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Research Article

A Comparison of Absolute, Ratio and Allometric Scaling Methods for Normalizing Strength in Elite American Football Players

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Abstract

Division I football players exemplify the greatest range in body mass of any modern team sport. Body mass may differ by over 80 kg between the various positions. Absolute muscular strength is typically greater in larger individuals, but such data does not allow for accurate comparisons. Therefore, in order to compare the performance indices of individual groups allometric rather than ratio scaling has been suggested. The purpose of this study was to compare absolute strength, normalized ratio and allometrically scaled data among players of different size. Following IRB approval, data were accessed on NCAA Division I football players over a six-year period at a mid-western university. Of the 606 cases accessed, the following characteristics were recorded: mean ± SD: age=20.1 ± 1.3, mass=107.38 ± 20.30 kg, height=186.76 ± 8.6 cm. With the exception of kickers, participants consisted of all offensive and defensive football players. Players were categorized into seven weight and seven height groups. Data on 1RM bench press and squat were recorded as absolute and subsequently ratio and allometrically scaled. Based on recommendations, the bench press and squat were scaled allometrically using m2/3 and m-1/3 for the bench press and squat respectively. Results of repeated measures ANOVAs yielded significant ($p<0.05$) and a near linear pattern of absolute strength by body mass, a significantly greater strength ratio for lighter mass than heavier mass, and no significant difference among the groups following allometric scaling. Results suggest that it may be possible to determine if an athlete falls within an acceptable range of the established standards derived from allometric scaling. Also, if an athlete falls outside by, say one standard deviation, he may demonstrate below acceptable performance and/or be more injury susceptible which should initiate a need for additional work.

Keywords

Athletes; Bench press; Normalization; Muscle

Introduction

Football at the NCAA Division I level requires extraordinary physical prowess inclusive of muscular strength, speed, and power. Theoretically, those teams possessing athletes with superior strength

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speed, and power may ultimately experience more success [1] in competition. Without exception, teams have constructed large training facilities with a substantial area devoted to strength training. Additionally, these facilities are staffed with specialists in the strength and conditioning field and contain an array of sophisticated resistance training equipment. Resistance and power training involves year-round training with maintenance work-outs during the season and with emphasis in building strength and power in the off-season.

In order to determine the degree of success achieved, athletes strength is assessed systematically, usually after summer conditioning (pre-season), after the season (post-season), and immediately prior to Spring Training (off-season). While clinical strength tests are usually focused on force or torque attributed to a single muscle group [2], strength testing in athletics are normally more oriented toward the field test model due to the numbers of athletes that need to be tested and the overall functional assessment of strength. Hence, testing involves the use of free weights rather than more sensitive, computerized equipment seen in rehabilitation. These physical assessments provide normative values for various positions and can be used to evaluate the year-to-year merits of the conditioning program as well as to provide information regarding post-injury progress.

Test for maximum upper and lower body strength typically include the 1RM bench press and the 1RM squat. These assessments provide raw, absolute values comparing progress in muscular strength. These tests utilize absolute measures of strength which involve the maximum force an athlete can exert irrespective of body size or muscle size. Assessing muscular strength has been done for decades, but absolute strength may be confounded by several variables that make it impractical to compare strength between gender, maturity level, history of resistance training, and body size. Experience suggests that those with greater body mass are stronger than those with less mass and that as the individuals' size increases, the strength of the relationship between strength and body size increases.

Hortobágyi et al. [3] contend that there are conflicting results in prior studies concerning the relationships among body size, muscle size, and muscular strength presumably due to factors such as body composition and segmental dimensions which may serve to confound these data. According to Jaric [4] the minimal relationship between the tested muscle strength and body size may be because of the relatively narrow range of human body sizes. The theory of "geometric similarity" assumes that all human bodies have the same shape, but differ in size [5-7]. However, some sports reflect a tremendous range in body size. In college and professional American football sizes frequently range from 75 kg to as much as 155 kg. Therefore, in order to compare performance, adjusted means by which to better compare results have been introduced. Adjusting the data beyond simply determining the quotient of the performance variable by the participant's body size was introduced by Atkins [8] to better indicate the absolute expression of physical performance when comparing individuals with large differences in size. Originally, normalization of strength or other physical variables was simply performed by dividing the performance output by body weight called "*ratio scaling*" [9-11] or "*isometric scaling*" [6]. This method has been

