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The Relationship Between Physical and Physiological Variables and Volleyball Spiking Velocity

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ABSTRACT

Thirteen female NCAA Division I volleyball players were given a battery of tests to assess various physical and physiological variables. Tested were body fat %, peak upper body power, arm segment lengths, vertical jump, and peak isokinetic torque of four arm motions—arm extension at the shoulder joint, arm internal rotation at the shoulder joint, forearm extension at the elbow joint, and hand flexion at the wrist joint—at three velocities (90, 180, and 270°/sec). The subjects were also assessed for maximum spiking speed (SSM) by use of a radar gun (18.1 ± 1.77 m s^{-1}). At the $p < 0.05$ level only two variables were found to be significantly correlated to SSM: arm extension torque at 270°/sec (AE270) ($r = 0.64$) and standing reach (SR) ($r = -0.58$). These results suggest that for collegiate female volleyball players, shoulder extension strength at high speed is the dominant alterable physiological variable related to spiking speed.

Key Words: isokinetic, radar, anthropometric

Introduction

Many studies have examined the relationships between physical and physiological characteristics and overall playing ability in volleyball players (2, 3, 4, 6, 8, 13). These studies have shown certain characteristics to be advantageous to players, including greater height (4, 13), greater vertical jumping distance (2, 4), greater mass (6, 13), greater upper body strength (3, 10), and lower body fat % (2, 8). However, each study compared the variables to some measure of overall playing ability and not to the performance of a specific on-court skill. An athlete can have a high overall playing ability but be weak in one specific skill.

Identifying those factors that are characteristic to high performance in a certain skill may provide a focus for improvement in that skill. Once weaknesses are revealed, the athlete may then concentrate on improving the factors that lead to high performance in that skill.

Along a similar rationale, Pedegana et al. (10) examined the correlation between isokinetic torque of different arm movements and baseball throwing speed. Eight professional baseball players were tested on an isokinetic dynamometer for 14 shoulder, elbow, forearm, and wrist movements. Each movement was measured at two velocities, 60 and 180°/sec for motions involving the shoulder and elbow joints, and 30 and 120°/sec for motions involving the radioulnar and wrist joints. Pedegana et al. found that the peak torque of two motions, hand extension at the wrist and forearm extension at the elbow, were significantly correlated with throwing speed as measured by a radar gun.

The volleyball spike is similar in kinesiology to a baseball pitch; both require high velocity for success. The power game in intercollegiate volleyball has made the spike the most important offensive weapon in competition. Two factors decide the success of a spike, trajectory and velocity. A high spiking velocity is desirable in competitive volleyball because it decreases the chances of a defender being able to successfully play the spike. By identifying the characteristics of high velocity spikers, we may gain insight as to the qualities required to produce a high spiking velocity. This study employed laboratory techniques to assess the correlations between an individual's physical and physiological characteristics and his or her maximal spiking velocity.

Methods

Subjects

Thirteen female NCAA Division I volleyball players from two teams served as subjects. All procedures were approved by the university's Medical Science Subcommittee for the Protection of Human Subjects, and informed written consent was obtained prior to testing.

The testing was conducted within 2 weeks of the conclusion of the competitive season.

Spiking Speeds

Each subject's spiking velocity were measured in a gym on a standard court using a net set at regulation height. The players were allowed to warm up as long as necessary before spike testing began. Subjects hit from their "on hand" side (left side for right-handed players and right side for left-handed players) and were given an unlimited number of high outside sets. They chose only those sets they wished to hit. The far court was divided into identical square quarters by two crossing pieces of tape, and subjects were instructed to hit into the deep cross-court quarter. Only those spikes that were legal and landed in the farthest opposite corner were recorded.

For spiking speed (SSM) measurement, an MPH Industries Model (Owensboro, KY) K-15 handheld radar gun was used. The radar gun was modified by the manufacturer to allow for small projectile tracking, reducing the validation time from 0.125 to 0.038 sec and increasing the center frequency of the tracking filters from 1,664 to 3,170 Hz. The calibration was validated before each testing session with a tuning fork according to the manufacturer's instructions.

