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Lower-body power, linear speed, and change-of-direction speed in Division I collegiate women's volleyball players

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ABSTRACT: Volleyball players need to sprint and change direction during a match. Lower-body power, often measured by jump tests, could contribute to faster movements. How different jumps relate to linear and change-of-direction (COD) speed has not been analyzed in Division I (DI) collegiate women's volleyball players. Fifteen female volleyball players completed the vertical jump (VJ), two-step approach jump (AppJ), and standing broad jump (SBJ). Peak power and power-to-body mass ratio (P:BM) were derived from VJ and AppJ height; relative SBJ was derived from SBJ distance. Linear speed was measured via a 20-m sprint (0–10 and 0–20 m intervals); COD speed was measured using the pro-agility shuttle. Pearson's correlations ($p < 0.05$) calculated relationships between the power variables, and speed tests. There were no significant relationships between the power variables and the 0–10 m sprint interval. Greater VJ height ($r = -0.534$) and P:BM ($r = -0.557$) related to a faster 0–20 m sprint interval. This be due to a greater emphasis on the stretch-shortening cycle to generate speed over 20 m. However, although a 20-m sprint may provide a measure of general athleticism, the distance may not be specific to volleyball. This was also indicated as the AppJ did not relate to any of the speed tests. Nonetheless, VJ height and P:BM, and SBJ distance and relative SBJ, all negatively correlated with the pro-agility shuttle ($r = -0.548$ to -0.729). DI women's collegiate volleyball players could develop absolute and relative power in the vertical and horizontal planes to enhance COD speed.

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INTRODUCTION

Volleyball is a sport that requires players to perform repeated bouts of high-intensity movements, interspersed with periods of low-intensity activity [1, 2]. The high-intensity movements occur repeatedly throughout match-play and are typically comprised of explosive efforts and multidirectional court movements [3]. Furthermore, these movements are often centered around critical match-play situations such as quick positional adjustments on the court when responding to, or setting for an attack, or when performing maximal effort jumps (e.g. blocking, spiking, and the jump serve) [4]. Thus, acceleration performance, change-of-direction (COD) speed, and superior lower-body power, as evident in maximal effort jumps, is imperative for volleyball players. Subsequently, the more developed these qualities are for an athlete, the more likely they are to be successful.

Acceleration speed over multiple distances has previously been linked to better performance of jump tests among athletic populations [5–7]. Specifically, several studies have demonstrated a significant relationship between jump test results in the vertical (vertical jump [VJ], squat jump) and horizontal (bilateral and unilateral standing broad jump [SBJ]) planes and faster acceleration performance while sprinting [6, 8]. These findings suggest that enhanced performance in jumps tests, as a measure of lower-body power in both the vertical and horizontal plane, may translate to better acceleration performance in game-like settings. For example, Banda et al. [5] reported that VJ average power had a significant, large, positive correlation ($r = 0.658$, $p = 0.02$), while relative SBJ also had a significant, large, negative correlation ($r = -0.628$, $p = 0.03$) with 10-m sprint performance among Division I (DI) collegiate women's basketball players. These results highlight the importance of lower-body power to acceleration. However, whether a similar relationship is present for DI collegiate women's volleyball players remains to be seen. There is currently a paucity of research investigating the relationship between lower-body power measures in the both the vertical and horizontal plane as measured by jump tests, and acceleration performance among DI collegiate women's volleyball players.

As previously stated, volleyball requires players to make quick changes of direction when responding to or setting for an attack within match-play. Previous literature has outlined that successful

COD ability requires enhanced physical capacities of lower-body strength and power [3, 7]. This perspective is supported by McFarland et al. [7] who demonstrated a significant relationship between VJ and squat jump with the pro-agility shuttle and T-test times (r = -0.50 to -0.79, $p < 0.05$), among Division II (DII) collegiate women's soccer players. Possessing appropriate levels of lower-body power, should help facilitate an athlete to rapidly change direction in response to the demands of the match. However, the extent to which this statement is true for DI collegiate women's volleyball players has yet to be determined, although jump performance would be expected to relate to change of direction speed.

