Relative Importance of Strength, Power, and Anthropometric Measures to Jump Performance of Elite Volleyball Players

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Abstract

The purpose of this investigation was to examine the potential strength, power, and anthropometric contributors to vertical jump performances that are considered specific to volleyball success: the spike jump (SPJ) and counter-movement vertical jump (CMVJ). To assess the relationship among strength, power, and anthropometric variables with CMVJ and SPJ, a correlation and regression analysis was performed. In addition, a comparison of strength, power, and anthropometric differences between the seven best subjects and the seven worst athletes on the CMVJ test and SPJ test was performed. When expressed as body mass relative measures, moderate correlations (0.53–0.65; $p \leq 0.01$) were observed between the 1RM measures and both relative CMVJ and relative SPJ. Very strong correlations were observed between relative (absolute height-standing reach height) depth jump performance and relative SPJ (0.85; $p \leq 0.01$) and relative CMVJ (0.93; $p \leq 0.01$). The single best regression model component for relative CMVJ was the relative depth jump performance, explaining 84% of performance. The single best predictor for relative SPJ was also the relative depth jump performance (72% of performance), with the three-component models of relative depth jump, relative CMVJ, spike jump contribution (percent difference between SPJ and CMVJ), and relative CMVJ, spike jump contribution, and peak force, accounting for 96% and 97%, respectively. The results of this study clearly demonstrate that in an elite population of volleyball players, stretch-shortening cycle performance and the ability to tolerate high stretch loads, as in the depth jump, is critical to performance in the jumps associated with volleyball performance.

Key Words spike jump, countermovement, jump, testing

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Introduction

Volleyball is characterized by short, frequent bouts of high-intensity exercise spaced between low-intensity activity periods and recovery time (13,18). During these high-intensity bouts of activity, and while in the front court, players are involved in defensive and offensive jumping activities (6,13). These jumping activities can include both horizontal approach movements (spike jumps, SPJ) and movements without an approach (jump setting, jousts, blocking). Considering the tactical nature of these jumping activities and the frequency with which they occur in a typical match, both counter-movement jump (CMVJ) ability (i.e., jump and reach height) and approach jump ability (i.e., SPJ height) are considered critical performance indicators in volleyball (7,14,16).

Several studies have shown strong relationships between strength and power measures and vertical jump performance (1,12,15,19–21), suggesting that to some extent, strength and power qualities influence performance in vertical jumping. However, it seems that the specific relationship among these different variables may vary from sport to sport and among development levels of athletes. Furthermore, correlation analysis within a heterogeneous sample can be misleading when attempting to apply the results to a homogeneous sample of elite athletes.

A precise understanding of the relationship between specific force-velocity characteristics and volleyball-specific vertical jump performance is unknown for elite jumping populations. Therefore, the purpose of this investigation was to examine the potential strength, power, and anthropometric contributors to vertical jump performances that are considered specific to volleyball success: the SPJ and CMVJ. As the key aim of this investigation was to elucidate the trainable aspects of vertical jumping performance in elite male volleyball players, a priority was placed on the interrelationships between those variables that could be enhanced to improve relative vertical jump performance.

Methods

Experimental Approach to the Problem

To assess the relationship between strength and power and anthropometric variables with CMVJ and SPJ, a correlation and regression analysis was performed. In addition, a comparison of strength and power performance and anthropometric variables between the seven best CMVJ (top third) and the seven worst CMVJ (bottom third), as well as the seven best spike jumpers and the seven worst spike jumpers, was performed. The researchers hypothesized that subjects with high relative strength and power qualities and well-developed stretch-shortening cycle abilities would perform better on the vertical jump tests. It was also hypothesized that data analysis would reveal that SPJ performance involves a greater array of contributing factors to performance compared with the CMVJ, as it involves both horizontal and vertical components.

Subjects

Twenty-one subjects whose mean age, height, and weight were 20.8 ± 3.9 years, 201.3 ± 7.0 cm, and 93.0 ± 8.1 kg, respectively, participated in this study. All subjects were scholarship holders within the national volleyball program. Eleven subjects divided their time between professional European contracts and national team duties during the time of the study, whereas the remaining 10 subjects divided their time between the domestic league and their national team duties. Ten of the subjects had Olympic Games experience or World Championships experience; the remaining 11 subjects had, at a minimum, experience in non-championship international tours.