The tester was positioned on a referee stand along the 3-m line and 1 meter outside the sideline, with the radar gun at an approximate height of 3 m. This positioning placed the operator directly behind the spiked ball's path into the deep cross-court corner, allowing the ball's trajectory to remain within the polarized radar beam. It is necessary to keep the trajectory within the radar beam because projectile speed can only be measured when the ball is approaching or leaving the gun in a straight line. Error resulting from measuring an object's velocity that is not in line with the radar beam is termed cosine error. At the volleyball speeds recorded, a 10° error in projectile path would amount to a cosine error of less than 0.33 $m\ s^{-1}$ (9).

Physical and Physiological Testing

The physical and physiological tests were performed at the Human Performance Laboratory. First each subject's height and mass was measured. Laboratory testing included arm segment length measurement, hydrostatic weighing, stationary and spike approach vertical jump, upper body power, and isokinetic torque assessment of four arm motions—arm extension at the shoulder, arm internal rotation at the shoulder, forearm extension at the elbow, and hand flexion at the wrist—at three velocities (90, 180, and 270°/sec).

To assess the importance of the lever arm lengths in the volleyball spike, each subject's spiking arm was measured for segment lengths. The segments measured were from acromial to stylion, stylion to radial, and radial to dactylion, in accordance with MacDougall et al. (7). The total arm length from acromial to dactylion was also measured. All measurements were taken by the same person.

Hydrostatic weighing was used to determine body density, and then fat-free mass (FFM), fat mass (FM), and percentage of body fat (% BF) were determined by the Siri equation (12). Residual volume was estimated by each subject's forced vital capacity as measured on a bell spirometer (W.E. Collins, Inc., Braintree, MA) (11). Hydrostatic weighing was determined by on-line collection using a calibrated load cell (Genisco AWS-A50, Genisco Technology, Simi Valley, CA) interfaced through an analog-to-digital converter (DAS 16G, Kecthley/Metrobyte Corp., Taunton, MA) to an IBM 55SX laboratory computer. Collection speed was set at 1,000 Hz and each trial lasted 3 sec. After several practice trials during which the subject became accustomed to the procedure, the heaviest underwater weight of three trials was used.

Subjects performed a warm-up prior to the physiological testing to prevent injury and facilitate maximum performance. Each subject jogged at a self-chosen speed on a treadmill for 5 min, followed by 10 min of stretching.

Standing reach (SR), standing vertical jump reach (SVJR), and spike approach vertical jump reach (AVJR) were measured using a Vertec (Questek Corp., Northridge, CA) vertical jump tester. The subject was given an unlimited number of trials. The standing vertical jump was performed without taking any forward or backward steps. The subject performed the AVJR by using a normal 3-step spike approach and striking the Vertec as if it were a ball to be spiked. SR was subtracted from SVJR and AVJR to determine the standing vertical jump (SVJ) and approach vertical jump (AVJ), respectively. The approach-standing difference (ASD) was the difference between SVJ and AVJ and revealed how much height was gained with the spike approach.

A Monarch cycle ergometer, modified for seated arm cranking and equipped with a load cell and magnetic closure switch to allow on-line collection of resistance and pedal speed, was used for upper body power testing (15). The ergometer was connected to a laboratory computer (IBM 55SX) through an analog-to-digital converter. A 6-sec test was used to measure peak power (PP) (15). Subjects performed a 2-min warm-up at a self-chosen pace with a 0.6-kg load. After the warm-up they were given a 3-min rest. The ergometer was then loaded with an optimal resistance of 5% body mass rounded to the nearest 1/10 kilogram (14). The subject then performed at all-out supramaximal effort, from a stationary start, for 6 sec. The test was repeated after a 15-min rest with the higher of the two trials recorded as upper body peak power (PP).

