Evaluation of Strength and Conditioning Measures With Game Success in Division I Collegiate Volleyball: A Retrospective Study

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Abstract

Bunn, JA, Ryan, GA, Button, GR, and, and Zhang, S. Evaluation of strength and conditioning measures with game success in Division I collegiate volleyball: A retrospective study. *J Strength Cond Res* 34(1): 183–191, 2020—The purpose of this study was to retrospectively assess relationships between strength and conditioning (SC) measures and game performance in Division I volleyball. Five years of SC and game data were collected from 1 women's Division I collegiate team, $n = 76$. Strength and conditioning measures included T-drill, 18.3 m sprint, back squat, hang clean, vertical jump, and broad jump. All game and SC stats were normalized to Z-scores. Analyses included assessing SC differences by position and multiple stepwise regression to assess relationships between game and SC stats. There was a significant difference by position for broad jump ($p = 0.002$), 18.3 m sprint ($p = 0.036$), vertical ($p \leq 0.001$), and total strength ($p = 0.019$). Overall, game performance and SC measures were significantly correlated ($r = 0.439$, $p \leq 0.001$). Multiple regression analyses indicated significant relationships ($p \leq 0.05$) between SC measures and game success by position as follows: defensive specialist stats with squat and total strength; setters game stats with hang cleans, T-drill, and broad jump; pin hitter game stats with vertical, squat, and total strength; middle blockers game stats with broad jump. These data indicate that SC measures correlate well with game performance and are specific by position. These data could help SC coaches create a more precise training approach to focus on improving specific measures by position, which could then translate to improved game performance. These data could also help coaches with talent identification to determine playing time and rotations to maximize player ability and achieve success.

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Introduction

Strength and conditioning (SC) training has long been emphasized to help improve performance in various sports. In traditional sports of endurance or power (e.g., running, cycling, jumping, throwing), the connection between performance in the weight room or with conditioning is much clearer and finite than sports that incorporate more skill and agility (e.g., football, basketball, volleyball, soccer). Incorporating various skills into a sport complicates how SC contributes directly to in-game performance. In particular, volleyball is complex because the quality of each contact (e.g., hit or spike) is affected by the previous contact. Specifically, a good attack is dependent on the quality of the set, and the set quality is dependent on the quality of the pass (or dig) (14). Most research published on the topic of competitive volleyball centers around specific skills that contribute to winning, anthropometric measures of successful players, and training to improve one's vertical jump or hitting velocity (6,7,9,10,39). These data help provide the basis for SC approaches to training in volleyball but do not offer information regarding the specific relationship between SC and volleyball skills.

Strength and conditioning approaches in volleyball have largely emphasized the importance of improving one's vertical jump because this skill is used frequently during hitting (spiking) and blocking. Evidence suggests that teams performing at a higher level have players with a higher vertical jump (39), and the average National Collegiate Athletic Association (NCAA) Division I player jumps 45 times in 2 sets (37). It has been proposed that reaching a threshold height above the net, although unspecified exactly what that is, through reach and vertical jump may be key factor in success, particularly in women's volleyball (10). Two studies have examined the relationship between vertical jump and hitting velocity, with mixed results (6,7). Specific to NCAA

Division I female players, no relationship was found between vertical jump height and hitting velocity (6). Various training programs including plyometrics, balance, and ballistic squat jump training have been shown to increase vertical jump performance in volleyball players (4,15,19,24,25). Strength training, particularly that of the squat, has also been shown to improve power, and therefore vertical jump (31,36,38). A significant correlation has been shown between the squat and power clean with that of vertical jump, suggesting greater strength results in a higher jump (33). Anecdotally, both of these lifts are part of regular training programs at the collegiate level and higher in the United States, thus SC coaches tend to focus on improving the vertical jump of volleyball players through strength training, but aspects of the game such as serve, receive, and setting are not focused on jumping ability.