All subjects received a clear explanation of the study, including the risks and benefits of participation. Testing was in accordance with and approved by institutional ethics, and written consent for testing was obtained in the athlete's scholarship holder's agreement.

Testing Protocols

All testing was conducted in accordance with current National Sport Science Quality Assurance program (NSSQA) protocols. These protocols stipulate that all testing be administered by a strength and conditioning coach or sport scientist who is currently certified by the NSSQA program and that all equipment and testing methodology used is in accordance with the accepted protocols specific to that test or assessment.

In the 24-hour period before performing the tests, the subjects did not engage in activity that was considered unduly fatiguing in regards to the maximal strength, vertical jump, or power testing. Because the subjects involved in this study were full-time athletes, typically training more than 25 hours per week, this was accomplished by testing the athletes the day after a complete rest day, over a 2-week block. For half of the group, the first day of testing involved anthropometry, vertical jumping, and 1RM strength testing, whereas the following week involved the incremental load power profile. The other half of the subject pool performed the testing in the reverse sequence.

All of the subjects were national program scholarship holders with at least 1 year of previous experience in the program. Therefore, all subjects had multiple exposures to the tests involved in this study in advance of data collection, and the group-specific repeatability of measures was established. Subjects were given up to four trials on each performance test, with 1 minute between jump test trials and 3–5 minutes' rest between trials of the incremental load power profile and the 1 RM lifts.

As per the normal testing protocol for this group, the subjects completed their typical practice warm-up before testing sessions. In brief, this warm-up includes 10 minutes of general activity (walk, jog, light stretching), followed by 10 minutes of dynamic activity that increased in speed and intensity (skips, leg swings, arm swings), 10 minutes of two-person volleyball skill rally (i.e., "pepper drill"), followed by 3–5 minutes of rest before commencing the testing session. Subjects were re-familiarized with the testing protocol via two to five submaximal practice attempts.

Vertical Jump Assessments

Subjects were tested on their standing reach height before they performed a maximal effort CMVJ, depth jump from a 0.35-m box (DJ35), and a SPJ (with approach) using a vaned jump and reach apparatus that allowed for recording of the maximal height reached to the nearest centimeter (Yardstick; Swift Systems, Lismore, Australia). The measurement of the standing reach height allowed for a calculation of their relative jump heights on each of the jumping tasks (absolute jump height (cm) – standing reach height (cm) = relative jump height). In the CMVJ, no horizontal approach was allowed, whereas in the SPJ, an approach of three or four steps was used based on the athlete's preference. For the DJ35, subjects stepped off the box and, immediately upon landing, attempted to jump as high as possible, sometimes referred to as a "bounce drop jump" (2). During pilot testing with this athlete population using these instructions and this drop height, ground contact times ranged from 145 to 220 ms, suggesting that this methodology assessed "fast" stretch-shortening cycle activity. The population-specific intraclass correlation coefficients (ICC) (%TE in parentheses) of the height of the CMVJ, DJ35, and SPJ were 0.98 (2.5%), 0.97 (3.0%), and 0.97 (3.2%), respectively.

A fourth jump variable, termed the "spike jump contribution" was calculated using the results of the relative displacement of the CMVJ and the relative displacement of the SPJ. This variable was calculated to reflect the additional contribution that the horizontal approach had on vertical jumping abilities, based on the premise that differences in horizontal power production and technique would be reflected among subjects with this variable. The formula used was:

$$\text{Spike Jump Contribution\%} = ([\text{Relative SPJ}/\text{Relative CMVJ}] - 1) \times 100$$

Incremental Load Power Profile

Subjects performed a maximal effort countermovement jump at body mass and body mass + 50%, with the intent to jump as explosively as possible. Jumps were conducted with the subjects standing on a commercially available force plate (400 Series Performance Force Plate; Fitness Technology, Adelaide, Australia). A position transducer (PT5A; Fitness Technology) was connected to a fiberglass pole (body weight jumps) or Olympic weightlifting bar and Olympic lifting plates (bodyweight plus 50%) held across the shoulders (Figure 1). Both the force plate and position transducer were interfaced with computer software (Ballistic Measurement System; Fitness Technology) that allowed direct measurement of force-time characteristics (force plate) and displacement-time and velocity-time (position transducer) variables as outlined by Dugan et al. (5).

