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Scaling of Maximal Strength Scores in Physically Active College Females

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Abstract **Background**: When an exercise scientist assesses an individual's muscular strength, the measurement and evaluation should not be impacted by the participant's body weight (BW). The purpose of this study was to compare the effectiveness of different scaling techniques in normalizing maximal strength scores for BW in college-aged females. **Methods**: Complete data for 37 traditional aged (18 to 24 years) females were used. Maximal strength tests included grip strength (GS), 1RM bench press (BP), 1RM leg press (LP), and vertical jump (VJ). Anthropometric measures of height, BW, BMI, and WC were also objectively measured. Two scaling techniques were used with the following calculation: MS/BW^b. Ratio scaling was simply the strength score (MS) divided by BW (i.e., b = 1.0). Allometric scaling used the fit BW coefficient (b) from log-log regression models. Pearson correlation coefficients determined the extent of influence of BW on unscaled and scaled strength scores. ANOVA determined the extent of influence of BW on group means of allometric-scaled strength scores. **Results**: Mean age of the sample was 20.7 ± 1.6 yr with mean BMI, GS, BP, LP, and VJ of 23.8 ± 3.1 kg/m^2, 34.3 ± 7.8 kg, 97.4 ± 23.5 lb, 316.5 ± 105.0 lb, and 15.7 ± 3.5 in, respectively. BW was significantly related to GS, BP, and LP but not VJ. Ratio scaling removed the influence of BW from all strength scores less VJ. Allometric scaling adequately removed the influence of BW from all strength scores. ANOVA models for each of the strength tests showed that allometric scaling for BW also removed its influence from group means. **Conclusion**: These results indicate that ratio scaling for BW was a sufficient technique for removing BW effects from low-speed strength tests in college-aged females. However, allometric scaling for BW adequately removed the influence of BW from all maximal strength scores in this population.

Keywords: *Allometry, Scaling, measurement, evaluation, muscular strength*

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1. Introduction

Many maximal strength tests can be weight-biased in that heavier individuals often outperform their lighter counterparts [1]. The influence of body weight (BW) on strength performance is problematic because it is muscular strength fitness that ought to be the discriminating trait among groups of individuals and not a measure of body size. *Scaling* is a technique applied in measurement and evaluation to control for body measures like BW [2]. Several different scaling techniques exist with two common one being ratio scaling and allometric scaling. *Ratio scaling* is a relative strength measure that simply divides the participant's strength score by the participant's BW [3]. *Allometric scaling* is a more sophisticated technique that attempts to first model the strength score and BW relationship and then adjust the strength score with a more fine-tuned BW value [4].

Several studies have applied different scaling techniques to strength scores in specialized populations [5,6]. However, data showing the need to scale various maximal strength tests for BW in traditional college-aged females is sparse. Additionally, no studies to date have compared the efficacy of different scaling techniques in this population. The aim of this study was to compare the effectiveness of different scaling techniques in normalizing maximal strength scores for BW in traditional college-aged females.

2. Methods

Study design

The study design and procedures have been reported elsewhere [7,8,9]. Briefly, this was a secondary analysis of a larger campus-based fitness assessment. Traditional college-aged (18 to 24 years) females were included in the current study if they had complete muscular strength and anthropometric data and were generally physically active.

Scaling

Scaling procedures for this study have been reported elsewhere [7]. Briefly, two different scaling techniques were performed using the following general calculation: MS/BW^b, where MS is the maximum strength score and *b* the scaling exponent for BW. An exponent of 1.0 was used for ratio scaling (MS_{RS}). The exponent for allometric scaling (MS_{AS}) came from the fit BW coefficient from log-log regression models.

Maximal strength performance

Strength test procedures in this study have been reported elsewhere [7]. Briefly, four maximal strength tests were used to cover the entire strength trait. Hand grip strength (GS, kg) was assessed using a hand grip dynamometer (Camry, Model: EH101) [10]. The 1RM bench press (BP, lb) was assessed by the heaviest load successfully lifted [11]. The 1RM leg press (LP, lb) was assessed by the heaviest load successfully pushed on a seated leg press [11]. Finally, vertical jump (VJ, in) was assessed as the difference between standing and jumped chalked finger marks on a wall [12]. VJ was included as a measure of high-speed explosive strength in this study.