Retrospective studies have been used to help determine which skills are most important to success in the game of volleyball. Specifically, looking back at international level play, skills in the counterattack process (blocking, digging, setting, and attacking), as well as fewer serve receive errors and hitting errors were the most important skills in predicting the match winner (5,28,29). Data from a men's Spanish league indicate that every serve receive error reduced the chance of winning by 0.6 times, and each blocked attack reduced the chance of winning by 0.7 times (30). Results from a Serbian men's league showed that efficiency (calculated by the number of successful game elements divided by the total number of attempts at that element) of the serve, block, and attack were the most impactful in determining success (20). In the women's game, digging, a defensive skill, may help to prolong rallies, and indicate the match winner (22).

Despite knowing which skills tend to be more important in game success, there is not sufficient data to address how SC training can contribute to the important skills and ultimately game success. This very idea was explicitly pointed out by Ziv and Lidor (39) in a 2010 review. The Volleyball Performance Index (VPI) was created by the American Volleyball Coaches Association (AVCA) as a method to evaluate SC and in-game metrics, and it includes a series of 8 metrics correlated with volleyball success: height, reach, vertical jump, block touch, arm swing speed, height of attack, acceleration, and lateral agility (1). While the VPI is helpful with talent identification, scouting, and playtime, it is still an incomplete tool. Therefore, the purpose of this study was to retrospectively assess correlations between SC measures (e.g., squat, hang clean, T-drill, vertical jump) and game performance in NCAA Division I women's volleyball. Furthermore, we sought to analyze position-specific relationships with SC measures and on-court performance as measured by specific volleyball skills and game statistics. We believe that this information will contribute to the scientific foundation of SC practices for collegiate volleyball, as well as potentially international and club-level volleyball. We hypothesized that agility, measured by the T-drill, would be the most important SC variable for on-court performance for setters, vertical would be the most important SC variable for the pin hitters, broad jump, and vertical would be the most important SC variables for the middle blockers, and hang clean would be the most important variable for the defensive specialists. To our knowledge, this is the first study to examine specific relationships between in-game and SC performance.

Methods

Experimental Approach and Problem

This study was a retrospective design, using data from 5 (2010–2014) NCAA volleyball seasons at 1 Division I institution. SC data (e.g., broad jump, vertical jump, squat, hang clean, 18.3 m sprint, T-drill) were measured at the beginning of each season and were the independent variables used in this study. These assessments were chosen because they are regular tests used in volleyball training studies for measuring power, agility, and strength, which are necessary for success in volleyball (8,13,16,21,23,34). The dependent variables were game statistics (e.g., kills, attempts, digs, assists, blocks) obtained from a publicly available website at the end of the competitive season. The aforementioned hypotheses were tested using correlation and multiple regression analyses were used to evaluate relationships between the SC data and the game performance data by each volleyball position.

Subjects

Participants completed the exercise trials in compliance with annual team testing, and were given the opportunity to ask questions about their participation. The study was approved by the Campbell University Institutional Review Board (CUIRB-IRB00005697) as exempt status due to the retrospective study design. All data were received in a de-identified format by researchers. Participants in this study included each contributing team member (playing in at least one-third of the sets each season) at a Division I university in one of the "power 5" NCAA conferences. Players had to be at least 18 years old, members of the varsity team, and cleared for activity by a certified athletic trainer to be considered for inclusion in the study. Each player was treated as a new participant during each season of competition. For example, if a player contributed during 3 of the seasons, she was considered 3 separate participants. Data for this study included 76 total participants over the 5-year period. Because of diversity in years of collegiate playing and training experience, participants varied in level of familiarity with the SC measures tested. At minimum, each participant had completed a familiarization with each measure before testing. Mean age was 19.5 ± 1.5 years (range, 18–22 years), mean height was 179.2 ± 7.8 cm, and mean mass was 73.7 ± 8.6 kg. The players were grouped by position to achieve specific statistical analyses. The positions were setters (n = 6, 19.9 ± 1.2 years, 179.3 ± 3.5 cm, 72.7 ± 6.5 kg), pin hitters (n = 31, 19.4 ± 1.9 years, 181.9 ± 4.4 cm, 77.6 ± 7.6 kg), middle blockers ($n = 16$, 19.7 ± 1.1 years, 185.3 ± 4.9 cm, 75.7 ± 8.3 kg), and defensive specialists ($n = 21$, 19.4 ± 1.2 years, 170.7 ± 7.9 cm, 67.5 ± 7.8 kg). The pin hitters included both left and right side (opposite) attackers.

