RELATIONSHIPS BETWEEN LOWER BODY MUSCULATURE AND PERFORMANCE IN COMPETITITVE MALE AND FEMALE WEIGHTLIFTERS

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INTRODUCTION: Certain performance characteristics such as maximal strength (Beckham et al., 2013), rate of force development (RFD) (Hornsby et al., 2017), and vertical jump height (Travis, Goodin, Beckham, & Bazyler, 2018) have been shown to strongly correlate to weightlifting (WL) performance. There is evidence that lower body muscle size and architecture plays a role in these abilities (Häkkinen, Komi, & Kauhanen, 1986; Methenitis et al., 2016) and consequently likely also influences WL ability (Stone, Pierce, Sands, & Stone, 2006). However, few studies have directly measured these morphological characteristics in weightlifters and related them to performance measures.

Estimates of muscle size or lean body mass based on height, weight, and body composition have been related to WL performance previously (Ford, Detterline, Ho, & Cao, 2000; Siahkouhian & Hedayatneja, 2010). Additionally, research conducted on strength sports such as powerlifting and strongmen have identified strong relationships between muscle size and success in these sports (Brechue & Abe, 2002; Winwood, Keogh, & Harris, 2012). When comparing elite weightlifters to collegiate level lifters within the same body weight range Funato, Kanehisa, and Fukunaga (2000) observed no statistically significant differences in the cross-sectional area (CSA) of the elbow or knee extensors but found the elite lifters had a higher force to CSA ratio during an isokinetic knee extension. However, no such study performed on weightlifters has directly correlated lower body CSA or muscle thickness (MT) to WL performance measures (snatch, clean and jerk, and total).

Due to the greater absolute loads involved in the clean and jerk, it is conceivable that the correlations with muscle size may differ in comparison to the snatch, but this has yet to be thoroughly investigated. Additionally, it would be useful to understand the relationships of muscle size in weightlifters have on performance tasks other than the WL movements. For instance, a weightlifter that is lacking in certain metrics that are strongly related to muscle size, such as isometric peak force (IPF), may benefit from periods of targeted training to address that deficiency. Previous research has demonstrated that the relationship between performance tasks and WL ability is weaker in females than males (Stone et al., 2005; Travis et al., 2018). Therefore, it is possible that a discrepancy in the relationship between muscle size and performance measures between the sexes also exists. Thus, the primary purpose of this study is to examine the relationships of physical characteristics, including vastus lateralis CSA, MT, and pennation angle (PA) on multi-joint isometric force production, vertical jumping, and absolute WL performance in male and female weightlifters.

METHODS; *Study Design*: This study evaluated the relationships between lower body musculature obtained using ultrasonography (US) and WL performance, isometric force, and vertical jumping ability in male and female weightlifters. All data was collected as part of a regular athlete monitoring program. Testing took place during the week following a competition. All testing procedures began with a hydration test to confirm adequate hydration levels. *Participants*: Athlete monitoring data from twenty-six collegiate weightlifters (13 males: 22.9 ± 2.4 yrs, 89.1 ± 16.8 kg, 171.3 ± 7.0 cm; 13 females: 20.6 ± 2.3 yrs, 63.9 ± 7.8 kg, 159.9 ± 57 cm) was used for analysis. All athletes were familiar with the testing procedures and gave consent for their data to be used. The Universities Institutional Review Board approved the study. *Procedures:* Participant MT, PA, and CSA values of the right vastus lateralis were collected in a standing position using US technology (LOGIQ P6, General Electric Healthcare, Wauwatosa, WI, USA) following previously published procedures (Wagle et al., 2017). The mean MT and PA was attained from the first, second, and third portion of the highest quality image. The average results of the two CSA images that best displayed the region of interest were used for analysis. All US images were analyzed by the same investigator using the software contained within the ultrasound device. Performance testing began with a standardized warm-up of jumping jacks, and dynamic mid-thigh pulls. The subjects then performed two submaximal (50 and 75% effort) warm-up vertical jumps before attempting maximal unloaded and loaded jumps from a static squat position (90-degree knee angle) holding either a PVC pipe (SJ0) or 20kg bar (SJ20) on their shoulders. Jump testing was conducted while standing on dual force plates (Rice Lake Weighing Systems, Rice Lake, WI, USA; 1000 Hz sampling rate) and jump height was estimated from flight time (Linthorne, 2001). The two highest jump trials for each condition were averaged together for analysis. Directly after jump testing, the participants performed isometric mid-thigh pull testing as previously described (Beckham et al., 2013; Travis et al., 2018). The two trials that displayed the highest IPF values were averaged for analysis.

Statistical Analyses: Descriptive statistics are expressed as mean ± standard deviation (Table 1 & 2). A Shapiro-Wilks test was used to confirm that the data was normally distributed. Relationships between the morphological and performance measures were assessed using Pearson's r. Strength of the relationships were determined using the following scale: r = 0.0-0.1 trivial, 0.1-0.3 weak, 0.3-0.5 moderate, 0.5-0.7 strong, 0.7-0.9 very strong, 0.9-1 nearly perfect. The alpha criterion for determining statistical significance was set at $p \leq 0.05$. All statistical analyses were performed using JASP (version 0.11.1.0).