The isokinetic torque assessment was conducted on a calibrated Biodex System 2 Testing Dynamometer (Biodex Medical Systems, Shirley, NY) according to the Biodex System 2 Manual (1). Four of the primary arm motions of the volleyball spike, arm extension

(AE), arm internal rotation (AIR), forearm extension (FE), and hand flexion (HF), were examined for peak concentric torque measurements. Three velocities (90, 180, and 270°/sec) were evaluated for each motion. This yielded data for the following 12 conditions: AE90, AE180, AE270, AIR90, AIR180, AIR270, FE90, FE180, FE270, HF90, HF180, and HF270.

For each of the 12 tests the subjects were instructed to perform 5 warm-up reps at 80% effort, rest for 1 min, and then perform 5 reps with maximal effort. The peak torque for the highest of the 5 reps was recorded.

Results

To provide an overall strength index, the peak torques of the four arm motions were added together for each of the three velocities to get three total torques: T90, T180, and T270. This was not used to estimate the total torque of the arm swing but to provide a simple strength index.

Table 1 compares the means for a number of anthropometric measurements for the subjects in this study to those reported for two other referenced studies (5, 6). The two studies were chosen for comparison because they utilized female collegiate volleyball players of ability levels closest to those of our subjects. Remaining physical and physiological variables are presented in Table 2, and all isokinetic peak torques are shown in Table 3.

A correlation analysis was performed on all of the variables with SSM as the dependent variable. Only two variables, AE270 and SR, were found to be significantly correlated with SSM ($p < 0.05$). AE270 was positively correlated ($r = 0.64$, $p = 0.026$) and SR was negatively correlated ($r = -0.58$, $p = 0.039$). The Pearson correlation coefficients for all physical and physiological variables are presented in Table 4 and the Pearson correlation coefficients for isokinetic peak torques are shown in Table 5.

Analysis of the peak torques by ANOVA revealed that arm extension produced significantly higher torques ($p < 0.05$) at all three tested velocities than the other three arm motions.

Discussion

Although the current subjects tended to be taller, heavier, and slightly higher in body fat than the players in the two previous studies (5, 6), the differences were not large.

The correlation results show two characteristics with a significant correlation to spiking speed, arm extension torque at 270°/sec and standing reach. The importance of arm extension in producing force during a complex movement such as the volleyball spike is demonstrated by arm extension having the highest torques of the four arm motions at all tested speeds. Another point of consideration is that for the three

Table 1
Comparison of Anthropometric Variables

Variable	Present study *M*	*SD*	Hosler et al. (5) *M*	*SD*	Kovaleski et al. (6) *M*	*SD*
Age (yrs)	19.5	1.1	19.5	1.6	19.9	1.2
Height (cm)	176.7	4.6	169.9	6.1	172.2	7.7
Mass (kg)	69.7	10.8	65.1	7.8	64.1	7.0
FFM (kg)	54.0	7.1	51.1	–	50.1	4.8
Fat mass (kg)	15.8	5.6	14.0	–	13.8	4.6
Body fat (%)	22.2	5.0	21.5	3.5	21.3	5.8

Table 2
Physical and Physiological Variables

Variable	Mean	*SD*	Min.	Max.
Acromial-Stylion*	32.5	1.38	30.5	35.0
Stylion-Radial	26.9	1.22	24.8	29.0
Radial-Dactylion	19.2	0.97	17.0	20.5
Acromial-Dactylion	78.6	3.03	74.5	83.5
Standing reach	230.7	5.76	219.7	241.3
Stand. vert. jump reach	276.2	7.25	259.1	288.3
Standing vert. jump	45.5	6.80	29.2	57.2
Appr. vert. jump reach	283.0	6.59	268.0	294.6
Approach vert. jump	52.4	6.05	38.1	63.5
Approach standing diff.	6.7	2.11	3.8	10.2
Peak power (watts)	381.7	51.99	306.1	502.0
SSM ($m\ s^{-1}$)	18.1	1.77	15.6	21.0

*All values in centimeters except peak power and SSM.