Procedures

All SC assessments were completed in August each year, 1 week before the first practice of the competitive season. Assessments were performed as part of the normal training calendar. The study design did not include any control over diet, hydration, or recovery before SC testing or game performance. Testing included assessments of power (vertical jump, broad jump, and 18.3 m sprint), agility (T-drill), and strength (hang clean and back squat), and took place annually over the course of 4 consecutive days. On the first day, vertical jump, broad jump, 18.3 m sprint, and T-drill were all tested. Both jumping tests were conducted before the sprint and agility tests. Back squat was tested on the second day, followed by a day off on the third day. On the fourth day, the players completed hang cleans. Game statistics were obtained from a publicly available website at the end of each volleyball season.

Power, Agility, and Strength Tests. Vertical jump was measured using a Vertec Jump Tester (Sports Imports, Hilliard, OH, USA). Athletes were allowed to take a 3-step hitting approach, jumping off 2 feet, and touching the apparatus with 1 hand. Each athlete was given 3 attempts with approximately 1 minute of rest in between; if they improved on the third jump they were allowed to attempt another jump. The intraclass correlation (ICC) using this device is 0.89–0.94 (27).

For the broad jump, athletes were instructed to keep toes behind a starting line and jump out as far as possible off 2 feet and land on 2 feet. Distance was recorded from the heel of the foot that was furthest back using a standard tape measure. Each athlete was given 3 attempts with approximately 1 minute of rest in between; if they improved on the third jump they were allowed 1 more attempt. The ICC for the broad jump is 0.80 (11).

For the 18.3 m sprint, a Brower (Draper, UT, USA) laser timer was set up at both 9.14 m and 18.3 m from the start line. Athletes were instructed to start behind a line in a 2-point staggered start. The timer was started on the athlete's first movement. Each athlete was given 2 attempts, with approximately 1 minute of rest in between, and the best time was recorded. The ICC for the 18.3 m sprint is 0.98 (13).

The T-drill was used to assess agility (ICC = 0.86) (35), and is shown in Figure 1. Four cones were placed in the shape of a "T" with 4.57 m between each cone. Athletes were instructed to start with toes behind the line at the bottom of the "T" in a 2-point athletic stance. The stopwatch was started on the athlete's first movement. The athlete was instructed to sprint up and around cone 1, shuffle laterally to cone 2, change direction and shuffle laterally to cone 3, change direction and shuffle laterally back to cone 1, and back pedal back through the starting line. Each athlete was given 2 attempts and they were allowed to choose which direction they wanted to go each repetition. Approximately 1–2 minutes of rest was provided in between attempts. The best time of the 2 attempts was recorded.

The 2 strength measures used were the back squat (ICC = 0.994) (32) and the hang power clean performed above the knee (ICC = 0.969) (3). One-rep maxes (1RM) were determined for both lifts using the same protocol. Athletes were provided a progression leading up to 1RM as follows: 5 reps at 55% of 1RM, 4 reps at 65% 1RM, 3 reps at 70% 1RM, 2 reps at 80% 1RM, 1 rep at 90% 1RM, and 1 rep at 100%. If the last set was successfully completed, they had the opportunity to keep attempting 1 rep until a max was determined. Approximately, 2 minutes of rest was provided between each set performed.