Body measures

Anthropometric measures for this study have been reported elsewhere [7]. Briefly, all anthropometric measurements were taken twice in rotational order and then averaged, unless large differences noted. Height (cm) was assessed using a wall mounted stadiometer (Seca, Model: 216). BW (kg) was assessed with a digital floor scale (Seca, Model: 803). BMI (kg/m^2) was computed as a calculation of weight divided by height in meters (m) squared (m^2) [13]. Waist circumference (WC, cm) was assessed using an elastic tape between the participant's umbilicus and xiphoid process [14].

Statistical analyses

Table 1 was created by computing descriptive statistics on all relevant study variables. Although not presented, histograms were inspected for normality and Z-scores computed to identify outliers. Table 2 was created by performing linear regression on log transformed variables (i.e., log-log regression). All models included the log-transformed strength scores as the dependent variable and log-transformed BW as the predictor. The BW coefficient from the regression models supplied the exponents for allometric scaling.

Table 1. Descriptive statistics for the study sample

Variable	*Mean*	*Median*	*SD*	*Min*	*Max*
Age (yr)	20.7	20.0	1.6	18.0	24.0
Height (cm)	168.8	168.0	8.0	157.0	189.0
BW (kg)	67.6	67.3	8.3	51.8	89.0
BMI (kg/m^2)	23.8	23.0	3.1	18.8	30.5
WC (cm)	73.3	71.5	6.5	60.0	93.0
GS (kg)	34.3	33.0	7.8	21.5	57.8
BP (lb)	97.4	95.0	23.5	45.0	155.0
LP (lb)	316.5	320.0	105.0	70.0	585.0
VJ (in)	15.7	16.0	3.5	8.0	23.5

Note. N = 37. BW is body weight. BMI is body mass index. WC is waist circumference. VJ is vertical jump. GS is grip strength. BP is bench press. LP is leg press. All variables had approximate bell-shaped distributions with slight right skewness of WC and GS.

Table 2. Power function exponents for allometric-scaled maximum strength scores using body weight

Variable	ln VJ	ln GS	ln BP	ln LP
b	-0.31435	0.71508	0.97215	1.47116
SE	0.3332	0.2779	0.3181	0.4763

Note. N = 37. b is BW exponent of the power (allometric) function. ln VJ is the natural log of vertical jump. ln GS is the natural log of grip strength. ln BP is the natural log of bench press. ln LP is the natural log of leg press.

Table 3 was created by computing Pearson correlation coefficients (*r*) on all pairs of BW and unscaled and scaled strength scores. A critical value of *r* was obtained where $|r| > r_{cv}$ of .325 was considered significant at a two-tailed α of .05 with $df = 35$. Table 4 was created by employing an analysis of variance (ANOVA) procedure for each strength test. Strength scores were first converted to T-scores (i.e., *Mean* = 50, *SD* = 10) to aid interpretation. Additionally, BW quartile groups were created where the 1^{st} BW quartile contained the lightest females and the 4^{th} BW quartile contained the heaviest females. SAS version 9.4 was used for all analyses with *p*-values reported as two-sided and significance set at $p < 0.05$.

Table 3. Pearson correlations for BW and scaled and unscaled strength scores

	BW Scaling Methods		
Variable	Unscaled	Ratio	Allometric
VJ	-.092	**-.556**	.074
GS	**.359**	-.146	.008
BP	**.416**	-.051	-.037
LP	**.453**	.114	-.066

Note. N = 37. Values of $|r| > r_{cv}$ of .325 are significant, p < .05 (bold). VJ is vertical jump. GS is grip strength. BP is bench press. LP is leg press.

3. Results

Table 1 contains descriptive statistics for the sample. Mean age of the participants was 20.7 ± 1.6 yr with mean BMI, GS, BP, LP, and VJ of 23.8 ± 3.1 kg/m2, 34.3 ± 7.8 kg, 97.4 ± 23.5 lb, 316.5 ± 105.0 lb, and 15.7 ± 3.5 in, respectively. All variables had approximate bell-shaped distributions with slight right skewness of WC and GS. Two different participants had a sample Z-score generally considered an outlier (i.e., |Z| > 3.00). One female had a large WC (93.0 cm, Z = 3.05). Another female had a high GS (57.8 kg, Z = 3.01). Both extreme values were checked and deemed accurately measured. Furthermore, neither histogram was excessively skewed. Therefore, both scores remained in the study.

Table 2 displays the results of the regression models on log-transformed variables. These coefficients can be interpreted as a percentage change in the strength score variable. That is, a 1% increase in BW is associated with a 0.72% increase in GS. Thus, coefficients close to 1.0 satisfy the proportional property requirement for ratio scaling. Conversely, values close to 0.0 indicate that scaling for BW is not necessary.

