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Relationships between Body Proportions and Maximal and Relative Strength in Strength Sports

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This study explores the relationships between some specific body proportions and maximal and relative strength of lower extremities, measured by 1 repetition maximum (RM) in a classic resistance exercise – the back squat. 42 athletes in total participate in the study. They were competitors at the national level in bodybuilding, powerlifting and Olympic weightlifting. Linear regression equations were estimated between three relative body measures (Height seated/Height, Length of lower extremity/Height and Height/Thigh circumference) and maximal and relative strength in the back squat. All studied variables reached statistical significance in the models except for height/thigh circumference as a predictor of relative squat strength. The studied relative body measures proved to be reliable predictors of strength and relative strength abilities of lower extremities. These results can find practical application in the process of sports selection and specialization in strength sports.

Key words: maximal strength, strength sports, bodybuilders, powerlifters, Olympic weightlifters

Introduction

Bodybuilding, powerlifting and Olympic weightlifting are popular under the common name of strength sports. Resistance training is one of the oldest sports disciplines. Ancient Egyptians, Greeks and Romans exercised with heavy objects to develop their strength. Many artefacts prove that ancient warriors regularly performed strength exercises and participated in strength tournaments. Athletes in the early Olympic

Games in Ancient Greece also used resistance movements. Weights were used not only for strength demonstrations but also in some track and field disciplines – for example, long jumps were performed while athletes held a weight, which had to be thrown back an instance before landing [21]. All strength sports use similar training means: different types of resistance exercises [14, 15]. However, their training goals and methodologies are quite different. Bodybuilders aim at achieving muscle hypertrophy, decreasing subcutaneous fat and modelling symmetric bodies [27]. Olympic weightlifters and powerlifters use resistance exercises to develop maximal and/or explosive strength and lift heavier weights [31]. Despite these two sports having similar goals, their training methodologies differ in many aspects. Powerlifting encompasses muscle efforts that are positioned on the upper part of the force-velocity curve [1, 34], close to the region of isometric contractions. On the other hand, Olympic weightlifting competitive exercises are technically complex and dynamic and require the development of the so-called strength-speed abilities [30, 35]. Differences in training methodologies of strength sports are the reason for variations in strength abilities and physical development of strength athletes [25, 33]. Powerlifters and Olympic weightlifters aim to increase their strength abilities without gaining excessive body weight [7, 12]. On the other hand, in bodybuilding, the purpose is to maximize muscle hypertrophy irrespective of the development of motor abilities [28]. Nevertheless, generally, muscle strength increases in parallel with muscle size [2, 17]. For these reasons, the three sports are considered similar not only in training means (resistance exercises) but also in outcomes.

We studied one of the most popular strength training exercise – barbell back squat. We should mention that Olympic weightlifters and bodybuilders generally use slightly different technique in the back squat compared to some powerlifters – the so-called high-bar squat [7, 29. 31]. While back squat is a competitive movement only in powerlifting, it is strongly correlated to the results in the snatch and clean-and-jerk and is widely used as an auxiliary exercise in Olympic weightlifting [7, 22]. Results in the squat may seem unimportant for bodybuilders at first glance, as judges assess them based on their visual appearance rather than motor abilities. However, this exercise is one of the most potent means for building muscle size and is widely used in many bodybuilding training routines. As all experienced athletes in strength sports are proficient in the different versions of squat, in this experiment, we standardized the technique for all participants – we used "high bar" squat [26].

The aim of this study was to determine whether some specific relative body proportions give advantages in low extremities strength in competitive athletes in the three strength sports. We studied the relationships between some body proportions and maximal and relative strength measured by the heaviest weight lifted in one of the most popular strength exercises – the back squat. We expect that our findings will be of practical use for coaches, especially in the sports selection process.

Materials and Methods

Participants

The contingent of the study consisted of 42 strength athletes with a competitive experience at National level. Among them: 14 bodybuilders aged 24.7 ± 4.97 years and sports age (duration of practice in sport) of 7.5 ± 4.47 years; 11 powerlifters aged 23.6 ± 3.14 years and sports age of 6.05 ± 25.37 years; and 17 Olympic weightlifters aged 21.29 ± 2.97 years and sports age of 6.56 ± 3.92 years. The studies were approved by the Ethics Commission of the National Sports Academy, Sofia, Bulgaria. The study was conducted in accordance with the local legislation and institutional requirements. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

Procedure

We measured 4 anthropometric parameters, all of them body segment lengths. The measurements were conducted by a standard methodology [24]:

Lengths and circumferences of the body and body segments measured by a standard anthropometer of Martin type [3] with an accuracy of 0.1 cm:

Height – the distance between the floor and the vertex (the highest point on the sagital line of the skull) while the participant is barefoot and standing upright.