Game Statistics. All game statistics were obtained from the university athletics website as end of season statistics (26). These data were publicly available. The game stats addressed in this study included kills, errors, hitting percentage, assists, ball handling errors, digs, block solos, and block assists. Each participant's individual statistics were recorded and then tabulated according to the number of sets played to control for playing time. Hitting percentage is the only statistic that was not calculated according to sets played because it is calculated based on the number of kills, errors, and total attempts to hit the ball.

Statistical Analyses

All SC and game variables were normalized using standardized Z-scores to allow for individual variables to be combined and analyzed together (18). Standardized Z-scores are approximate normal distributions with a mean equal to 0 and a standard deviation (*SD*) of 1. A Z-score of 1, 2, or 3 corresponds with 1, 2, or 3 *SD* from the estimated mean of

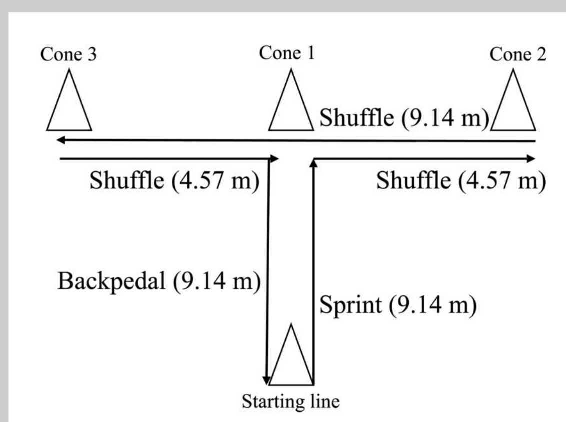

Figure 1. Schematic of the T-drill used to measure agility.

Table 1. Mean and *SD* for each position and all players for each strength and conditioning variable assessed.

	Setters	Pin hitters	Middle blockers	Defensive specialists	All players
Hang clean (kg)	58.6 ± 9.8	60.1 ± 9.8	58.8 ± 4.8	53.7 ± 7.9	57.8 ± 8.8
Squat (kg)	86.1 ± 10.9	91.7 ± 15.2	92.7 ± 10.1	85.6 ± 13.7	89.5 ± 14.3
Vertical jump (cm)	59.7 ± 4.9‡	62.4 ± 7.1‡§	66.4 ± 7.0*†§	54.9 ± 5.8†‡	60.9 ± 7.8
Broad jump (cm)	232.8 ± 8.6†‡§	213.6 ± 14.9*‡	225.3 ± 16.9*†§	208.9 ± 13.3*†‡	216.4 ± 16.4
T-drill (s)	8.14 ± 0.38	8.34 ± 0.32	8.38 ± 0.30	8.45 ± 0.32	8.38 ± 0.33
18.3 m sprint (s)	3.05 ± 0.08§	3.13 ± 0.14§	3.10 ± 0.11§	3.23 ± 0.16*,†,‡	3.14 ± 0.15

*Indicates a significant difference from the setters.
†Indicates a significant difference from the pin hitters.
‡Indicates a significant difference from the middle blockers.
§Indicates a significant difference from the defensive specialists.

a given variable, assuming a normal distribution of data. Z-scores were obtained for each of the SC variables and combined to calculate a total SC testing Z-score (SCZ) for each athlete. The same procedure was performed to calculate a total in-game performance Z-score (GZ) for each athlete using all in-game variables selected. Inverse Z-scores were calculated for variables where lower numbers mean better performance (18.3 m sprint, T-drill run, and errors) to ensure that the more desirable outcome was always scored positively. ICCs were calculated for reliability of the Z-score analysis of both SC and in-game statistics.

Athletes were separated by position grouping (setter, pin hitter, middle blocker, and defensive specialist) and compared (using a confidence level of 95%) within each grouping, in addition to the overall team comparison. A Pearson correlation was used to examine a relationship between the SCZ score GZ score for the entire team. A multiple analysis of variance (MANOVA) was used to assess differences in SC performance by position. Least significant difference post hoc analysis was used to examine specific differences if significance was determined in the main effects.