Therefore, the purpose of this study was to determine relationships between lower-body power measured via jump tests with linear and COD speed in DI collegiate women's volleyball players. A correlation analysis of a DI collegiate women's volleyball team was conducted using sport-specific field tests, including: VJ, approach vertical jump (AppJ) and SBJ; 20-m sprint test, including the 0–10 m and 0–20 m intervals; and the pro-agility shuttle. It was hypothesized that the jump tests would correlate with performance in the 20-m sprint and pro-agility shuttle. Specifically, the players with higher absolute and relative power would perform better in the linear and COD speed tests.

MATERIALS AND METHODS

Subjects

A retrospective analysis of existing data was conducted on a women's DI collegiate volleyball team, which encompassed 15 players (height = 178.13 ± 8.96 cm; body mass = 70.18 ± 7.58 kg). Similar to Banda et al. [5], age for the players was not provided in the data set. Nonetheless, the team was typical of collegiate women's volleyball players [9, 10]. All players were required to be actively competing and training with the team and were injury-free at the time of testing. The data used in this study arose as a condition of monitoring conducted by the team's coaching staff. As described by Lockie et al. [11], although data was not collected for the express purpose of research, the strict procedures adhered to by the staff ensured the data that was collected was as accurate as possible. Further, all staff members were Certified Strength and Conditioning Specialists, and followed standard procedures to ensure accurate testing and therefore data collection [12, 13]. The institutional ethics committee approved the use of pre-existing data (HSR-18-19-121). The study conformed to the recommendations of the Declaration of Helsinki. Each player had also completed the university-mandated physical examination and read and signed the university consent and medical forms for participation in collegiate athletics.

Procedures

The team's coaching staff tested all players using procedures established in the literature [5, 11]. This testing protocol was conducted at different time points across the academic year to evaluate whether the strength and conditioning program was effective. As a result, all players were familiar with the tests completed in this study. The data analyzed in this study were from assessments administered during the start of Fall semester (pre-season). Firstly, players had their height and body mass recorded. Height was measured barefoot using a portable stadiometer (Detecto, Webb City, MO, USA), while body mass was recorded by electronic digital scales (Ohaus, Parsippany, NJ, USA). Each of the player's height was measured in feet and inches and converted to cm. Body mass was given in pounds and converted to kilograms.

All three jump tests were conducted in one session, and the 20-m sprint and pro-agility shuttle were conducted in another session 24–48 hours later. The dynamic warm-up that was performed has been described in previous research [5, 11], and was performed in eight movements: lunge and twist, inchworm and frog, up dog down dog, scorpion kicks, knee hugs, overhead squat, pigeon plus twist, and band shoulder rotations. There was also a jump rope warm-up: 100 repetitions, jump warm-up, and then a jump and stick completed five times. Three trials for each jump test were completed in the university weight room, with the best trial analyzed. The running tests were performed on a volleyball court where the players regularly trained. Depending on coach preference with a particular player, 2–3 attempts were provided for the speed tests. The fastest trial for the 20-m sprint and pro-agility shuttle was analyzed.

Vertical Jump (VJ)

The VJ was used to indirectly measure lower-body power in the vertical plane [8]. This test utilized guidelines previously documented in the literature [5, 11, 14]. The Brower Vertical Jump device (Brower Timing System, UT, USA) was used to measure the jumps. Players initially stood with their dominant side toward the Brower Vertical Jump device, and while facing forwards and keeping their heels on the ground, reached upward as high as possible to calculate standing reach. The player then jumped as high as explosively as possible, with no preparatory or jab step, and extended their dominant hand along the device as high as they could. The highest jump was recorded (jump height minus the standing reach) and converted to cm. Peak anaerobic power measured in watts (PAPw) from the VJ was calculated by using the equation: $PAPw = (60.7 \cdot VJ\ height\ [cm]) + (45.3 \cdot body\ mass\ [kg]) - 2055$ [15]. PAPw was also calculated relative to body mass to provide a power-to-body mass ratio (P:BM) [5, 7, 16].