Height seated – the distance between surface of seating and the *vertex*.

Length of the lower extremity – the distance between the floor and *spina iliaca anterior superior*.

Thigh circumference – the circumference of the right thigh on the level of the *sulcus glutaeus* in shoulder-width stance.

All measurements were taken by the same investigator who was assisted by a colleague as instructions were given verbally to the participants.

As length of body segments is strongly correlated with body mass, and thus, indirectly, with maximal strength we only used relative variables based on these measurements. Four indices that describe the length of different body parts relative to body height were calculated:

$\frac{Height\ seated}{Height}$ (HSH) – we used this index to calculate the relative length of the torso

$\frac{Length\ of\ lower\ extremity}{Height}$ (LEH) – this index measures the relative length of the lower extremity

$\frac{Height}{Thigh\ circumference}$ (HT) – with this index we measured the muscularity of lower extremity. We corrected for height to obtain a universal measure independent of body dimensions.

Additionally, we calculated an index to estimate the relative strength. As the standard approach of evaluating it as maximal strength per kilogram of body mass suffers from significant inaccuracies, we corrected the data in accordance to the equation suggested by Zatsiorsky & Kraemer [34]:

$$Max.strength = a.(Body\ mass)^{\frac{2}{3}}$$

We used an arbitrary value of 1 for the constant ***a***. Despite this approach not being exactly accurate, it captures the essence of the formula – to correct the power of body mass in order to eliminate the inaccuracy due to the positive relationship between maximal strength and body mass. As the constant ***a*** only changes proportionally the slope of the curve (its first derivative) but not its type, we consider this index as an appropriate proxy with relative strength. In both powerlifting and Olympic weightlifting similar approaches (based on variations of this formula) are used to determine the best lifter in a competition [13, 16]. Accordingly, relative strength is an important parameter of training and preparation in strength sports.

The index was calculated as:

$$\frac{Squat}{Body\ mass^{\frac{2}{3}}} \text{ (Relative squat),}$$

and measures the relative strength in the squat.

Test protocol

We used the following test to measure the maximal strength:

Barbell back squat: The bar is placed behind the neck on the top of the back. The grip is wider than shoulder-width. The stance is shoulder-wide. The participant squats to the point when the hip joint is below knee joint.

We modified the Comfort [4] protocol for measuring maximal strength (estimating 1 repetition maximum/RM) [4]. It is relatively easy to perform, has high statistical reliability and is suitable for experienced athletes:

Participants warmed up by performing the exercises with submaximal loads that they were accustomed to from their normal training. Participants were permitted a maximum of 6 progressively increasing loads, for each exercise, although all participants completed the testing within 4–5 attempts. Weight was increased in increments of between 5 and 20 kg starting with larger increments and gradually decreasing them until the maximum was reached.

We specifically chose this exercise because it is widely used in training routines of all strength sports and accordingly, all subjects were well acquainted with the technique of execution. Maximal strength is defined as one's ability to exert maximal force against an external resistance and requires a maximal voluntary contraction [32]. All participants used lifting belts and shoes. No other accessory equipment was allowed.

Statistical analysis

We used the following statistical methods to interpret the results of the study:

- *Variation analysis.* The following parameters were calculated: mean value, standard deviation, minimum value and maximum value.
- *Correlation analysis.* We studied the relationships between the measured variables by calculating Pearson correlation coefficients at a level of significance of $p<0.05$. We tested our data set for normality by the Kolmogorov-Smirnov test [10].
- *Stepwise regression analysis*. A stepwise regression analysis was performed with a forward multiple linear regression approach to estimate the value of the studied variables as predictors of each of the maximal strength tests [11, 23].

All statistical analyses were conducted on the IBM SPSS Statistics for Windows software package (version 21).

