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Association Between Body Composition and Vertical Jump Performance in Female Collegiate Volleyball Athletes

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ABSTRACT

Background of Study: Associations between measures of body composition and vertical jump height have previously been established using a range of instrumentation and prediction equations. Limited data has presented using gold standard measurements for both variables **Objective:** This investigation sought to examination the relationship between total body and lower extremity measures of body composition and vertical jump performance using gold standard measurements within an athletic population. **Methods:** Using a cross-sectional, correlational research design fourteen collegiate female volleyball athletes completed body composition, three countermovement jumps (CMJ) and three squat jumps (SJ) analysis using DXA and force platforms. **Results:** High to very high positive relationships were seen between total body lean ($p < 0.001$) and fat mass ($p < 0.05$), lower extremity lean and fat mass ($p < 0.01$), and CMJ force and power. High negative relationships were present between total body fat percentage($p < 0.05$), total fat mass ($p < 0.01$) and CMJ jump height. Relationships between all body composition variables and SJ performance tended to be weaker, with the exception of total body lean mass ($p < 0.05$), lower extremity lean mass, and power output ($p < 0.01$). **Conclusions:** These findings support much of the previous literature in that increases of mass have subsequent increases in force and power production; however caution should be taken will increases in mass coming from fat or lean tissue.

Key words: Body Composition, Vertical Jump, Volleyball, Team Sports, Collegiate Athletes, Physical Functional Performance

INTRODUCTION

Volleyball is a team sport that is characterized by repeated jumping maneuvers in an attempt to hit a ball as hard as possible across a net. Differences in jump height have distinguished higher level from lower-level volleyball players (Nikolaidis et al., 2017). While jumping ability is a key component of success in volleyball other factors such as, anthropometry have also been shown to distinguish between competitive levels. Previous investigations have shown that lower body fat percentages and greater amounts of lean mass have been associated with success in higher levels of competitions (Malousaris et al., 2008; Nikolaidis, 2013; Nikolaidis, Afonso, & Busko, 2015). Nikolaidis et al. (2017) established a relationship between jump height and body composition in a population of youth volleyball athletes where individuals with lower body fat percentages had higher recorded jump heights (Nikolaidis et al., 2017). Similar relationships have been established in female both collegiate and adult volleyball athletes (MacDonald et al., 2013; Nikolaidis, 2013).

Being that the vertical jump is an integral part of successful performance in volleyball, testing of physical capabilities in volleyball athletes typically includes a vertical jump task. (Taylor, Chapman, Cronin, Newton, & Gill, 2012) In addition to volleyball performance, jumping tests are utilized to predict muscular power of the lower extremity (Sayers, Harackiewicz, Harman, Frykman, & Rosenstein, 1999). Previous research has shown positive strong relationships between body composition and power output in several jumping tasks (Ishida, Travis, & Stone, 2021; MacDonald et al., 2013). This positive relationship has largely been explained by an increase in one's body mass would require more muscular power to complete the jumping task. Similarly it has been shown that a significant relationships exist with body composition, and strength (isokinetic and isometric) of the quadriceps (Potteiger, Smith, Maier, & Foster, 2010; Vaara et al., 2012). Moreover, lean mass has been shown to have significant associations with more dynamic movements such as the power clean exercise, which mimics the movement patterns of the vertical jump tasks (Collins, Silberlicht, Perzinski, Smith, & Davidson, 2014;

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MacKenzie, Lavers, & Wallace, 2014). Furthermore, total body and lower extremity lean mass percentage has shown significant relationships to force and power production in a general population of adults between 18 and 65 years of age performing the countermovement jump (CMJ) (Stephenson et al., 2015).