Multiple stepwise regression analyses were used to find which specific SC variables had a significant relationship with specific in-game statistics by position. In-game statistics that were addressed for the setter included: assists, digs, block assists, and GZ. In-game statistics for the pin hitters included digs, kills, errors, hitting percentage, block assists, and GZ. For the middle blocker, in-game statistics addressed were kills, errors, hitting percentage, block assists, block solos, and GZ. Last, for the defensive specialists, the only 2 in-game statistics used were digs and GZ. All SC variables were used in the stepwise regression analysis as independent variables, and all in-game statistics were dependent variables.

Descriptive, SC data, and in-game data are presented as mean ± *SD*. Regression analyses are presented as r^2 values, significance, and Cohen's f^2 effect size calculations. Effect sizes were interpreted as small 0.02–0.15, moderate 0.15–0.35, and large >0.35 (2). Statistical power was assessed using these effect sizes for the primary in-game statistic for each position: assists for setters, kills for pin hitters and middle blockers, and digs for defensive specialists. All data were analyzed using Microsoft Excel 2010 (Microsoft, Redmond,

Table 2. All game data calculated by the number of sets played.*

	Setters	Pin hitters	Middle blockers	Defensive specialists	All players
Kills/set	0.8 ± 0.3	1.6 ± 0.9†	1.9 ± 0.8†	0.1 ± 0.4	1.2 ± 1.0
Errors/set	0.2 ± 0.1	0.9 ± 0.5†	0.8 ± 0.1†	0.1 ± 0.3	0.6 ± 0.5
Hitting %	0.277 ± 0.121	0.160 ± 0.074†	0.247 ± 0.072†	N/A	0.150 ± 0.189
Assists/set	9.1 ± 1.6†	0.1 ± 0.1	0.0 ± 0.0	0.3 ± 0.2	1.0 ± 2.7
Digs/set	2.0 ± 0.6†	0.9 ± 0.8†	0.3 ± 0.2	2.1 ± 1.2†	1.2 ± 1.1
Block solos/set	0.04 ± 0.04	0.03 ± 0.03	0.14 ± 0.05†	N/A	0.05 ± 0.05
Block assists/set	0.45 ± 0.09†	0.38 ± 0.24†	0.74 ± 0.21†	N/A	0.4 ± 0.3

*TA is total attempts.
†Indicates the statistic used for each position in analyses to assess relationships with strength and conditioning data.

TABLE 3. Results of the multiple regression analyses by position.*†

Skill	Vertical jump	Broad jump	T-drill	18.3 m Sprint	Hang clean	Squat	SCZ	Statistics
Setters								
Assists/set					‡			$r^2 = 0.670$, $p = 0.024$, $f^2 = 2.03$
Block assists/set		‡						$r^2 = 0.716$, $p = 0.016$, $f^2 = 2.52$
Digs/set			‡		‡			$r^2 = 0.953$, $p = 0.020$, $f^2 = 20.27$
GZ		‡						$r^2 = 0.642$, $p = 0.030$, $f^2 = 1.79$
Pin hitters								
Kills/set							‡	$r^2 = 0.436$, $p \leq 0.001$, $f^2 = 0.77$
Errors/set							‡	$r^2 = 0.333$, $p = 0.001$, $f^2 = 0.499$
Digs/set	‡							$r^2 = 0.197$, $p = 0.012$, $f^2 = 0.245$
Block assists/set						‡		$r^2 = 0.334$, $p = 0.001$, $f^2 = 0.502$
Hitting %								–
GZ	‡							$r^2 = 0.280$, $p = 0.002$, $f^2 = 0.389$
Middle blockers								
Kills/set		‡						$r^2 = 0.482$, $p = 0.003$, $f^2 = 0.931$
Errors/set		‡						$r^2 = 0.542$, $p = 0.001$, $f^2 = 1.18$
Block assists/set		‡						$r^2 = 0.497$, $p = 0.002$, $f^2 = 0.988$
Block solos/set		‡						$r^2 = 0.477$, $p = 0.003$, $f^2 = 0.912$
Hitting %								–
GZ		‡						$r^2 = 0.353$, $p = 0.015$, $f^2 = 0.546$
Defensive specialists								
Digs/set							‡	$r^2 = 0.637$, $p \leq 0.001$, $f^2 = 1.75$
GZ	‡					‡		$r^2 = 0.571$, $p \leq 0.001$, $f^2 = 1.33$