Results

The variation analysis of the data is presented and the results of Kolmogorov-Smirnov test for normality of each variable are presented in **Table 1**. Pearson linear correlation coefficients of the studied variables are shown in **Table 2**. We found statistically significant correlations between both squat and relative squat and all studied variables with the exception of only this between relative squat and HT. These results (although expected) set the basis for the search for quantifying these relationships by regression models. The correlation coefficient between HSH and LEH is also statistically significant. No statistically significant correlations were calculated between HT and HSH or LEH. Accordingly, the regression models derived for HSH and LEH may provide overlapping information to some extend (due to the correlation between them) while LH carries independent predictive value.

Table 1. Variation analysis of obtained data

	Minimum	Maximum	Mean	Std. Deviation	K-S test
Height	1.580	1.855	1.729	0.061	0.747
Height seated	0.840	1.010	0.920	0.040	0.129
Upper extremity length	65.000	83.000	74.900	4.230	0.071
Lower extremity length	87.000	105.000	98.33	4.315	0.449
HSH	0.500	0.562	0.426	0.187	0.309
LEH	52.352	59.195	56.871	1.486	0.994
HT	0.722	0.897	0.814	0.049	0.495
Squat	120.000	320.000	206.845	45.9290	0.389
Relative squat	7.873	16.540	10.758	2.057	0.913

Abbreviations: HSH – height seated/height; LEH – length of lower extremity/height; HT – height/thigh circumference; K-S test – Kolmogorov-Smirnov test

Table 2. Correlation matrix of studied variables

	HSH	LEH	HT	Squat	Relative squat
HSH	-				
LEH	-0584*				
HT	0.187	0.163			
Squat	-0.543*	0.459*	-0.385*		
Relative squat	-0.519*	0.507*	0.089	0.886*	-

Statistically significant correlations ($p<0.05$) are marked with *

Abbreviations: HSH – height seated/height; LEH – length of lower extremity/height; HT – height/thigh circumference

The parameters of the models of linear regression are presented in **Tables 3** and **4**. For the squat, all of them are statistically significant with Adjusted R squared values varying between 0.148 (for HT) to 0.277 (for HSH). Prima facie, each of the models taken separately explains a relatively small portion of data variance, but the combined information of the three may be a powerful tool in the training and preparation process of athletes. Interestingly, for the relative squat, only two of the models (for HSH and LEH) show statistical significance of the estimated parameters with higher values of Adjusted R squared – 0.253 and 0.256 respectively. Although somewhat unexpected, these findings are consistent with the lack of correlation between relative squat and HT (**Table 2**).

Table 3. Linear regression models of studied variables vs. Squat

Model B		Unstandardized Coefficients		t	Sig.	Adjusted R Squared
		Std. Error				
Squat	Constant	918.506	174.126	5.275	0.000	0.277
	HSH	-1335.359	326.534	-4.089	0.000	
Squat	Constant	-411.161	189.433	-2.170	0.036	0.191
	LEH	1427.125	437.199	3.264	0.002	
Squat	Constant	463.231	97.523	4.750	0.000	0.148
	HT	-9567.536	3630.865	-2.635	0.012	

Abbreviations: HSH – height seated/height; LEH – length of lower extremity/height; HT – height/thigh circumference

Table 4. Linear regression models of studied variables vs. Relative squat

Model B		Unstandardized Coefficients		t	Sig.	Adjusted R Squared
		Std. Error				
Relative Squat	Constant	41.516	8.076	5.140	0.000	0.253
	HSH	-57.657	15.131	-3.811	0.000	
Relative Squat	Constant	-19.585	8.290	-2.362	0.023	0.256
	LEH	70.114	19.144	3.662	0.001	
Relative Squat	Constant	13.277	4.756	2.792	0.008	0.007
	HT	-93.865	176.832	-.531	0.599	

Abbreviations: HSH – height seated/height; LEH – length of lower extremity/height; HT – height/thigh circumference