Much of the literature that investigates the relationships between body composition and physical performance outcomes uses a wide range of testing modalities. For example, reported body composition values have come from skinfold measurements (3 and 10 site) (Ishida et al., 2021; Nikolaidis et al., 2017), bioelectrical impedance (Vaara et al., 2012), air-displacement plethysmography (Collins et al., 2014; Potteiger et al., 2010), and dual energy X-ray absorptiometry (DXA) (MacDonald et al., 2013; Stephenson et al., 2015). While all of the above assessment techniques have been identified as valid and reliable measurements of body composition, differences between instrumentation can explain some of the differences in the strength of the relationships reported (r = -0.39 – -0.81 in jump height). The same methodological issues are present in the assessment of the vertical jump through the use of force platforms (Ishida et al., 2021; Raymond-Pope, Dengel, Fitzgerald, & Bosch, 2020; Stephenson et al., 2015), flight times (Nikolaidis, 2013; Nikolaidis et al., 2017), and wearable accelerometers (MacDonald et al., 2013). Limited research has used the gold standard in both body composition (DXA) and vertical jump assessment (force platform) (Raymond-Pope et al., 2020; Stephenson et al., 2015). While both the CMJ and squat jump (SJ) relationship to body composition have been assessed using gold standard measurements, using both styles of jumps within a single population has not been previously reported to the author's knowledge. Additionally, the use of an athletic population that all participant in the same sport that requires having some level of jumping ability may create differing relationships then the general athletic and recreational populations previously used. Therefore, the purpose of this investigation was to examine the relationships between body composition of both the total and lower extremity to vertical jump performance in an athletic population.

METHODS

Participants and Study Design

Fourteen (n=14) members of a Division I collegiate volleyball program (age 19.86 ± 0.86 years, height 180.61 ± 3.99 cm, body 69.93 ± 9.73 kg) participated in this investigation. Subjects participated in similar strength training programs in the 4 months prior to the investigation as testing was completed one week after the completion of the competitive season. Prior to testing each participants performed biweekly resistance training sessions. Each session consisted of total-body training focused on strength and power development. Inclusionary criteria for this investigation consisted of being currently free from injury, cleared for sport participation by the athletic training staff, and membership on a NCAA Division I volleyball roster. Prior to data being collected, study procedures were approved by the university institutional review board and participants provided written informed consent.

A cross-sectional design was used to evaluate the associations between body composition parameters (total and lower extremity fat percentage, lean mass and fat mass) and vertical jump (peak force and power, mean force and power, jump height and reactive strength index modified) performance. Testing was conducted during two sessions. The first session included the CMJ and SJ testing while DXA analyses was completed in the second session. All testing was completed during a one-week period.

Procedures

Jump testing

After completing a general dynamic warm-up (jumping jacks, body weight squats, straight leg marches, walking quad stretch, each for 10 repetitions), three CMJ were performed using a portable force platform (AMTI, Accupower, Watertown, MA, USA). A dowel was placed on the participant's back in a high-bar squat position. The participants were allowed 5 practice jumps to familiarize themselves with jumping without use of their arms. Participants were told to perform familiarization jumps between 50 and 75 percent of maximal effort. Three successful jumps were performed using self-selected foot width countermovement depth (Argus, Gill, Keogh, & Hopkins, 2011). Each participant was instructed to step on the force plate and remain as still as possible for one second to calculate body mass. Using a "3-2-1-go" cadence, the participants were instructed to jump as high as possible, while keeping the dowel in contact with their back the entire time. (Donahue, Wilson, Williams, Valliant, & Garner, 2019) Keeping the dowel on their back ensured the participants moved as a single system. Thirty seconds were given between the trials.

During the squat jump participants were instructed to lower themselves into a semi-squat position in which they felt they could jump the highest and hold that position for three seconds. Again using a "3-2-1-go" countdown participants performed a concentric only jump. Each trial was visually inspected for a countermovement. If detected another trial was performed until a total of three successful trials were collected (Donahue et al., 2019) Thirty seconds separated each trial and two minutes was given between CMJ and SJ trials.

All force-time data was collected data at 1000 Hz. Force data was then used in the calculation of all jump performance variables. Force data was integrated similar to methods previous recommended and described by Chavada et al., (2018) and Donahue et al., (2019) using a customized Excel spreadsheet (Microsoft, Redmond, WA) (Chavda et al., 2018; Donahue et al., 2019). Peak and mean values of force and power, jump height and RSIm were used in this analysis.

Body composition

Body composition measures were obtained using DXA assessment (GE Lunar iDXA and enCORE software, GE

Healthcare, Madison WI, USA). Prior to testing participants were instructed to maintain normal eating and drinking routines. Participants were also instructed to abstain from high-intensity exercise prior to their visit. Variables used in the analysis were body fat percentage, lean mass, and fat mass in kilograms (kg) of the total body and the lower extremities.