criticized [2,8,12] because it presumes a linear relationship between size and strength and may penalize heavier individuals in selected physical assessments [8]. An alternate method of adjusting for body size in the attempt to normalize data is the use of allometric scaling. Allometry is the relationship between size and physiology and is calculated by implying that two individuals of different size with common dimensions will have similar ratio values [5-7]. It has been recommended that allometric scaling be based on the presumption of human geometric similarity [6] in order to compare the performance indices of individual groups or certain populations [2].

A wide range of scaling exponents has been employed to normalize performance data, but normalization of tested muscle strength has been inconsistent [4]. These methods most often incorporate body mass in the equation in conjunction with certain constants [12,13]. Allometric scaling is the most accepted approach to normalization of data through the removal of the direct influence of body size. Allometry provides a more effective method for standardizing performance controlling for body dimensions [14] than ratio scaling. Based on the theory posited by Jaric and associates [2], muscle force is proportional to the muscle cross-sectional area and thereby increases with body size in a manner that is proportional to $m^{2/3}$. Hence, the allometric scaling presumes that area-based properties change proportionally to mass to the 2/3 power ($m^{2/3}$) or body height squared (H^2) and all length-based properties change with mass to power of 1/3 ($ht^{1/3}$) [2,6,7,15]. Consequently, this method has been used in several recent studies with overall acceptance [2,8,16] because it provides a means by which to evaluate performance while controlling for body mass [2,8,17,18].

For performance consisting of supporting body weight such as the squat or chin-ups, studies have demonstrated that while lighter subjects generate less external force than heavier subjects, lighter subjects fare better when involved in an activity that require them to overcome their body mass [19-21]. Aasa et al. [18] and Markovic and Jaric [22] have concluded that the association between body weight supporting performance and body size is negative and the allometric equation is closer to the predicted -0.33 or $m^{-1/3}$. The purpose of this study was to compare absolute, ratio, and allometrically scaled strength data in NCAA Division I football players based in ordinal scaled weights and heights.

Methods

Subjects

Subjects included NCAA Division I football players who competed between 2006 and 2011 at mid-western university. The University Institutional Review Board and Athletic Department sanctioned the project by allowing the researchers access to pre-collected data relative to anthropometric and performance variables. Of the 606 cases accessed, the following characteristics were recorded: mean ± SD: age=20.1 ± 1.3, mass=107.38 ± 20.30 kg, height=186.76 ± 8.6 cm and included in the analysis. With the exception of kickers, participants consisted of all offensive and defensive football players.

Procedure

Data collected over a six-year period yielded a total of 658 cases, but due to injury, drop-outs, and other confounding variables that would otherwise interfere with accurate assessment of strength, 582 individual cases were accessed and analyzed. Tests for maximum upper and lower body strength included the 1RM bench press and the

1RM squat. The data utilized in the current study were those collected at pre-season testing in the month of August, thus theoretically yielding peak seasonal performance.

Prior to all testing, players were required to undergo a 5 minute supervised warm up session consisting of stretching, slow agility exercises, and submaximal lifting. For the bench press 1RM trial, required technique constituted that the bar was to be lowered until it touched the mid chest and then, without a bounce, raised to full extension of the elbows. A spotter was allowed to help in un-racking and racking the bar before and after each trial. Only fully completed repetitions were counted resulting in only whole numbers. The 1RM squat test utilized a squat rack equipped with a bar and weights. Technique required that the lifter lower himself until the thighs were horizontal or parallel to the ground then in a counter movement, raised to a standing position with knees fully locked. A supervisor alerted the athlete when his thighs were horizontal and a spotter was used to help un-rack and rack the bar. Olympic style barbells and weights were used for all testing.