Two-step Approach Jump (AppJ)

The AppJ was used to more closely replicate measures of jump performances a volleyball player may use during a match, and was conducting according to established methods [5, 11]. The Brower Vertical Jump device was again used to record jump height. Players were allowed to use an self-selected two-step approach (maximum 5-m distance from start to take-off) and performed a bounce jump with an arm swing. This task was followed by a quick upward vertical jump, accompanied with one-arm maximal reach along the device.

As per the VJ, the highest jump was recorded (jump height minus the standing reach) and converted to cm. PAPw and P:BM were also calculated for the AppJ.

Standing Broad Jump (SBJ)

The SBJ provided an indirect measure of horizontal power [8], and was completed following standard procedures [5, 8, 16]. The volleyball player placed the toes of both feet on the back of a start line marked on the ground by tape. With a simultaneous arm swing and crouch, the player jumped forward as far as possible. For the jump distance to be recorded, the player needed to land with both feet grounded; if not, the trial was reattempted. Distance was measured using a standard tape measure, which was the perpendicular line from the front of the start line to the posterior surface of the back heel at the landing. SBJ distance was made relative to body mass via the formula: *relative SBJ = jump distance·body mass*$^{-1}$ [5, 14, 16].

20-m Sprint

Sprint time over 20-m was recorded by timing gates (PowerMax TC Gates, Brower Timing System, UT, USA). Gates were positioned at 0, 10, and 20 m, to measure the 0–10 m and 0–20 m intervals. Sprints over 10-m and 20-m have been used to assess the linear speed of athletes [17–20]. Once ready, the volleyball player began 50-cm behind the first gate in order to initiate timing once they broke the first gate, and were instructed to perform a maximal sprint from the starting line through the last gate. If the player rocked backwards or forwards prior to the initiation of the sprint, the trial was disregarded and repeated [19]. Time for each interval was recorded to the nearest 0.01 s.

Pro-agility Shuttle

This test was completed using established methods [5, 14, 19], and is shown in Figure 1. Volleyball players straddled the middle line in a 3-point stance in between the timing gate. As per the timing system set-up, one timing gate (PowerMax TC Gates, Brower Timing System, UT, USA) was used. Once the player was stable in their 3-point stance they could begin the test. Timing was initiated by the first movement of the hand. To start the test, the player turned and ran 4.57 m (5 yards) to the right side and touched the line with the right hand. The player then turned and ran 9.14 m (10 yards) to the left side and touched the other line with the left hand, before turning and sprinting back through the start/finish line. Coaches were positioned at either end of the pro-agility shuttle to ensure players touched the designated lines. If they failed to touch a line the trial was disregarded and reattempted. The timing system started when the player exited the light beam and stopped recording when players returned through the gate for the last time.

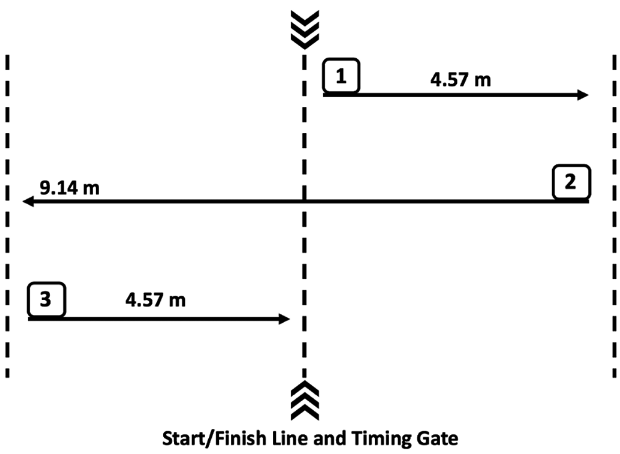

FIG. 1. Pro-agility shuttle.