*GZ = game Z-score; SCZ = strength and conditioning total Z-score; SC = strength and conditioning.
†The r^2, significance, and effect size (f^2) are provided for each in-game statistic where SC variables were correlated.
‡Indicates the SC variable that was placed in the regression with the specific in-game statistic.

WA, USA) and SPSS (version 23.0; Chicago, IL, USA). An alpha level of 0.05 was used to determine significance.

Results

The Pearson product correlation for all players between GZ and SCZ was $r = 0.439$, $p \leq 0.001$, indicating a significant relationship between SC metrics and game performance. ICCs were as follows for each group: setters = 0.869 (95% CI: 0.550–0.991); pin hitters = 0.651 (95% CI: 0.253–0.889); middle blockers = 0.775 (95% CI: 0.380–0.963); and defensive specialists = 0.358 (95% CI: −0.481 to 0.828). ICCs for each position except for defensive specialists indicate a moderate to high correlation Z-scores of SC and in-game metrics. The ICC for defensive specialists can be classified as low to moderate.

Table 1 shows the mean ± *SD* for all SC data by position and for all players combined. The MANOVA revealed a significant difference among positions for several SC variables including: broad jump ($F(3,71) = 5.639$, $p = 0.002$), vertical ($F(3,71) = 9.923$, $p \leq 0.001$), 18.3 m sprint ($F(3,71) = 3.003$, $p = 0.036$), and SCZ ($F(3,71) = 3.516$, $p = 0.019$). Specifically, the middle blockers had a higher vertical jump compared with the other positions, the setters and middle blockers had a longer broad jump than the other 2 positions, and the defensive specialists were slower in the 18.3 m sprint than the other 3 positions. There was also a significant difference between positions for SCZ, with the defensive specialists having a lower SCZ score than the other 3 positions (setters, $p = 0.030$; pin hitters, $p = 0.029$; and middle blockers $p = 0.005$). Table 2 shows the mean ± *SD* game data calculated per set played for the season by position and for all players combined. This table also shows which specific game stats were used in the stepwise regression analyses with the SC data. From these 2 tables, the data support the need for separate positional analysis because different skills are important by position, and players in different positions do not show a likeness in each of the SC metrics.

The stepwise multiple regression analyses revealed that there are several differences in importance of SC metrics by position. Table 3 shows which SC metric was kept in the multiple regression analysis for each in-game measure of importance by position. The statistics column indicates the r-squared value, significance, and effect size of the regression for each skill. The hang clean, broad jump, and T-drill had the strongest relationships with the specific in-game skills used for setters. Overall, these SC metrics made up 64–95% of the variation with in-game success. We hypothesized that the T-drill would be the most important SC metric, for this group, but both the broad jump and hang clean were correlated with more setter-specific skills. The power analysis for this group was 0.44. All effect sizes from these regressions are classified as large. For the pin hitters, the stepwise multiple regression analysis revealed that vertical jump, SCZ, and squat had the strongest relationships with game statistics. None of the SC variables were significantly correlated with hitting percentage. The variation attributed to SC metrics with pin hitters is lower, ranging from 20 to 44%. We hypothesized that the vertical jump would have the greatest link with success for this position, but total strength and squat also proved to be impactful. The power analysis for this group was 0.99. All effect sizes from these regressions are classified as large, except digs/set which showed a moderate effect size. For the middle blockers, the broad jump was the only SC variable that was significantly correlated with game statistics. None of the SC variables were significantly correlated with hitting percentage. Collectively, the SC metrics account for 35–54% variation with in-game statistics. We hypothesized that the broad jump and vertical jumps would both be correlated with specific in-game statistics for this position, but the broad jump proved to be the more important variable. The power analysis for this group was 0.87. All effect sizes from these regressions are classified as large. The regression analyses revealed that squat, vertical jump, and SCZ were the significantly correlated SC metrics with in-game metrics for defensive specialists. The data indicate that the SC measures accounted for 57–64% of the variation in in-game statistics. We hypothesized that hang cleans would be the most impactful SC measure for this group, but it was not significant for either in-game metric. The power analysis for this group was 0.96. Both effect sizes from these regressions are classified as large.