Data collected consisted of height, weight, 1RM bench press and 1RM squat. The original data was converted from pounds to kilograms, from inches to centimeters, and subsequently entered onto a spread sheet. Similarly to Bale et al. [23], players' weights were categorized by ordinal scale into seven 10 kg increments: (75-85 kg. n=90, 85.1-95 kg. n=116, 95.1-105 kg. n=110, 105.1-115 kg. n=77, 115.1-125 kg. n=65, 125.1-135 kg. n=96, 135.1-145 kg. n=28).

Once the data had been entered onto a spread sheet, analysis consisted of calculating and comparing the aforementioned variables through absolute strength, ratio scaling and allometric scaling. Ratio scale calculations consisted of determining the resultant quotient of the performance variable and body weight. Allometric scaling consisted of two methods: a) the resultant quotient of the performance variable and the body mass to the 2/3rd power ($m^{2/3}$) for the bench press and b) the resultant quotient of the performance variable and body mass to the negative -1/3rd power ($m^{-1/3}$) for the squat [2]. Data were analyzed by repeated measures ANOVA using SPSS 18. Newman-Keuls post hoc tests were utilized when the ANOVA F values reached significance at P<0.05.

Results

Absolute 1RM strength for the bench press followed a near linear pattern with the players possessing the greater body mass demonstrating greater bench press strength (Figure 1). Correlations between body mass and 1 RMs in the bench press and squat were significant (r=0.69-0.72) in that heavier players were associated with greater strength. The largest strength differences occurred between the first and second weight groups (11.9%), between the fourth and fifth weight groups (9.7%), and between the sixth and seventh weight groups (8.9%). The average increase in absolute strength by weight category was 5.5 kg. The absolute strength difference between the lightest players (75-85 kg) and the heaviest players (136-145 kg) was 53.2 kg or 43%. When a ratio scale (strength relative to body mass) was calculated the pattern looked markedly different with the ratio decreasing as body mass increased. The three lightest weight groups (75 kg through 105 kg) demonstrated significantly (p<0.05) greater ratio scaled strength than the remaining four weights groups (106 kg through 145 kg) (Figure 2). Following allometric scaling (performance/$m^{2/3}$) of the bench press, the results became much more

uniform among the weight groups and there were no statistically significant differences among the groups (p=0.25-0.95) (Figure 3).

For the squat the absolute 1RM strength followed a similar linear pattern that of the bench press in those players with the greatest body mass produced the greatest squat strength. In general, significant differences tended to exist between alternate weight groups, but not with the adjacent weight groups (Figure 4). The average increase in squat strength between weight categories was 6.7 % with the largest difference occurring between group 6 and 7 (7.7%). The difference between the absolute strength of the lightest group compared to the heaviest group was 64.6 kg or 68.2%. Ratio scaling resulted in a linear-like decrease from the lightest players to the heaviest players (Figure 5) which appears to flow in the opposite direction when compared to absolute strength. The first three lightest weight categories were significantly different from the last three heaviest categories. Also, there was no significant difference in relative strength between the last four categories. For the allometrically scaled squat strength, the weight groups were strikingly similar with no significant difference among any of the groups (Figure 6).

Discussion

The findings of the present study demonstrated that heavier players were significantly stronger than lighter players on an absolute scale and that normalizing 1RM strength using ratio scaling resulted in higher relative strength for the lighter players compared to heavier
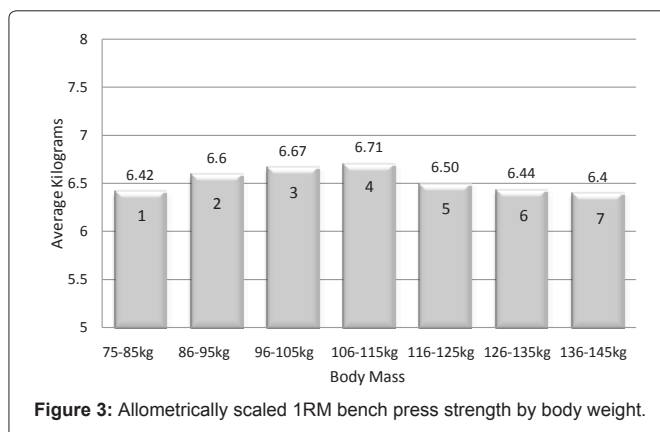