Before all data collection procedures, the force plate was calibrated using a spectrum of known loads, then assessed against three criterion masses. The position transducer was calibrated using a known distance of 1 m. The ICC and %TE of the force, velocity, and power measures used in the assessment methodology with this population group was 0.95–0.97 (3.1–4.0%), 0.71–0.83 (3.3–7.3%), and 0.80–0.98 (3.0–9.5%), respectively.

1 Repetition Maximum Testing

Subjects performed a maximal effort, single-repetition power clean and maximal effort, single-repetition parallel squat as part of this investigation. A complete warm-up, including three submaximal incrementing load sets not approaching volitional failure, was performed. This was followed by a single repetition set using a load of approximately 90% of maximum. Thereafter, subjects increased the barbell load by 2.5–10 kg until a maximal successful lift was performed, with the aim that this lift would be accomplished within four sets of the 90% lift. The subjects were given 3-minute rests between warm-up attempts and 5-minute rests between near-maximal and maximal attempts (90% lift to 1RM). The population-specific ICC and %TE of the 1RM power clean and 1RM squat were 0.94 (4.8%) and 0.97 (3.5%), respectively.

Figure 1. Loaded counter-movement vertical jump assessment used in the Incremental Load Power Profile. Position Transducer is attached to the bar and mounted on an overhead 4 meter beam. Force platform is inset into a 4 m x 4 m Olympic lifting platform.

Anthropometric Variables

All subjects were assessed for height, weight, standing reach, and ratio of body-mass divided by the sum of seven skinfolds. All of these tests were conducted by a certified International Society for the Advancement of Kinanthropometry (ISAK) anthropometrist and were in accordance with the protocols developed by the ISAK (which are identical to those of NSSQA). All anthropometric testing was conducted by a single researcher.

The height and weight assessments were conducted using a recently calibrated stadiometer and scale. Standing reach was assessed using the same vaned jump and reach apparatus used for vertical jump assessments. For the standing reach, wearing their normal footwear, the subjects stood underneath the vanes of the apparatus and were encouraged to fully extend their dominant arm to displace the highest vane possible to determine their maximal standing reach height. The ICC and %TE for height, weight, and standing reach were 0.99 (1.5%), 0.99 (1.2%), and 0.98 (2.0%), respectively.

The sum of seven skinfolds included measurement of the triceps, sub scapulae, biceps, supra-spinale, abdominals, quadriceps, and calf. The ratio of body mass/sum of seven skinfolds was used to reflect the amount of mass made up of lean tissue. The test-retest ICC and %TE for the skinfold assessment was 0.99 (2.2%); the researcher's credentialing against an ISAK criterion tester was 0.98 (2.8%).

Statistical Analyses

Tests of normality of distribution and skewness revealed no abnormal data patterns. Therefore, Pearson product correlation analysis was performed to assess the relationships between the CMVJ and SPJ and the 1RM tests, anthropometry, and the force-velocity measures obtained from the incremental load power profile. Correlations were considered significant and highly significant at values of $p \leq 0.05$ and $p \leq 0.01$, respectively. Stepwise multiple linear regression models were constructed to examine the components of CMVJ and SPJ performance. Independent t-tests were performed on each variable, comparing the test results of the seven best and seven worst relative SPJ subjects and with the seven best and seven worst relative CMVJ subjects to identify characteristics of the best and worst jumpers. Differences between groups were considered significant when values of $p < 0.05$ were observed. In addition, Cohen's effect size statistics (ESS) were calculated for the magnitude of difference between groups using the following descriptors: $>0.5 =$ large; $0.1–0.3 =$ moderate; $<0.1 =$ small (4).

Results

The strength and significance of the relationships among strength, anthropometric, force-velocity, and vertical jump variables are presented in Table 1. Regression analysis for the

TABLE 1. Correlation matrix of strength, power, and anthropometric variables of elite volleyball players.