Table 3
Isokinetic Torques

Test (Nm)	Mean	*SD*	Min.	Max.
AE90	58.5	9.55	45.8	79.1
AE180	52.4	12.32	35.5	76.6
AE270	39.6	13.15	24.5	67.9
AIR90	32.5	6.47	25.6	44.5
AIR180	31.1	6.46	22.1	42.8
AIR270	29.5	5.76	20.5	37.8
FE90	37.1	6.56	28.9	54.2
FE180	32.5	6.10	25.2	46.1
FE270	27.3	6.15	20.9	43.7
HF90	18.6	2.66	16.1	25.0
HF180	18.4	2.82	13.8	24.1
HF270	17.9	2.87	14.1	22.6
T90	146.6	23.10	117.4	201.4
T180	134.1	23.84	104.3	189.6
T270	113.8	22.72	89.8	171.6

Table 4
Pearson Correlation Coefficients Between SSM and Physical and Physiological Variables

Variable	*r*	*p*
Age	–0.115	0.707
Height	–0.499	0.082
Mass	0.152	0.619
Fat-free mass	0.130	0.672
Fat mass	0.131	0.669
% Body fat	0.091	0.766
Acromial-Stylion	–0.438	0.135
Stylion-Radial	0.031	0.918
Radial-Dactylion	–0.247	0.417
Acromial-Dactylion	–0.266	0.380
Standing reach	–0.576	0.039
Standing vert. jump reach	–0.163	0.594
Standing vertical jump	0.314	0.296
Approach vert. jump reach	–0.234	0.442
Approach vert. jump	0.297	0.324
Approach standing diff.	–0.162	0.597
Peak power	0.285	0.349

Table 5
Pearson Correlation Coefficients Between SSM and Isokinetic Peak Torques

Test	*r*	*p*
AE90	0.419	0.154
AE180	0.512	0.073
AE270	0.636	0.026
AIR90	–0.018	0.954
AIR180	–0.195	0.523
AIR270	–0.170	0.579
FE90	0.140	0.665
FE180	–0.035	0.914
FE270	0.095	0.769
HF90	0.058	0.851
HF180	0.203	0.507
HF270	0.179	0.558
T90	0.225	0.481
T180	0.234	0.464
T270	0.357	0.281

velocities of isokinetic arm extension, increasing velocity led to increasing correlation to SSM. This should be expected because of the high arm speed required for the volleyball spike. However, the negative correlation between SR and SSM is not as easily explained. It may be that lengthy lever arms are at a disadvantage in producing lever arm speed. Or perhaps we need to examine more closely the play in intercollegiate women's volleyball.

Those players with the highest standing reach tend to play the position of middle blocker as opposed to setter or outside hitter. The sets they receive in the middle are very different from those used in this study. The high outside sets used during this study are commonly seen by outside hitters. Middle sets are usually lower and quicker than outside sets. They are intended for a quick swing to catch the defense off guard.

Middle hits do not require the power that is typical of outside hits. Since middle hitters primarily concentrate on these quicker, more compact swings during practice, they may not develop the full powerful swing of outside hitters. Another possibility may be that due to their superior standing reach, they do not require a large or lengthy vertical jump to hit the ball downward into the opposing court. This would make their best attack a short quick downward spike as opposed to a full powerful swing with a long approach. Again the practice of this shorter spiking movement could hinder their development of a high spiking speed.

These results suggest that the players with the greatest arm extension torque at high velocities generate the fastest spikes. This relationship should be examined further to determine whether an increase in strength produces an increase in spiking speed. The effect of high-speed strength training on spiking speed could be researched. These results also suggest that players with a greater standing reach tend to have slower spiking speeds. Whether this is training induced or a physical limitation might be revealed by biomechanical analyses. Future studies could include differentiation by position, comparison of angular velocities, and inclusion of training to reveal the source of this trend.

Practical Applications

Although this is a correlational study and no causal relationships can be derived, there is a significant association between maximum volleyball spiking velocity and torque produced by high speed arm extension at the shoulder joint. Inclusion of exercises designed to increase the strength of the shoulder extensors, especially at high speeds, may enhance a player's spiking ability. One group that may benefit greatly is beginning collegiate players. The high school game is usually more ball-control oriented than power oriented. High speed resistance training, concentrating on the shoulder extensors, could help recent high school graduates make the transition to the power game common to intercollegiate volleyball.

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