Statistical Analysis

Correlation coefficients were calculated using Pearson product moments between all jump performance and body composition measures. An a priori alpha level of 0.05 was used in determining significant relationships. Correlation coefficients were interpreted as trivial (r = 0.00 – 0.1), small (r = 0.1 – 0.3), moderate (r = 0.3 – 0.5), large (r = 0.5 – 0.70), very large (r = 0.7 – 0.9), and nearly perfect (r = 0.9 – 1.0) as recommended by Hopkins (Hopkins, 2002). Statistical analysis were performed using SPSS version 25 (IBM, Chicago, IL).

RESULTS

Descriptive statistics for each variable used in the correlational analysis is presented in Table 1, as mean ± *SD* and range. Correlation coefficients between body composition and CMJ performance are presented in Table 2. Very large positive significant relationships were present between total lean mass, lower extremity lean mass, lower extremity fat mass, mean force and mean power during the CMJ. A large negative significant relationship was present between total body percentage fat, total fat mass and CMJ jump height. Significant large positive relationships were seen between total fat mass, lower extremity lean mass, lower extremity fat mass, peak force and peak power in the CMJ. Strong positive relationships were present between total fat mass, lower extremity fat percentage, mean force and mean power during the CMJ.

Correlation coefficients between body composition and SJ performance are presented in Table 3. Very large significant positive relationships between lower extremity lean mass, peak and mean power were displayed in the SJ. Large significant positive relationships between total lean mass, peak and mean power were present in the SJ. Lastly, a large positive significant relationship was present between lower extremity lean mass and mean force in the SJ.

DISCUSSION

The primary findings of this investigation support previously established relationships between measures of body composition and vertical jump performance through the use of gold standard measurements, while also displaying relationships between jump performance and lower extremity fat and lean mass values (MacDonald et al., 2013; Raymond-Pope et al., 2020; Stephenson et al., 2015). Specifically in the CMJ, a large to very large correlation was established between mean power and force regarding total and lower extremity lean mass, and total and lower extremity fat mass. Furthermore, the data of this investigation supported the limited published data between body composition and SJ performance. Total fat mass and total body fat percentage showed significant strong inverse relationships to jump height in the CMJ. Though, no significant relationship was seen between body composition and SJ jump height.

These findings are comparable with that of and MacDonald et al (2013) and Ishida et al (2021), which examined the relationship of body composition to strength and power in both male and female collegiate athletes (Ishida et al., 2021; MacDonald et al., 2013). MacDonald et al. (2013) found a strong inverse relationship between CMJ height and total body fat percentage (r = -0.82) (MacDonald et al., 2013). It is of importance to note that the relationship seen in the present investigation (r = -0.61) is lower than of those previously reported. Both the current investigation and MacDonald et al. (2013) assessed collegiate female athlete's body composition using DXA whole body scans, while jump assessments differed greatly in the instrumentation used. CMJ and SJ were performed using the gold standard measurement of a force platform in the present study, while a wearable accelerometer was used in the previous investigation (MacDonald et al., 2013). Copic et al. (2014) found lower relationships between body fat percentage and CMJ height to those in the present study using elite volleyball athletes

Table 1. Descriptive statistics for all variables

	Mean ± *SD*	**Range**
Total Body Fat Percentage (%)	25.26 ± 3.96	19.1 – 33.1
Total Lean Mass (kg)	16.77 ± 3.87	41.45 – 54.81
Total Fat Mass (kg)	13.24 ± 8.82	10.91 – 23.73
Lower Extremity Body Fat Percentage (%)	29.13 ± 4.08	21.2 – 35.6
Lower Extremity Lean Mass (kg)	17.36 ± 1.81	14.27 – 21.95
Lower Extremity Fat Mass (kg)	7.27 ± 1.75	4.14 – 10.23
CMJ Peak Force (N)	820.71 ± 123.04	644.81 – 1172.83
CMJ Mean Force (N)	575.65 ± 76.63	469.32 – 738.00
CMJ Peak Power (W)	3148.21 ± 289.34	2644.33 – 3516.20
CMJ Mean Power (W)	1624.37 ± 158.93	1339.22 – 1915.19
CMJ Jump Height (m)	0.29 ± 0.02	24.00 – 33.00
CMJ RSIm	0.37 ± 0.06	0.27 – 0.43
SJ Peak Force (N)	935.12 ± 163.25	688.53 – 1347.17
SJ Mean Force (N)	456.45 ± 92.13	273.59 – 620.25
SJ Peak Power (W)	3337.83 ± 362.37	2541.15 – 3914.83
SJ Mean Power (W)	1246.69 ± 209.06	804.19 – 1464.15
SJ Jump Height (m)	0.28 ± 0.02	0.25 – 0.34
SJ RSIm	0.79 ± 0.18	0.51 – 0.15