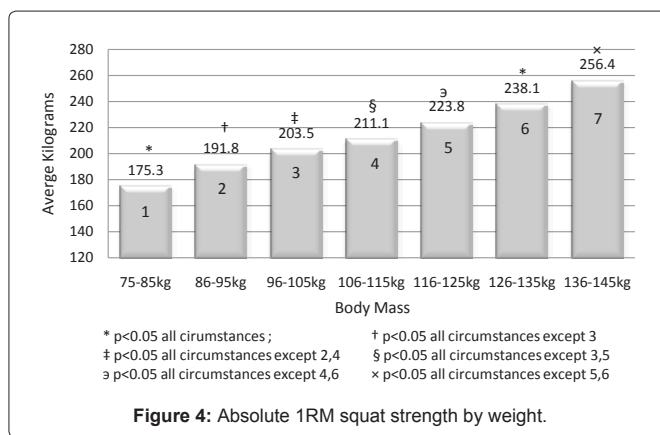**Figure 3:** Allometrically scaled 1RM bench press strength by body weight.

* p<0.05 all cirumstances ;   † p<0.05 all circumstances except 3
‡ p<0.05 all circumstances except 2,4   § p<0.05 all circumstances except 3,5
Ə p<0.05 all circumstances except 4,6   × p<0.05 all circumstances except 5,6
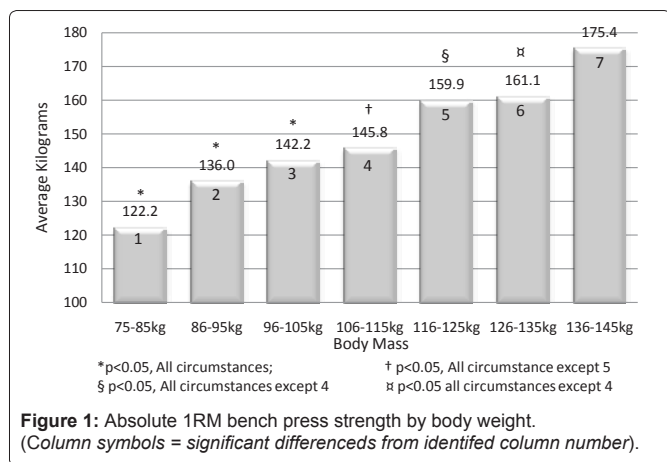
Figure 4: Absolute 1RM squat strength by weight.

Figure 1: Absolute 1RM bench press strength by body weight.
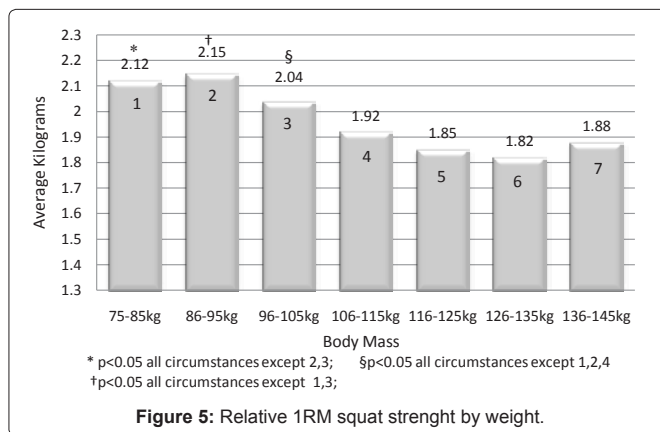(*Column symbols = significant differenceds from identifed column number*).

* p<0.05 all circumstances except 2,3;   §p<0.05 all circumstances except 1,2,4
†p<0.05 all circumstances except 1,3;

Figure 5: Relative 1RM squat strenght by weight.