Discussion

The purpose of this study was to assess if specific SC measures were significantly related to game performance in Division I NCAA women's volleyball. The results indicate that there is a significant correlation between SC measures and on-court performance, and correlations also exist at the position-specific level. To our knowledge, this is the first study to directly assess these relationships.

Studies have shown that proficiency in skills related to the counterattack (blocking, digging, setting, and attacking) are related with greater team success (5,22,28,29). In addition, reduced hitting errors have also been associated with winning (5,28,29). Addressing each of these skills by position, the results from this study suggest that it may be beneficial if SC training were more position-specific. For example, hang cleans and agility make up approximately 95% of the variation in digs/set for setters, thus it would be beneficial for setters to focus on these aspects in their training. On the contrary, having all around good power, agility, and strength makes up approximately 64% of the variation in defensive specialists, therefore, their off-court training would need to be different from setters. Interestingly, the 3 positions responsible for making most digs had 3 different SC measures associated with the skill. The SC metrics associated with setters and defensive specialists is congruent with data from the VPI (1). Speculatively, the association between digs and vertical jump for pin hitters occurred because athletic pin hitters who play all 6 rotations tend to have a high vertical jump.

For success in assists, these data indicate that setters should work to improve their hang clean performance. This disagreed with our hypotheses that the T-drill, a measure of agility, would be the most impactful test on this statistic. On-court training in this skill is largely centered on footwork and improving movement to the ball, thus having good agility was thought to be the primary SC component. The data may have been different from expected because the n-size of this particular group was so small ($n = 6$) and because individuals involved during multiple seasons of this study could therefore have a larger influence on the data. Specifically, 1 athlete was included in this group 3 times because she set for the team 3 of the 5 years analyzed. Therefore, her data could have provided a larger influence on the results of this study. This is a limitation of the study design with a multiyear study like this. Further analyses with a larger n-size, more statistical power, and greater player variation within this position will help to understand these data further.

For attacking, the data indicate that total strength was the only variable related to kills and errors for the pin hitters, whereas the broad jump was of greater importance for kills and errors for the middle blockers. First, we hypothesized that vertical jump would have the strongest association with all hitting, and these data disagree with our hypothesis. Second, it is important to note the positional difference with this skill because the movement of hitting within the counterattack is different between these 2 positions. During the counterattack both players transition from defense to offense, but in very different ways. The middle blocker generally covers more space and has less time to achieve the movements necessary for hitting compared with the pin hitter. Thus, the significance of the broad jump associated with hitting success for the middle blocker does make sense. This skill is likely used more by the middle blocker to achieve fast explosive motion when there is little time for them to transition from defense to offense. Conversely, because the pin hitter has more time for these actions, they are more likely to hit against a double block that is against multiple defenders. This emphasizes the need for good total strength, which could then transfer into a high vertical jump and fast arm swing and more powerful strike.