CMJ = Countermovement jump; SJ = Squat jump; RSIm = Reactive strength index modified

Table 2. Correlation coefficients between body composition and countermovement jump performance

	Peak Force	Mean Force	Peak Power	Mean Power
Total Body Fat Percentage	0.34	0.44	0.37	0.42
Total Lean Mass	0.68**	0.79**	0.68**	0.79**
Total Fat Mass	0.54*	0.64*	0.54*	0.61*
Lower Extremity Fat Percentage	0.44	0.55*	0.52	0.55*
Lower Extremity Lean Mass	0.69**	0.75**	0.66**	0.76**
Lower Extremity Fat Mass	0.68**	0.76**	0.69**	0.74**

RSIm = Reactive Strength Index Modified
*p < 0.05
**p < 0.01

Table 3. Correlation coefficients between body composition and squat jump performance

	Peak Force	Mean Force	Peak Power	Mean Power	Jump Height	RSIm
Total Body Fat Percentage	-0.18	-0.02	0.10	0.20	-0.39	-0.40
Total Lean Mass	0.31	0.52	0.65*	0.65*	0.08	0.06
Total Fat Mass	-0.08	0.12	0.28	0.36	-0.33	-0.36
Lower Extremity Fat Percentage	-0.18	-0.01	0.13	0.22	-0.34	-0.42
Lower Extremity Lean Mass	0.31	0.56*	0.71**	0.72**	0.22	0.12
Lower Extremity Fat Mass	-0.3	0.21	0.40	0.46	-0.18	-0.30

RSIm = Reactive Strength Index Modified
*p < 0.05
**p < 0.01

(r ≈ 0.40) (Ćopić, Dopsaj, Ivanović, Nešić, & Jarić, 2014). Similar assessment techniques were used regarding jump performance using a force platform, however used a bioelectrical impedance device for body composition. This points to the importance of using gold standard measurements and how correlational coefficients can differ depending on the measurements used. Similar populations were used to that in the present investigation, however differing assessments of the same variables resulted in a wide spread of correlation coefficients (r = -0.39 – -0.82) (Ćopić et al., 2014; MacDonald et al., 2013). Present findings fall near perfectly in the middle (-0.61) of the range of seen those previously reported. Suggesting that the error could be coming from either body composition or the vertical jump assessment.

As mentioned previously, the SJ is used as a common assessment tool along with the CMJ in performance testing (Taylor et al., 2012). The relationships between body composition and SJ performance are less widely reported than the CMJ. MacDonald et al. (2013) found a significant inverse relationship between SJ height and body fat percentage across 21 female athletes of varying sports, and no significant relationship specifically in volleyball athletes (MacDonald et al., 2013). More recently, Ishida et al. (2021) found there to be no significant relationship between SJ peak power and body fat percentage in collegiate male soccer athletes (Ishida et al., 2021). However they reported a large relationship between lean body mass and SJ peak power (Ishida et al., 2021). Similar correlation coefficients were found between the current investigation and those of Ishida et al. (2021). Peak power and lean body mass in both the SJ and CMJ both showed significant strong positive correlations. While a small to moderate correlation was demonstrated between peak power and total body fat percentage in the SJ and CMJ. Based on these findings and those previously reported, increasing the amount of lean mass an individual has appears to be beneficial to lower body power output regardless of the relative value of that fat mass. Again, differences in the coefficient values between studies can be potentially explained through differences in the assessments used (DXA vs 3 site skinfolds).