Discussion

According to the common wisdom among strength training coaches, certain specific body proportions can provide advantages in basic resistance exercises (e.g., front and back squats or deadlifts) and are therefore beneficial for developing strength in competitive lifting. For instance, relatively long hands are considered advantageous for conventional or sumo deadlift and short lower extremities for squat [31]. In our study, all anthropometric parameters analysed proved to be statistically significant predictors of maximal and relative strength in the squat, with the exception of HT and relative squat. Irrespective of the fact that adjusted R-squared values (the variance explained by the model) are not high, the significance of the statistical models is for all constants and predictors (**Tables 3** and **4**). These findings indicate that other (unidentified) predictors exist that explain the variation of the results. Interestingly, the parameters of the regression model for HT as a predictor of squat strength are not statistically significant. HT is a measure of muscularity (and thus indirectly, strength, as muscle strength is proportional to muscle cross sectional area or volume) of thigh muscles relative to body height. Thus, it is logical HT to be highly correlated to strength of lower limbs. Despite the fact that HT is an indirect indicator of relative strength as it does not measure muscle strength directly, it still provides information on this parameter. According to our findings, muscle volume (of thighs) does not have any predictive value for relative squat strength – i. e., athletes with different levels of thigh hypertrophy would have similar strength per kilogram body mass in the squat. However, relative squat is a measure of a specific muscle quality – strength per kilogram and it is logical for it to be uncorrelated with the amount of muscle mass measured – both absolutely or relatively (HT). In this regard, our results are not unexpected, especially considering the fact that we studied athletes in strength sports with similar body compositions.

Not many authors have explored relationships between anthropometric measures and performance in strength sports and logically, no systemized unanimous opinions and conclusions on the topic exist among the scientific community. Keogh et al. [17] studied anthropometric profiles and somatotypes of competitive New Zealand powerlifters of different weight classes [18]. These authors made a brief comparison of their results with anthropometric measures of bodybuilders and Olympic weightlifters (reported by other researchers). The same researchers analysed the relationships between anthropometric parameters and strength abilities in powerlifters [19]. They found no differences in body segment lengths between weaker and stronger athletes. Differences in body lengths were observed between powerlifters of different weight classes. However, unlike the present study, the authors concentrated their attention on determining differences in body proportions and body composition between stronger and weaker athletes.

Ferrari et al. [9] studied the relationships between body composition and maximal strength in powerlifters. The authors derived multiple regression equations using these variables as predictors for the three competitive lifts (and the total) in powerlifting. Vis-a-vis our study, their results are focused on body circumferences. The only reported statistically significant relationship was between the length of the upper limb/height and performance.

Similarly, Ebada [5] studied the relationships between anthropometric measures and results in Olympic weightlifting [10]. However, the only body length the authors measured was maximal height, which makes their results incomparable to ours.

Lovera & Keogh [19] studied 31 anthropometric measures of Argentinean competitive powerlifters [20]. Irrespective of the fact that the study was focused primarily on measuring body composition, the authors also did not find any statistically significant relationships between body segment lengths and results in the competitive lifts. Our study differs in methods, as we aimed at establishing universal relationships between strength and body proportions and accordingly, only examined relative body segment lengths.

Our study corroborates some of the conclusions of a previous experiment, which studied experienced powerlifters [9]. The authors used a stepwise multinomial regression approach to derive equations predicting maximal strength in squat, bench press and deadlift based on anthropometric data. Although in addition to the lengths of the body segments, they also measured the circumferences, their results demonstrate that relative torso length is an important factor of performance in powerlifting. Following a similar protocol, Ferland et al. [7] studied junior competitive powerlifters and compared their maximal strength abilities to those of American football players. They derived similar multiple regression equations to their previous study. Regrettably, we cannot compare their results to ours as they only report data on the combined group of subjects – powerlifters and American football players.

Conclusions

The most important practical use of our results is the opportunity the models can give to coaches to access athletes' potential to excel in one of the most popular strength exercises that is competitive in powerlifting – the back squat. This is a powerful tool (which is based on simple sometometric measurements that can be easily done on site) in the process of sports selection and specialization. Additionally, the models can quantify the expected gains in these exercises, especially regarding their relative variants. This is important for predicting athlete's potential for better ranking in the absolute category in powerlifting events.

Admittedly, the study has limitations. Most importantly, due to the specifics of the studied sample (highly qualified strength athletes), our results most probably are not directly applicable to competitors in other sports or the general population. The same holds true for female and youth athletes in strength sports. It is also important to mention that the exercise we used for testing (back squat) is technically complex and requires enough time for technique perfecting. In this regard, it is not appropriate for use by inexperienced athletes. Additionally, the testing protocol for estimating 1 RM is also taxing and requires training experience.

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