–		Height	Skinfolds	Reach	RPKPBM	RMPBM	RPKFBM	PKVBM	$RPKP_{50}$	RMP_{50}	$RPKF_{50}$	PKV_{50}	RPC	R1SRM	CMVJ	RCMVJ	SPJ	RSPJ	%CONT	DJ35	RDJ35
Height	Pearson *R*	1.00	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	Sig.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Skinfolds	Pearson *R*	0.04	1.00	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	Sig.	0.87	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Reach	Pearson *R*	0.95†	0.05	1.00	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	Sig.	0.00	0.82	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
RPKPBM	Pearson *R*	−0.21	0.46*	−0.20	1.00	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	Sig.	0.34	0.03	0.38	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
RMPBM	Pearson *R*	−0.23	0.26	−0.25	0.85†	1.00	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	Sig.	0.30	0.24	0.26	0.00	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
RPKFBM	Pearson *R*	−0.11	0.10	−0.14	0.03	0.34	1.00	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	Sig.	0.62	0.67	0.54	0.90	0.12	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
PKVBM	Pearson *R*	−0.04	0.42*	−0.02	0.82†	0.66†	−0.26	1.00	–	–	–	–	–	–	–	–	–	–	–	–	–
–	Sig.	0.84	0.05	0.93	0.00	0.00	0.25	–	–	–	–	–	–	–	–	–	–	–	–	–	–
$RPKP_{50}$	Pearson *R*	−0.42	0.20	−0.43*	0.63†	0.76†	0.38	0.31	1.00	–	–	–	–	–	–	–	–	–	–	–	–
–	Sig.	0.06	0.39	0.05	0.00	0.00	0.09	0.17	–	–	–	–	–	–	–	–	–	–	–	–	–
RMP_{50}	Pearson *R*	−0.46*	0.06	−0.46*	0.53†	0.74†	0.41	0.30	0.93†	1.00	–	–	–	–	–	–	–	–	–	–	–
–	Sig.	0.03	0.80	0.04	0.01	0.00	0.07	0.19	0.00	–	–	–	–	–	–	–	–	–	–	–	–
$RPKF_{50}$	Pearson *R*	−0.52†	0.20	−0.48*	0.51*	0.56†	0.43*	0.22	0.81†	0.82†	1.00	–	–	–	–	–	–	–	–	–	–
–	Sig.	0.01	0.37	0.03	0.02	0.01	0.05	0.33	0.00	0.00	–	–	–	–	–	–	–	–	–	–	–
PKV_{50}	Pearson *R*	−0.13	0.17	−0.18	0.42	0.52†	0.18	0.25	0.85†	0.77†	0.53†	1.00	–	–	–	–	–	–	–	–	–
–	Sig.	0.59	0.47	0.44	0.06	0.01	0.43	0.28	0.00	0.00	0.01	–	–	–	–	–	–	–	–	–	–
RPC	Pearson *R*	−0.67†	0.35	−0.72†	0.50*	0.44*	0.03	0.42*	0.51*	0.49*	0.57†	0.27	1.00	–	–	–	–	–	–	–	–
–	Sig.	0.00	0.11	0.00	0.02	0.04	0.91	0.05	0.02	0.02	0.01	0.23	–	–	–	–	–	–	–	–	–
R1SRM	Pearson *R*	−0.75†	0.27	−0.77†	0.52†	0.54†	0.27	0.41*	0.59†	0.61†	0.63†	0.32	0.90†	1.00	–	–	–	–	–	–	–
–	Sig.	0.00	0.23	0.00	0.01	0.01	0.23	0.05	0.00	0.00	0.00	0.16	0.00	–	–	–	–	–	–	–	–
CMVJ	Pearson *R*	0.77†	0.15	0.71†	0.18	0.17	0.03	0.15	−0.01	−0.15	−0.29	0.17	−0.40	−0.44*	1.00	–	–	–	–	–	–
–	Sig.	0.00	0.52	0.00	0.43	0.44	0.89	0.51	0.96	0.52	0.21	0.45	0.07	0.04	–	–	–	–	–	–	–
RCMVJ	Pearson *R*	−0.41	0.10	−0.53†	0.48*	0.55†	0.24	0.20	0.62†	0.50*	0.38	0.46*	0.53†	0.54†	0.21	1.00	–	–	–	–	–
–	Sig.	0.06	0.67	0.01	0.02	0.01	0.29	0.38	0.00	0.02	0.09	0.03	0.01	0.01	0.35	–	–	–	–	–	–
SPJ	Pearson *R*	0.42*	0.51†	0.38	0.54†	0.43*	0.15	0.45*	0.20	0.05	0.02	0.17	−0.01	−0.06	0.77†	0.40	1.00	–	–	–	–
–	Sig.	0.05	0.01	0.08	0.01	0.04	0.51	0.03	0.38	0.84	0.95	0.46	0.97	0.80	0.00	0.06	–	–	–	–	–
RSPJ	Pearson *R*	−0.49*	0.41	−0.56†	0.66†	0.61†	0.26	0.41*	0.57†	0.46*	0.46*	0.31	0.65†	0.64†	0.05	0.84†	0.54†	1.00	–	–	–
–	Sig.	0.02	0.06	0.01	0.00	0.00	0.24	0.05	0.01	0.03	0.03	0.17	0.00	0.00	0.83	0.00	0.01	–	–	–	–
%CONT	Pearson *R*	−0.34	0.54†	−0.28	0.48*	0.23	0.02	0.49*	0.03	0.00	0.25	−0.21	0.36	0.37	−0.34	−0.03	0.25	0.47*	1.00	–	–
–	Sig.	0.12	0.01	0.21	0.02	0.31	0.93	0.02	0.88	0.99	0.27	0.36	0.10	0.09	0.12	0.90	0.26	0.03	–	–	–
DJ35	Pearson *R*	0.66†	0.14	0.59†	0.20	0.21	0.01	0.22	0.04	−0.06	−0.22	0.22	−0.29	−0.35	0.92†	0.28	0.80†	0.17	−0.26	1.00	–
–	Sig.	0.00	0.53	0.00	0.37	0.36	0.98	0.33	0.88	0.79	0.34	0.35	0.19	0.11	0.00	0.20	0.00	0.44	0.25	–	–
RDJ35	Pearson *R*	−0.44*	0.08	−0.57†	0.43*	0.50*	0.18	0.24	0.58†	0.52†	0.41	0.43*	0.55†	0.55†	0.11	0.92†	0.37	0.84†	0.06	0.32	1.00
–	Sig.	0.04	0.73	0.01	0.04	0.02	0.44	0.28	0.01	0.01	0.07	0.05	0.01	0.01	0.63	0.00	0.09	0.00	0.79	0.15	–