RESULTS: When analyzed as a single group (n = 26) both MT and CSA significantly (r = 0.65- 0.82; $p < 0.01$) correlated with all measured performance variables. Pennation angle was only moderately correlated (r = 0.467; p = 0.016) with SJ0. In the females (n = 13) both MT and CSA were significantly correlated to snatch, IPF, and SJ20 (Table 3). In the males (n = 13) there was no statistically significant correlation ($p \geq 0.05$) between lower body musculature and the performance variables.

TABLE 1. Descriptive statistics for performance variables

Sex	Sn (kg)	CJ (kg)	WT (kg)	IPF (N)	SJ 0 (cm)	SJ 20 (cm)
Females (n=13)	67 ± 7	87 ± 8	153 ± 16	3892 ± 668	27 ± 3	20 ± 2
Males (n=13)	118 ± 16	150 ± 21	268 ± 37	5579 ± 1322	35 ± 4	28 ± 4

Mean ± SD. Sn=Snatch; CJ = Clean and Jerk; WT=Weightlifting Total; IPF = Isometric Peak Force, SJ = Static Jump.

TABLE 2. Descriptive statistics for morphological variables

Sex	MT (cm)	PA (°)	CSA (cm^2)
Females (n=13)	2.82 ± 0.26	19.57 ± 2.99	33.84 ± 4.60
Males (n=13)	3.28 ± 9.83	21.51 ± 3.281	48.2 ± 7.99

Mean ± SD. MT = Muscle Thickness, PA = Pennation Angle, CSA = Cross-sectional area.

DISCUSSION: The current investigation demonstrated that statistically significant relationships existed between vastus lateralis muscle size measured using US and snatch, IPF, and SJ20 in a sample of female weightlifters. The lack of a statistically significant relationship between performance and musculature in this sample of males may be due to the large difference in levels of the athletes. The range of totals for the males was between 172-323kg, whereas the range for the females was 129-189kg. Therefore, it is possible the large discrepancy in skill level between the males made the relationships between muscle size and WL performance weaker. However, the females also demonstrated a very strong relationship between muscle size and IPF (Table 3). Therefore, factors such as dissimilarities in muscle distribution between the sexes (Miller, MacDougall, Tarnopolsky, & Sale, 1993) may affect the relationship between lower body musculature and maximum strength performance in weightlifters. Additionally, it was hypothesized that due to the greater absolute loads used in the clean and jerk, the relationships to muscle size would be stronger than in the snatch. However, in this sample of females, the opposite result was found. It may be that the required upper body contribution during the jerk portion of the lift diminishes the degree to which lower body musculature is associated with clean and jerk performance in females.

TABLE 3. Pearson correlation coefficients for females (n = 13) and males (n = 13)

	Snatch	CJ	Total	IPF	SJ 0	SJ 20	MT	PA
Females								
CJ	0.885***							
Total	0.967***	0.968***						
IPF	0.478	0.429	0.445					
SJ 0	0.659*	0.625*	0.694**	0.389				
SJ 20	0.685**	0.649*	0.708**	0.593*	0.790**			
MT	0.565*	0.385	0.498	0.568*	0.551	0.780**		
PA	-0.026	-0.061	-0.029	-0.073	0.370	0.009	0.072	
CSA	0.582*	0.442	0.543	0.709**	0.456	0.737**	0.850***	-0.014
Males								
CJ	0.966***							
Total	0.989***	0.993***						
IPF	0.317	0.427	0.382					
SJ 0	0.589*	0.655*	0.632*	0.418				
SJ 20	0.747**	0.793**	0.779**	0.549	0.860***			
MT	0.274	0.334	0.310	0.326	-0.154	0.153		
PA	-0.186	-0.050	-0.111	0.085	0.394	0.198	-0.138	
CSA	0.489	0.478	0.487	0.493	0.079	0.472	0.784**	-0.173

* p < .05, ** p < .01, *** p < .001; CJ = Clean and Jerk, IPF = Isometric Peak Force, SJ = Static Jump, MT = Muscle Thickness, PA = Pennation Angle, CSA = Cross-Sectional Area.

CONCLUSIONS AND PRACTICAL APPLICATIONS: Further investigations involving larger samples with a smaller distribution in weightlifting skill will be required to better clarify the findings of this investigation. Despite being similar measurements, CSA and MT were not perfectly correlated (Table 3), and CSA demonstrated stronger relationships with most performance measures. Individual variations in the shape of the muscle will have a greater influence on MT since it is only taken at one site. Therefore, when attempting to associate muscle size with performance measures, CSA seems to be a more effective metric. Measures of lower body musculature may discriminate better weightlifters to a greater degree in females than males; however, moderate correlations to WL performance were still observed in both sexes (Table 3). Therefore, the quantification of lower body CSA may be a beneficial addition to talent identification and athlete monitoring programs involving weightlifters.

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