Statistical Analysis

All statistical analyses were computed using the Statistics Package for Social Sciences (Version 26.0; IBM Corporation, New York, USA). Descriptive statistics (mean ± standard deviation [SD]) were calculated for each variable. Pearson's two-tailed correlations were used to calculate relationships between the jump test (VJ, AppJ, and SBJ) variables with the speed tests (0–10 m sprint interval, 0–20 sprint interval, and the pro-agility shuttle). An alpha level of $p < 0.05$ was required for significance. Correlation strength was defined as: *r* between 0 to 0.3, or 0 to -0.3, was considered small; 0.31 to 0.49, or -0.31 to -0.49, moderate; 0.5 to 0.69, or -0.5 to -0.69, large; 0.7 to 0.89, or -0.7 to -0.89, very large; and 0.9 to 1, or -0.9 to -1, near perfect for relationship prediction [21].

TABLE 1. Descriptive data for DI collegiate women's volleyball (N = 15) players in the: vertical jump (VJ); peak anaerobic power measured in watts (PAPw) and power-body mass ratio (P:BM) derived from VJ height; two-step approach jump (AppJ); PAPw and P:BM derived from AppJ height; standing broad jump (SBJ) distance and relative SBJ; 0–10 m and 0–20 m sprint interval times; and pro-agility shuttle time.

	Mean ± SD
VJ (cm)	45.74 ± 7.89
VJ PAPw (watts)	3900.47 ± 625.20
VJ P:BM (watts/kg)	55.56 ± 6.93
AppJ (cm)	59.81 ± 9.71
AppJ PAPw (watts)	4754.61 ± 584.73
AppJ P:BM (watts/kg)	68.21 ± 9.43
SBJ (cm)	203.71 ± 26.03
Relative SBJ (cm/kg)	2.94 ± 0.52
0–10 m Sprint Interval (s)	2.03 ± 0.12
0–20 m Sprint Interval (s)	3.51 ± 0.16
Pro-Agility Shuttle (s)	4.88 ± 0.19

TABLE 2. Correlations between vertical jump (VJ), VJ peak anaerobic power measured in watts (PAPw), VJ power-body mass ratio (P:BM), two-step approach jump (AppJ), AppJ PAPw, AppJ P:BM, standing broad jump (SBJ), and relative SBJ with 0–10 m and 0–20 m sprint intervals and the pro-agility shuttle time in DI collegiate women's volleyball players (N = 15).

		0–10 m	0–20 m	Pro-Agility Shuttle
VJ	*r*	-0.436	-0.534*	-0.549*
	p	0.104	0.040	0.034
VJ PAPw	*r*	-0.120	-0.252	-0.348
	p	0.670	0.364	0.204
VJ P:BM	*r*	-0.475	-0.557*	-0.548*
	p	0.074	0.031	0.035
AppJ	*r*	-0.460	-0.386	-0.351
	p	0.084	0.156	0.200
AppJ PAPw	*r*	-0.235	-0.222	-0.276
	p	0.399	0.427	0.320
AppJ P:BM	*r*	-0.509	-0.428	-0.370
	p	0.053	0.112	0.175
SBJ	*r*	-0.214	-0.209	-0.729*
	p	0.444	0.454	0.002
Relative SBJ	*r*	-0.376	-0.296	-0.589*
	p	0.167	0.283	0.021

* Significant ($p < 0.05$) relationship between the two variables.

RESULTS

Descriptive data is shown in Table 1, while the correlation data is shown in Table 2. There were no significant relationships between any of the lower-body power variables with the 0–10 m sprint interval. VJ height and P:BM exhibited significant large correlations with the 0–20 m sprint interval. The negative relationships suggested a greater VJ and P:BM related to a faster 20-m sprint. VJ height and P:BM (both large), and SBJ distance and relative SBJ (very large and large, respectively), all negatively correlated with the pro-agility shuttle. PAPw derived from the VJ, and none of the AppJ variables, correlated with linear and COD speed.