MP_{50} = mean power with body mass + 50%; $RPKP_{50}$ = relative peak power with body mass + 50%; RMP_{50} = relative mean power with body mass + 50% ; $RPKF_{50}$ = relative peak force with body mass + 50%; PKV_{50} = peak velocity with body mass + 50%; RPC = maximal relative strength of a power clean; R1SRM = relative maximal strength of squat jump; CMVJ = absolute counter−movement vertical jump; RCMVJ = relative counter−movement vertical jump; SPJ = absolute spike jump; RSJ = relative spike jump; %CON = % contribution of the approach run to the spike jump; DJ35 = depth jump from 0.35 m; RDJ35 = relative depth jump from 0.35 m.

*Significant at $p \leq 0.05$.

†Significant at $p \leq 0.01$.

TABLE 2A. Stepwise linear regression model summary for components of relative counter-movement vertical jump performance.

Model	*R*	R^2	Adjusted R^2	*SE* of the estimate
1	0.92	0.84	0.83	2.56

Predictors: (Constant), Relative depth jump.

component factors models for relative CMVJ and relative SPJ are presented in Tables 2A and 2B, respectively.

When expressed as body mass-relative measures, moderate correlations (0.53–0.65; $p \leq 0.01$) were observed between the 1RM measures and both relative CMVJ and relative SPJ. Skinfold ratio was observed to be moderately correlated with SPJ (0.52; $p \leq 0.01$) and spike jump contribution (0.55; $p \leq 0.01$), whereas spike jump contribution was moderately correlated with relative SPJ (0.48; $p \leq 0.05$). Very strong correlations were observed between relative DJ35 values and relative SPJ (0.85; $p \leq 0.01$) and relative CMVJ (0.93; $p \leq 0.01$).

Using regression analysis modeling, the single best component for relative CMVJ was the relative DJ35 score, explaining 84% of performance. The single best predictor for relative SPJ was also the relative DJ35 score (72% of performance), with the three-component models of relative DJ35, relative CMVJ, spike jump contribution, and relative CMVJ, spike jump contribution, and peak force during the body mass condition (incremental load power profile) accounting for 96% and 97%, respectively.