Table 3 contains the Pearson correlations for BW and raw unscaled, ratio-scaled, and allometric-scaled maximum strength scores. BW was significantly correlated with unscaled GS (*r* = .359), BP (*r* = .416), and LP (*r* = .453) but not VJ (*r* = -.092). Interestingly, the significance between BW and the unscaled strength scores were transposed for the ratio-scaled scores. Specifically, BW was not significantly correlated with ratio-scaled GS (*r* = -.146), BP (*r* = -.051), and LP (*r* = .114) but was correlated with VJ (*r* = -.556). Finally, no significant correlations were noted between BW and the allometric-scaled strength scores.

Table 4 contains the group mean comparisons of allometric-scaled maximum strength T-scores across BW quartiles. No significant differences were observed for VJ_T, GS_T, BP_T, or LP_T across the BW groups. Additionally, no significant linear trends were noted across the quartiles for the allometric-scaled strength scores.

Table 4. Comparison of allometric-scaled maximum strength T-scores across body weight tertiles

	1st BW Quartile		2nd BW Quartile		3rd BW Quartile		4th BW Quartile		ANOVA	
Variable	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	p^a	p^b
VJ_T	47.2	7.4	50.5	6.5	52.8	9.1	49.2	15.5	.690	.585
GS_T	47.1	7.4	51.6	5.1	50.5	11.6	50.7	14.3	.807	.530
BP_T	48.7	11.4	49.8	10.5	55.6	7.6	45.3	8.9	.151	.761
LP_T	49.5	10.4	48.6	8.6	52.9	11.5	48.7	10.2	.773	.904

Note. N = 37. The 1st BW quartile contains the lightest males and the 4th BW quartile contains the heaviest males. [a]One-way ANOVA testing for differences in group means. [b]Linear trend test. VJ_T is allometric-scaled vertical jump scores converted to T-scores. GS_T is allometric-scaled grip strength scores converted to T-scores. BP_T is allometric-scaled bench press scores converted to T-scores. LP_T is allometric-scaled leg press scores converted to T-scores.

4. Discussion

The purpose of this study was to compare the effectiveness of different scaling techniques in normalizing maximal strength scores for BW in college-aged females. The findings compel four noteworthy discussion points. First, it was found that the low-speed strength tests were correlated with BW but the high-speed strength test was not. The lack of association between BW and VJ was not found in the literature. In fact, findings from traditional college-aged males indicated a significant negative correlation between these variables [7]. Thus, this finding is important and should be investigated further. Second, it was found that ratio-scaling removed the influence of BW from the low-speed strength tests yet created bias in the high-speed test. That is, ratio scaling completely transposed the unscaled associations between BW and strength tests. This finding highlights the fact that the high-speed strength test did not require scaling – but also identifies the fact that ratio scaling may adequately remove the BW influence from low-speed strength tests.

Third, it was found that allometric scaling removed the BW influence from all four strength tests. This was observed regardless of the need to scale for BW. Therefore, it could be suggested that allometric scaling is the better approach to scaling strength scores overall. Fourth, and finally, it was found that allometric scaling adequately removed the influence of BW from strength test score means across different BW groups. This finding is important in human performance evaluation where comparisons of groups are often made.

A major strength regarding this study is its use of four different maximal strength tests. Multiple tests on a single trait have the advantage over single tests in that multiple tests have greater reliability and are more likely to target the full range of the trait [15]. In the current study, this was seen as an advantage where ratio scaling was found to be an adequate scaling technique in low-speed strength tests but not high-speed. Without the inclusion of four different strength tests, this finding might not have otherwise been found. Another strength regarding this study is its use of a specifically defined population of traditional college-aged females. Homogenous samples allow for more specific findings and inferences. For example, the current study population consisted of younger, generally healthy, and physically active college students. Thus, the current findings likely differ substantially from what may have been observed in the general population.

The most important limitation in this study is its use of non-lab-based maximal strength tests. Although field-based strength tests can lack certain control and standardization, the strength tests used in this study are the ones more likely to be administered to this population. A final limitation of this study is the use of BW over lean mass to adjust for size differentials in maximal strength. BW though is a commonly assessed measure and has a strong association with percent body fat.

5. Conclusions

Results from this study showed that ratio scaling for BW was a sufficient technique for low-speed strength tests in traditional college-aged females. However, allometric scaling for BW adequately removed the influence of BW from all maximal strength scores in this population. Furthermore, allometric scaling adequately removed the influence of BW from strength test means across groups of varying body size in this population.

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