Blocking has been shown to be an integral skill in volleyball success (20). Pin hitters and setters usually taking 1 or 2 quick lateral adjustment steps before performing the block jump, whereas middle blockers are responsible for covering more space using either several running steps or a 3-step cross-over. The squat was the SC variable correlated with blocking success for the pin hitters. A standard block jump uses a countermovement before jumping, and this movement is very similar to a squat. Biomechanical research shows that the knee angle during the lateral motion to block, as well as during the block jump is approximately 90° (17). The broad jump was strongly correlated with blocking success for middle blockers and setters. Oftentimes, middle blockers will move in a more linear fashion, rather than lateral, because of the need to cover space faster to be part of a block, which is likely why the broad jump can account for 47–49% of the variation in blocking. It is likely that the broad jump was strongly correlated with blocking for setters because of the small n-size. Again, further analyses of this position are necessary to determine whether this relationship is sustained.

Total GZ was correlated with hang clean for setters and the broad jump for middle blockers. The hang clean is believed to improve power output and vertical jump, which may directly impact success in volleyball (12), and this correlation helps to create a stronger case for the use of this dynamic lift. Motion for the hang clean occurs from at or just below the knee to racking the weight on the shoulders with fast and powerful motions in the hips and arms. This motion mimics similar movements taken by setters when preparing to set a ball. Similarly, the broad jump mimics middle blocker movements on the court, and this was a significant correlate with several of the middle blocker in-game skills evaluated, including GZ. The GZ was also significantly correlated with the vertical jump and squat for defensive specialists. This is in agreement with previous assessments indicating that the better defensive players at the international and national levels of play had a high vertical jump (1).

Talent identification is a new "science" incorporating anthropometrics and various assessments. Data from SC measurements now have an applied association with success with in-game volleyball statistics. This information could work in conjunction with the VPI created by the AVCA (1). While the VPI is intended to be a tool to help evaluate a portion of athletic talent, not an end-all assessment of volleyball ability, it does indicate specific areas of importance by position. For setters, vertical jump, arm swing speed, acceleration, and proagility were differentiating factors. For pin hitters, the factors included are reach, block touch, and acceleration. For middle blockers, the proagility test was the most significant factor, and for defensive specialists, a high vertical jump, fast arm speed, and the proagility test were rated for better athleticism. The results from this study agree with the VPI and indicate differences in SC by position.

The results of this study provide insight about the transfer and correlation of some SC variables to game play in NCAA Division I volleyball. A strength of this study was that it followed the same university with the same head volleyball coach and SC coach over a 5-year period, so coaching and SC measurement was very consistent during this time. However, because the study was used at only 1 university, players who were there longer in the 5-year period were more impactful in the results of the study than those that were there for a shorter time. This likely influenced the results of the setters than any other position because of the small size of that group, thus having the lowest statistical power. Another limitation of this study is related to motivation, toughness, and game vision. It is recognized that both can significantly impact one's play and success, and these were not measured in this study. Still, the regression analyses by position show that SC metrics are responsible for a moderate to large portion of variation with in-game skills, and perhaps the remaining portions can be attributed to vision, motivation, and toughness, as well as other variables.

Practical Applications

Intuitively, volleyball, and SC coaches have often thought that various sessions in the weight room and conditioning were impactful in on-court performance, but no statistical procedures were ever used to address this "hunch." The information from this study suggests that there is a direct link between performance in the weight room and success in matches on the volleyball court in elite collegiate athletes. This information may be beneficial for a volleyball coach to help determine starting lineups, playing rotations, playing style, and substitutions during a match. These data can help SC coaches better assess strengths and weaknesses of players, and select training that can specifically impact certain SC measures, and therefore certain performance outcomes. In addition, this information could help the SC coach to relate performance in the weight room with success on the court. These results also suggest that SC coaches may want to incorporate position-specific SC training, with setters focusing on improving hang cleans, middle blockers focusing on improving their broad jump, pin hitters focusing improving vertical jump and squat, and defensive specialists focusing on improving their overall strength. Last, these data can also be used in conjunction with other talent identification methods such as the VPI as tools to help determine success in volleyball, or distribution of scholarship offers on the collegiate level.

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