DISCUSSION

This study firstly described the lower-body power, linear speed, and COD qualities of DI collegiate volleyball players. When compared to DI women's basketball players that had their jump performance measured using similar methods [5], the volleyball players in this study had slightly greater VJ height (45.74 ± 7.89 cm vs. 43.8 ± 6.87 cm). The basketball players from Banda et al. [5] had a slightly greater AppJ height (62.01 ± 7.13 cm) compared to the volleyball players in this study (59.81 ± 9.71 cm). Lastly, the volleyball players had a superior SBJ distance compared to the basketball players from Banda et al. [5] (203.71 ± 26.03 cm vs. 199.25 ± 14.61 cm). This supports previous research in young athletes has shown specific volleyball training can translate to better jumping performance compared to athletes from other sports such as basketball and soccer [22]. The data from this study also indicates that the volleyball players from this study provided a good representative standard of collegiate female athletes. Secondly, the results from this study suggested that there were limited relationships between performance in the jump tests, and the 20-m sprint and pro-agility shuttle in DI collegiate women's volleyball players. These data have important implications for volleyball and strength and conditioning coaches.

A 10-m sprint distance provides an indicator for an athlete's ability to accelerate [18]. In DI collegiate women's basketball players, Banda et al. [5] found that P:BM (r = -0.620) and relative SBJ (r = -0.628) related to sprint speed over a 10-m distance, and suggested that these results highlighted the importance of relative power for acceleration. Although volleyball players are also court sport athletes, the results from this study demonstrated that there were no significant relationships between the VJ, AppJ, and SBJ with the 0–10 m sprint interval. There are several reasons why this may have occurred. All the jumps used in this study emphasized the stretch-shortening cycle in the lower-body muscles. Concentric power, as opposed to reactive power, may be more important for speed over short distances [23]. Accordingly, concentric power tests such as squat jumps should also be measured in DI collegiate women's volleyball players to predict acceleration performance. This type of jump test has been used for European volleyball players across different age groups, and amateur and professional levels [22, 24, 25]. Further, the 10-m sprint distance is somewhat atypical to the distances volleyball players may need to cover during a match [1]. Sprint acceleration over shorter distances has been measured in other court sport athletes. For example, Hewit et al. [26] used a 2.5-m linear sprint distance in female netball players. Future research should investigate shorter sprint acceleration distances in DI collegiate women's volleyball players to investigate how they express power over a shorter acceleration distance.

In contrast to the 0–10 m interval, there were some significant relationships between select jump tests and the 0–20 m sprint interval. Greater VJ height and P:BM had large relationships with a faster 0–20 m time. In support of these findings, Banda et al. [5] found a significant relationship between greater VJ P:BM and a faster sprint 23-m (¾ court) sprint time (r = -0.758) in DI women's collegiate basketball players. A sprint over a 20-m distance will draw more heavily on the elastic properties of the lower-body muscles [27, 28], which highlights why the results from the current study likely occurred. Nonetheless, there were no other significant relationships between the volleyball-specific jumps tests and the 20-m sprint for the players in this study. A 20-m sprint may not be indicative of the distance covered by volleyball players during a typical match [1], which could limit how the women's collegiate volleyball players in this study were able to express their lower-body power. As stated, shorter sprint distances may be more specific for court sport athletes [26]. Nonetheless, linear sprint tests do provide an indication of general athleticism and thus features in the testing batteries for many athletes [29]. This forms part of the reason why the coaching staff for this team used a 20-m sprint as part of their testing battery for volleyball.