*p<0.05 All circumstances except 2,3;   †p<0.05 All circumstances except 1,3
§p<0.05 All circumstances except 1,2,4;   ‡p<0.05 All circumstances except 3
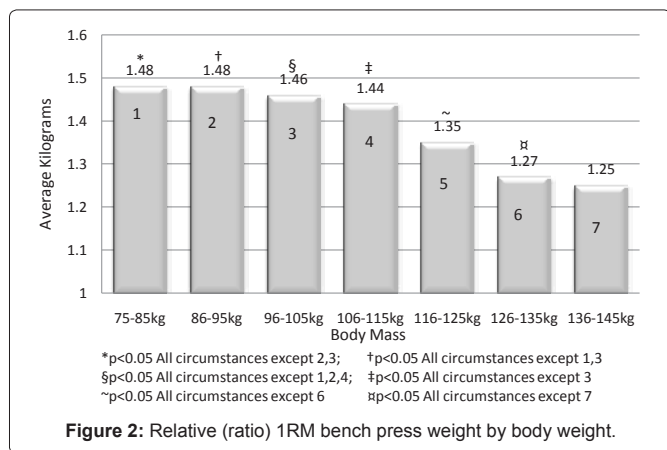~p<0.05 All circumstances except 6   ¤p<0.05 All circumstances except 7

Figure 2: Relative (ratio) 1RM bench press weight by body weight.

players for both the bench press and squat assessment. However, when allometric scaling normalization procedures were utilized, there were no differences observed between any of the body weight groups, indicating unbiased removal of the influence of body mass for bench press and squat 1RM.

Although previous studies have typically evaluated body mass differences and scaling procedures using dichotomously divided groups (i.e. heavy *vs.* light), the present study aimed to evaluate smaller subsets of ordinal categorized groups to further elucidate the body mass and scaling associations across a wide spectrum of body size differences often observed in collegiate football players.
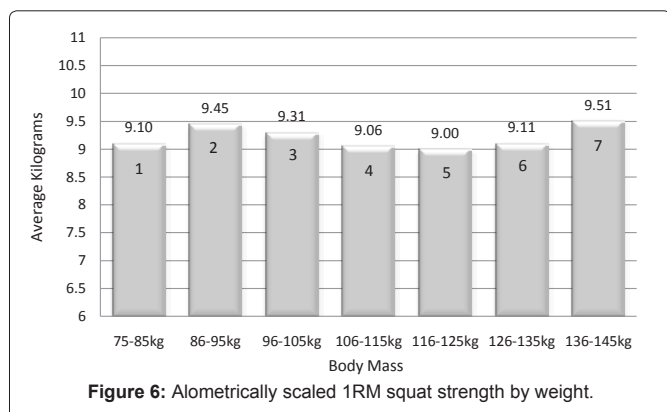
Figure 6: Alometrically scaled 1RM squat strength by weight.

While large absolute strength differences were observed between extreme body mass variation (lightest *vs.* heaviest), these significant differences were also revealed between adjacent body mass groups in 10 kg increments. For example, a significant absolute strength difference was observed between groups 1, 2, 3 and 4 for the bench press, even though they were separated by only 10 kg in body mass. These findings thus demonstrate the sensitivity of strength based performance to both large and small body mass variations. The significant relationship between body mass and dynamic upper and lower body strength in elite athletes with large body mass variations provides further support for the need to utilize effective normalization procedures to remove the influence of body mass on strength based performance variables. Normalization of data allows calculation of performance tests independent of body size and the assessment of the relationship between the results of two assessments without the confounding variable of body size. It has been suggested that one of the chief benefits of accurate normalization is that such calculations facilitate "profiling" of specific groups of varied physical stature and abilities, such as children, elderly, patients, etc. [2]. Once profiled, data may be used as standards to assess relative performance variables of selected populations. Most previous reporting of physical performance, particularly strength, has been confounded by body size [2]. The primary problems in most previous reports of strength exist in the neglect to consider body size or the lack of utilizing a consistent standardization of methodology.

Ratio scaling procedures are typically used in an attempt to remove the influence of body mass on performance measures. This method of normalization has been criticized because of its bias towards lighter individuals on strength and power based performances [2,8,12]. Previous authors have reported that ratio scaling procedures have indeed favored lighter players which results in penalizing those with greater body mass [8,16,17]. The present findings provide further support for these biases and concerns as ratio scaling in the current study resulted in the lighter players being significantly stronger in relative strength when compared to the heavier weight groups for both the bench press and squat movements. This would suggest that ratio scaling may not provide a completely accurate representation of relative muscle strength when evaluating populations with body mass differences even as low as 10 kg.