Table 3A outlines the differences between groupings of the seven best and worst athletes in CMVJ ability, whereas Table 3B outlines the differences between groupings of the seven best and worst athletes in SPJ ability. Statistically significant, large differences (ESS > 0.50) were observed for many variables, but particularly for the relative and peak power measures at both the body mass and body mass +50% conditions (ESS 0.94–2.43). The largest ESS differences between the seven best and seven worst jumpers in this group were observed on the relative depth jump scores (4.13 and 4.78 for CMVJ and SPJ, respectively).

DISCUSSION

The present study examined the potential strength, power, and anthropometric contributors to the SPJ and CMVJ, as these jumps are considered critical to success in elite volleyball. The results of this study demonstrate that there are several important strength and power characteristics that contribute to jumping performance in elite volleyball players.

The relationships of the strength, power, and anthropometric variables with the CMVJ and SPJ were assessed using correlation analysis and regression models. The results of this analysis clearly demonstrate the need for high relative force application, power generation, and velocity production capabilities. This observation was evidenced by significant relationships between the jumps and traditional strength training lifts (1RM squat and power clean) as well significant and strong correlations in the laboratory assessment of the leg extensors (incremental load power profile).

This observation was further supported with analysis of the seven best and seven worst jumpers for relative CMVJ and relative SPJ. Significant and large (ESS > 0.50) differences were observed between groups for the traditional strength training lifts and for the force-velocity variables assessed in the incremental load power profile. The largest differences were observed in the power measures, but, as would be expected, large differences between groups were also observed for the force and velocity measures (ESS 0.50–2.00), as these measures constitute power performance. Considering that this analysis was conducted on a relatively homogeneous group of athletes in regards to playing level

TABLE 2B. Stepwise linear regression model summary for components of relative spike jump performance.

Model	*R*	R^2	Adjusted R^2	*SE* of the estimate
1	0.85	0.72	0.70	5.46
2	0.94	0.89	0.88	3.47
3	0.98	0.96	0.96	2.09
4	0.98	0.96	0.96	2.12
5	0.99	0.97	0.97	1.87

1 Predictors: (Constant), Relative depth jump.
2 Predictors: (Constant), Relative depth jump, %Contribution.
3 Predictors: (Constant), Relative depth jump, %Contribution, relative CMVJ.
4 Predictors: (Constant), %Contribution, relative CMVJ.
5 Predictors: (Constant), %Contribution, relative CMVJ, peak force with body-mass jump.

TABLE 3A. Differences between the seven best and seven worst athletes on countermovement vertical jump.

	Group	Mean ± *SD*	*P*	ESS
Height	7 worst	205.85 ± 5.24		
	7 best	198.78 ± 4.26	0.00†	1.48
Skinfolds	7 worst	1.55 ± 0.30		
	7 best	1.63 ± 0.38	0.82	0.00
Reach	7 worst	273.42 ± 5.86		
	7 best	261.14 ± 5.05	0.00†	2.25
RPKPBM	7 worst	67.06 ± 11.98		
	7 best	77.44 ± 9.73	0.07	0.94
RMPBM	7 worst	37.12 ± 6.04		
	7 best	44.68 ± 5.13	0.00†	1.36
RPKFBM	7 worst	22.89 ± 1.77		
	7 best	24.06 ± 2.49	0.15	0.55
PKVBM	7 worst	3.22 ± 0.44		
	7 best	3.36 ± 0.38	0.34	0.50
$RPKP_{50}$	7 worst	56.29 ± 5.96		
	7 best	66.85 ± 4.57	0.00†	1.96
RMP_{50}	7 worst	29.40 ± 3.80		
	7 best	36.63 ± 4.63	0.00†	1.71
$RPKF_{50}$	7 worst	26.05 ± 1.98		
	7 best	28.60 ± 2.28	0.04*	1.21
PKV_{50}	7 worst	2.36 ± 0.14		
	7 best	2.59 ± 0.12	0.00†	2.00
RPC	7 worst	0.74 ± 0.16		
	7 best	0.96 ± 0.12	0.01†	1.64
R1SRM	7 worst	1.12 ± 0.18		
	7 best	1.39 ± 0.13	0.00†	1.77
CMVJ	7 worst	326.57 ± 6.60		
	7 best	328.85 ± 6.15	0.85	0.36
RCMVJ	7 worst	53.14 ± 3.76		
	7 best	67.57 ± 2.94	0.00†	4.29
SPIKE	7 worst	340.28 ± 5.82		
	7 best	346.85 ± 11.74	0.55	0.71
RSPIKE	7 worst	66.85 ± 5.34		
	7 best	85.57 ± 9.07	0.00†	2.51
%CONT	7 worst	25.95 ± 8.18		
	7 best	24.21 ± 12.29	0.79	0.17
DJ35	7 worst	327.42 ± 7.61		
	7 best	331.71 ± 6.32	0.82	0.62
RDJ35	7 worst	54.00 ± 4.40		
	7 best	70.42 ± 3.51	0.00†	4.13

