-corresponding changes in positions. The three methods often discriminated individuals in relation to 1RM force differently. In addition, no adjusted force ranking was equal to the ranking by absolute force values (1RM).

Results suggest that there is a range of values within which differences between exponents do not reflect different ranks (below 0.07 points) and a range within which rankings may be essentially different (above 0.14 points). This may be important in the long term selection of allometric exponents that are universally accepted, considering the variation of values found in different studies. Exponent standardization may lead to the use of allometry as an additional tool in prescribing and controlling resistance exercises.

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