In order to enable effective comparisons of performance one group of researchers [2] suggested that using an allometric normalization method could allow for a better means by which to measure and compare current performance variables and the progress of training

or rehabilitation. Previous authors have demonstrated that allometric scaling is potentially a more effective method compared to ratio scaling for removing the influence of body size when comparing athletes with large body mass variations [16,17]. The present findings are in agreement with previous studies as the allometric scaling method effectively removed the influence of body mass for all groups for both the bench press and squat 1RM. The removal of the influence of body mass using allometric scaling was found to be the only method of strength reporting that did not favor either heavy or lighter players. Thus it appears that the effects of allometrically scaling upper and lower body strength using previously suggested exponents (bench press=$m^{2/3}$; squat=$m^{-1/3}$) is a more effective method compared to absolute or ratio scaled strength values when practitioners aim to provide unbiased evaluations of either upper or lower body strength across players of varying body mass. Further, these findings add novel insight into the amount of body mass variation necessary to influence scaling bias as ratio scaling procedures favored lighter players that were in adjacent groups (i.e. 10 kg variation in body mass), while the allometric method effectively removed both large group body mass variations (lightest *vs.* heaviest) as well as the differences between groups with smaller variations in body mass.

The distinct and broad range in body size apparent in American football lends itself to the need for normalization of performance to better compare strength and power parameters based on established norms. Players range from around 72 kg to over 145 kg, thus providing the justification for "profiling" performance. With such information it is possible to determine whether a player is within his normative values, is progressing at the established rate, or if additional training or rehabilitation is warranted. For example, Figures 3 and 6 illustrate the distinct similarities of allometrically treated data regardless of body mass. Thus, it is possible to identify those athletes who do not fall within an acceptable range of the established standards. For instance, in the bench press or squat results falling outside one standard deviation (Tables 1 and 2) may indicate an above or below normal performance. While, high performance is desirable, the athlete with low results may need additional attention. Furthermore,

Table 1: Unweighted means, standard deviations (SD) and confidence intervals (CI) for allometrically normalized bench press strength.

Group	N	Mean	SD	CI
75-85 kg	90	6.42	0.89	6.21-6.61
86-95 kg	116	6.68	1.00	6.51-6.84
96-105 kg	110	6.67	0.89	6.48-6.84
106-115 kg	77	6.71	0.93	6.50-6.92
116-125 kg	65	6.49	1.07	6.26-6.72
126-135 kg	96	6.43	0.83	6.21-6.66
136-145 kg	28	6.39	0.76	6.16-6.63

Table 2: Unweighted means, standard deviations (SD) and confidence intervals (CI) for allometrically normalized squat strength.

Group	N	Mean	SD	CI
75-85 kg	60	9.10	1.50	8.71-9.48
86-95 kg	83	9.45	1.48	9.12-9.77
96-105 kg	73	9.29	1.71	8.95-9.64
106-115 kg	57	9.06	1.35	8.67-9.45
116-125 kg	43	9.00	1.41	8.55-9.45
126-135 kg	49	9.10	1.40	8.68-9.52
136-145 kg	44	9.51	1.53	9.07-9.95

post-injury rehabilitation personnel may benefit from knowing how close to established standards the athlete is progressing.

Conclusion

It is not surprising that maximum voluntary strength is greater in those athletes with greater body mass. By establishing norms based on allometric scaling, all athletes, regardless of body mass, may be equally compared. These comparisons provide a means by which athletes who fall below an acceptable range may be more closely monitored and provided with customized training protocols. For example, your athletes may not have gained the appropriate strength compared to the more mature athletes and thus may be more susceptible to injury. These norms can identify such cases and steps may be taken to try to prevent injury until the athlete reaches acceptable levels. Equally important is the post-injury readiness of athletes. Those athletes who fall significantly below acceptable levels may need to be afforded additional rehabilitation prior to returning to practice. These data can be used to compare actual performance with established norms. Lastly, the opportunity for potential future research could focus on the viability of using allometric scaling in sub maximal strength testing during the active season to determine the effectiveness of a typical strength maintenance program.

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