MP_{50} = mean power with body mass + 50%; $RPKP_{50}$ = relative peak power with body mass + 50%; RMP_{50} = relative mean power with body mass + 50% ; $RPKF_{50}$ = relative peak force with body mass + 50%; PKV_{50} = peak velocity with body mass + 50%; RPC = maximal relative strength of a power clean; R1SRM = relative maximal strength of squat jump; CMVJ = absolute counter-movement vertical jump; RCMVJ = relative counter-movement vertical jump; SPJ = absolute spike jump; RSJ = relative spike jump; %CON = % contribution of the approach run to the spike jump; DJ35 = depth jump from 0.35 m; RDJ35 = relative depth jump from 0.35 m.

*Significant at $p \leq 0.05$.

†Significant at $p \leq 0.01$.

(they were all involved in the national program) and that the total subject pool consisted of only 21 athletes, the large differences observed between the seven best and seven worst jumpers within this group provides compelling evidence as to the importance of these variables.

The highest correlation value, single best predictor, and largest ESS difference between best and worst jumpers were observed to be for relative depth jump performance. This is a unique and important finding, particularly considering that many researchers have reported considerable kinetic and kinematic disparities between depth jumping and CMVJ and SPJ tasks (8,9). The important relationship between depth jump performance and CMVJ and SPJ may be explained by examining the conditions under which a depth jump is performed. Although there are kinematic and kinetic disparities between the depth jump and the CMVJ and SPJ, the depth jump may be a unique overload of fast stretch-shortening cycle activity, which emphasizes a short contact time (<250 ms), fast force production, and high power outputs (3,11), all of which are considered important to jumping performance, as demonstrated by our findings and those of others (10,11). Training the neuromuscular system to generate as much tension as possible, under conditions in which the Golgi tendon organ reflexes are driving reduced neural activation, will improve the ground reaction force in jumping. This will result in higher upward acceleration, shorter contact time, and higher vertical jump heights.

In support of this contention, several studies involving depth jump training have demonstrated an increase in CMVJ performance (for a review, see reference 2). In addition, researchers have previously reported a significant and meaningful increase in depth jump performance in a ballistic resistance training intervention group, with a concomitant increase in CMVJ and SPJ performance in elite volleyball players (10,11). Because correlation and regression analysis is

TABLE 3B. Differences between the seven best and seven worst athletes on spike jump.

	Group	Mean ± *SD*	*P*	ESS
Height	7 worst	205.71 ± 5.19		
	7 best	196.57 ± 8.27	0.03*	1.31
Skinfolds	7 worst	1.60 ± 0.27		
	7 best	1.67 ± 0.35	0.29	0.33
Reach	7 worst	273.14 ± 5.93		
	7 best	259 ± 9.40	0.02*	1.80
RPKPBM	7 worst	65.49 ± 9.93		
	7 best	78.65 ± 8.24	0.02*	1.44
RMPBM	7 worst	36.45 ± 5.01		
	7 best	45.38 ± 4.52	0.02*	1.89
RPKFBM	7 worst	22.80 ± 1.85		
	7 best	24.54 ± 2.34	0.30	0.82
PKVBM	7 worst	3.18 ± 0.38		
	7 best	3.43 ± 0.33	0.12	0.62
$RPKP_{50}$	7 worst	55.92 ± 5.51		
	7 best	67.44 ± 3.84	0.02*	2.43
RMP_{50}	7 worst	28.56 ± 2.82		
	7 best	37.16 ± 4.33	0.03*	2.37
$RPKF_{50}$	7 worst	25.81 ± 2.02		
	7 best	29.08 ± 2.02	0.03*	1.65
PKV_{50}	7 worst	2.39 ± 0.18		
	7 best	2.58 ± 0.13	0.24	1.26
RPC	7 worst	0.74 ± 0.16		
	7 best	1.02 ± 0.16	0.00†	1.50
R1SRM	7 worst	1.10 ± 0.17		
	7 best	1.48 ± 0.22	0.00†	2.00
CMVJ	7 worst	326.57 ± 6.60		
	7 best	326.28 ± 11.71	0.85	0.03
RCMVJ	7 worst	53.42 ± 4.24		
	7 best	67.14 ± 3.53	0.00†	3.54
SPIKE	7 worst	339.42 ± 5.26		
	7 best	346.71 ± 12.02	0.11	0.79
RSPIKE	7 worst	66.28 ± 4.75		
	7 best	87.57 ± 6.85	0.00†	3.64
%CONT	7 worst	24.4 ± 9.17		
	7 best	28.20 ± 11.72	0.42	0.36
DJ35	7 worst	326.71 ± 7.23		
	7 best	329.71 ± 10.86	0.51	0.32
RDJ35	7 worst	53.57 ± 3.82		
	7 best	70.57 ± 3.31	0.00†	4.78