This investigation also sought to find the relationships of between the lower extremity composition and jump performance. While the vertical jump consists of displacement of the entire body, the force generation needed to create this displacement is produced through the lower extremity. The arm swing is commonly used while jumping in sport, it is largely controlled for when assessing vertical jump ability in controlled environments to understand lower extremity force and power capacity. Previous investigations have used lower extremity composition analysis and vertical jump ability. In contrast to the results reported in the current investigation, Raymond- Pop et al (2020) showed nearly perfect correlation coefficients (r = 0.94) for lower extremity lean mass and SJ height in a sample of Division I athletes (Raymond-Pope et al., 2020). The vast differences in the strength of the relationship in lower extremity lean mass and SJ height could be explained in the range of SJ height values. In the current investigation, SJ height ranges between 0.25m – 0.34m. While the range of jump heights is much greater in the previous investigations (≈0.2 – 0.52cm), thus allowing for a larger relationship to be present (Raymond-Pope et al., 2020). Similar findings are seen concerning lower extremity lean mass and peak force production (Raymond-Pope et al., 2020).

Relationships between jump height and lower extremity percentage of body fat and fat mass become smaller and non-significant in the CMJ (-0.61 vs -0.45 and -0.67 vs -0.48 respectively). These decreases in relationship strength and significance were not previously seen in a sample of recreationally active adults (Stephenson et al., 2015). Again, the distribution of values for both body composition and CMJ height may explain the differences between the present study and previous investigations. Additionally, differences between relative and absolute values of lean mass may explain differing results. The differences in the relative and absolute values relationships can be seen in the present study, with changes in the relationship strength between total body fat percentage and total body fat mass in force and power production. Similarities between total and lower extremity lean mass relationships with force and power coincide with those of previous investigations (Stephenson et al., 2015). Slight increases in the relationship between lower extremity fat mass and CMJ force and power are seen. The same can be seen with mean force and power and lower extremity fat percentage. Thus, the greater mass of an individual, the greater force and power output one needs to accelerate that mass. This greater force however does not translate into greater jump heights. This is because a larger individual is requiring more force to complete the jumping task. This is shown in the negative relationships been body composition and CMJ jump heights.

The results of this study would appear to have a level of transfer across Division I collegiate volleyball players. Bisch et al. (2020) performed body composition analysis using DXA on 90 female athletes across 5 different Division I volleyball programs with similar values to those reported in the present study (Bisch et al., 2020). As for jump performance, both CMJ height and CMJ RSIm values are similar to those previously reported on Division I collegiate volleyball athletes at multiple Division I universities (Kipp, Kiely, & Geiser, 2016; Suchomel, Sole, Bailey, Grazer, & Beckham, 2015). The stretch shortening cycle in the CMJ is commonly utilized in athletic performance, especially in the sport of volleyball. The SJ would appear to more of a novel task and jump heights have less dispersion across the sample, again potentially explaining the reduction in relationship strengths seen from previous findings.

The use of gold standard measurement techniques in both the assessment of body composition and vertical jump ability, provide a level of confidence in the associations presented. Additionally, the use of a population that is accustomed to performing the vertical jump task also provides strength the findings, as it has been previously shown that intersession and intrasession reliability of CMJ jump height and RSIm is highly reliable in collegiate volleyball athletes (Carroll, Wagle, Sole, & Stone, 2019). This investigation is not without limitations. The use of a small sample size in a correlational analysis is a limitation of the current study. Sample size was dictated by roster size of the team during the week assessments were taken. Three athletes from the active roster were excluded for injury or failing to complete all testing assessments within the one-week period. Though small, the sample size is similar to other investigations using high-level female collegiate volleyball athletes and the vertical jump task (Carroll et al., 2019; Kipp et al., 2016; Suchomel et al., 2015). Future investigations in other sports that rely heavily on jumping ability, such as basketball, would provide greater context to the associations presented above. Additionally, continued use of gold standard measurements in both the assessment of body composition and vertical jumping ability in diverse populations as those previously reported would be of great value in understanding how measurement error plays a role in associative research designs such as the current investigation.

CONCLUSION

The associations presented in this study indicate that body composition has substantial relationships to CMJ performance and are more limited in the SJ. This is important to for strength and conditioning professionals when looking to improve jump performance. As increases in mass can increase muscular force and power output during the vertical jump. However, caution should be taken with regard to increases in mass coming from lean or fat mass. Increases in lean mass would provide or maintain the strength to mass ratios needed to maintain vertical jump performance.

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