The pro-agility shuttle is one of the most common tests used in North America to measure COD speed in athletic populations [30]. Banda et al. [5] documented that a greater VJ P:BM, higher AppJ height, and greater relative SBJ related to a faster pro-agility shuttle in DI collegiate women's basketball players. The findings from Banda et al. [5] indicated the value of lower-body power for COD speed measured by the pro-agility shuttle. This was supported by the results from this study. A greater VJ height and P:BM, and greater SBJ distance and relative SBJ, all related to a faster pro-agility shuttle time. This would suggest that to enhance COD speed, collegiate women's volleyball players should enhance absolute and relative lower-body power in both the vertical and horizontal planes. However, it should be noted that the pro-agility shuttle still features approximately 18.3-m of linear sprinting about the two direction changes [31], which may not always represent the direction changes required in volleyball. The 505 has been used to assess COD speed in DII women's volleyball players [3], and this isolates COD ability for each leg. Future research should consider utilizing a test such as the 505 in DI women's volleyball players. Nevertheless, this study indicated that collegiate women's volleyball players should develop lower-body power to improve their ability to change directions on the court. Although this has been shown in other athletic female populations [5, 7] and DII collegiate volleyball players [3], this has not been shown in DI volleyball players.

Interestingly, the AppJ did not correlate to linear or COD speed in this study. Banda et al. [5] found that AppJ height related to a faster 23-m (¾ court) sprint (r = -0.663) and pro-agility shuttle (r = -0. 805) in DI collegiate women's basketball players. However, this was not the case in the current study. The AppJ in particular is specific to volleyball, as it emulates the jumping pattern required for a spike or block [4, 5, 11, 32]. As noted, the distances covered in the 20-m sprint and pro-agility shuttle, although valuable as tests of linear [29] and COD [30] speed, may not provide the best representation of the movements required in volleyball [1]. This could have limited how the collegiate volleyball players in this study were able to express their volleyball-specific power in the 20-m sprint and pro-agility shuttle. Whether this can be shown in shorter linear and COD speed tests, such as those used in netball players [26], should be investigated in future research.

There are study limitations in this study that should be documented. Similar to Banda et al. [5], this research primarily relied on the analysis of lower-body power, irrespective of strength. Strength has been shown to contribute to linear and COD speed in DII women's collegiate volleyball players [3]. Tramel et al. [3] used a hexagonal bar deadlift to measure strength in their sample of DII volleyball players. Future research in DI women's volleyball players could also adopt this type of maximal strength test. Eccentric strength could also be a consideration as it pertains to COD speed [33], and this should be investigated specifically in collegiate women's volleyball players. This research only analyzed players from one collegiate volleyball team, so the sample may have been relatively homogenous. Future studies should test multiple volleyball teams to increase the sample size, and to allow for greater utility of the results relative to relationships between lower-body power, linear speed, and COD speed. Future studies should also consider using squat jumps [22, 24, 25], short sprint tests [26], and COD tests such as the 505 [3] to analyze speed in DI collegiate women's volleyball players. A further extension of this research could also analyze how different models of resistance training could affect lower-body power, linear speed, and COD speed in DI collegiate women's volleyball players [20].

CONCLUSIONS

This study described the lower-body power (VJ, AppJ, and SBJ), linear speed over 0–10 m and 0–20 m intervals, and COD speed measured by the pro-agility shuttle of DI collegiate women's volleyball players. The relationships between lower-body power as measured by the jump tests, with linear and COD speed was also detailed. There were no significant relationships between the jump tests with the 0–10 m interval. This may have been because the VJ, AppJ, and SBJ did not emphasize concentric power over the use of the elastic properties of the lower-body muscles. Greater VJ height and P:BM had large relationships with a faster 0–20 m time. These results showed the potential value of lower-body power to linear speed, especially considering the VJ and a 20-m sprint both stress the stretch-shortening cycle capacities of the lower-body muscles. Lastly, a greater VJ height and P:BM, and greater SBJ distance and relative SBJ, all related to a faster pro-agility shuttle time. DI collegiate women's volleyball players could develop absolute and relative power in the vertical and horizontal planes to enhance COD speed.

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Conflict of Interest Declaration

None of the authors have any conflict of interest.

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