MP_{50} = mean power with body mass + 50%; $RPKP_{50}$ = relative peak power with body mass + 50%; RMP_{50} = relative mean power with body mass + 50% ; $RPKF_{50}$ = relative peak force with body mass + 50%; PKV_{50} = peak velocity with body mass + 50%; RPC = maximal relative strength of a power clean; R1SRM = relative maximal strength of squat jump; CMVJ = absolute counter-movement vertical jump; RCMVJ = relative counter-movement vertical jump; SPJ = absolute spike jump; RSJ = relative spike jump; %CON = % contribution of the approach run to the spike jump; DJ35 = depth jump from 0.35 m; RDJ35 = relative depth jump from 0.35 m.

*Significant at $p \leq 0.05$.

†Significant at $p \leq 0.01$.

population-specific, the atypically strong relationships of depth jump ability with CMVJ and SPJ observed in this study might suggest that, with elite-level jumpers, the force and velocity qualities during fast stretch-shortening cycle activity are of even greater importance compared with sub-elite populations.

The observation that several strength and power components were observed to be different between groups emphasizes the importance of these physical qualities in jumping performance in volleyball players. However, when considered with the correlation analysis, in which many strength and power qualities were observed to be significantly related with each other, these findings outline the interdependent nature of strength and power characteristics. Stepwise linear regression analysis provides a prediction of the qualities that may have the most influence on jump performance. Many other strength and power qualities that did not fit the regression model positively influence the qualities that are outlined in the model. As an example, although relative peak and average power capabilities are not outlined in the regression model, these qualities were found to be moderately and significantly (0.44–0.59; $p \leq 0.05$) related to relative depth jump performance, which was the single best predictor of both relative CMVJ and relative SPJ. In turn, relative peak force capabilities were found to be significantly and moderate to highly (0.51–0.83; $p \leq 0.05$) related to relative and peak power, as one would expect. It is important to recognize that although some qualities may seem to be only moderately related to jump performance, they may have a greatly important influence on characteristics that are considered to be highly influential to jump performance. In other words, force and power qualities can be considered foundation qualities, and depth jump performance is composed of several of these kinetic qualities, and thus summarizes them and well predicts CMVJ and SPJ performance.

Practical Applications

It stands to reason that no single strength and power characteristic is necessarily most important in the development of volleyball players, and that the strength and conditioning emphasis would logically change and progress throughout the training phases and over the span of the players' multi-year development. The results of this study demonstrate the importance of recognizing the influence of the various force-velocity qualities on each other, highlighting the need for an understanding of specific assessment techniques that will identify the individual sub-components of strength and power qualities that influence jump performance. With the knowledge of the limiting factors in strength and power performance of an athlete (e.g. maximal force, maximal velocity, stretch-shortening cycling utilization), the strength and conditioning coach and sport scientist can more effectively tailor the training accordingly so that a performance increase can more likely be achieved.

The results of this analysis strongly support the contention that the ability to produce high force and tolerate high tendon tension in rapid stretch shortening cycle movements is very important to jump performance in volleyball. This is best developed by depth jump training. Practical experience would suggest that depth jump training is best employed with a progression from low volumes, under well monitored conditions in which the performance response (jump height) is used to ensure high-quality training and to reduce injury risk associated with such impacting activities.

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