Abstract

Purpose: The volleyball attack is the action winning the majority of points during a game and attack effectiveness (AE) is therefore one of the most important predictors of victory. Traditionally, greater vertical jump heights (VJH) and higher spike speeds (SS) have been thought to increase AE, however relevant research is limited. Our aim was to assess the relationship of VJH and SS with AE as well as identify possible associations of demographic and anthropometric factors, including common volleyball injuries, with VJH, SS and AE.

Methods: Twenty two male volleyball players from two teams in the top division of the Cypriot championship were included in the study. VJH was measured with the “jump-and-reach” test, SS was tested with a sports speed radar and AE was calculated from performance sheets of four games between the two teams.

Results: Significant results included strong, positive correlations between VJH and SS, %lean mass and SS, body-bone% and SS, height and SS, and frequency of resistance training and SS. AE was found to increase with increasing age, while SS over 90km·h^{-1} appeared to have a negative effect on AE. History of pain in the dominant shoulder and in the ankles/knees was associated with lower SS and higher VJH respectively.

Conclusions: Based on our findings and the existing literature, we advise volleyball players and coaches to focus on maximisation of VJH and optimisation of attack technique and we provide recommendations to improve attack success.

Keywords: *spike, speed, jump, height, effectiveness*

1. INTRODUCTION

The volleyball attack is the action winning most of the points during a game and attack effectiveness (AE) is consequently thought to be one of the most important predictors of victory [1,2]. It can be performed in a number of ways, most commonly in the form of a 'spike'. This is a unique overhead movement that requires both power and skill and consists of the following phases: windup, cocking, acceleration, deceleration and follow-through [3,4].

Two of the most important factors determining the success of a spike are thought to be the magnitude of the vertical jump (vertical jump height; VJH) performed by the attacking player prior to striking the ball and the speed of the ball after impact (spike speed; SS). A higher vertical jump usually results in ball impact at a greater height by the attacking player, which reduces the probability of the ball being stopped by the opposing team's block. Equally, spikes of greater velocities are expected to be more effective as faster balls are more difficult to be blocked or picked up by the defenders of the opposing team [1].

Considering the complexity of the different skills involved and the dependence of each individual action on a number of other factors related both to a player's teammates and their opponents, volleyball performance is not easy to evaluate. VJH has received the greatest attention in the literature as it is the most independent and also the easiest to measure, while SS and AE have been studied very little, although the last is arguably the most important of the three with respect to volleyball performance [1,5,6]. This lack of research on AE is primarily due to its dependence on and close relationship to other subjective parameters that are difficult to quantify, including, but not limited to, the quality of sets received and the quality and effectiveness of the opposing block and defence.

The aim of the present study was to assess the relationship of VJH and SS with AE as well as identify possible associations of anthropometric and demographic factors (including common volleyball injuries) with VJH, SS and AE. We hypothesised that a) AE would be positively associated with both VJH and SS; b) VJH would have a positive correlation with percentage lean mass, bone-body percentage, calf circumference and thigh circumference, and a negative correlation with body mass index (BMI) and body-fat percentage; c) SS would have a positive correlation with BMI, percentage lean mass and body-bone percentage; d) ankle/knee pathology would have an adverse effect on VJH and AE; e) shoulder pathology would negatively affect SS and AE. To the best of our knowledge, this is the first study assessing correlations between AE and athletes' specific characteristics.

2. METHODS

Definitions

The word ‘spike’ is used where the attack is exclusively a spike (e.g. in ‘spike speed’) rather than any type of attack including ‘tips’ and ‘roll shots’, while ‘attack effectiveness’ refers to the success percentage of any type of attack, which we define as passing the ball over the net to the opposite side while performing a jump. A ‘tip’ is passing the ball over the net with the fingers of one hand, and a ‘roll shot’ is a soft spike with a lot of spin, both while the player is in the air. In both a ‘tip’ and a ‘roll shot’, the ball is passed over the net in a curved path compared with a spike where the ball is directed forcefully to the ground in a straight, downward path.

Subjects

During the 2014-2015 season, 22 male volleyball players from two teams participating in the first division of the Cypriot championship were included in the study. The right arm was the dominant (and hitting) arm in all participants and none of the athletes participated in any overhead activities other than volleyball and resistance training. All players used their left leg as the lead-leg during attacks. The players were either professionals (n=8) or semi-professionals (n=14); fifteen of them were Cypriots and the rest ‘foreign’ (one Brazilian, one Canadian, one Latvian, two Serbians, one Slovakian and one Venezuelan).

Informed consent was obtained verbally from each player separately prior to data collection after the aims and methods of the study were described. Ethical approval was granted by the Cyprus Volleyball Federation.

Tests

A short standardised survey enquired about the players' age, team role, years of volleyball experience, weekly hours of practising volleyball and resistance training, present or past shoulder pain (shoulder pain history) and present or past ankle/knee pain (ankle/knee pain history). Players were included in the shoulder pain history and/or ankle/knee pain history groups if they thought that their pain was significantly affecting their performance or if they required medical attention and/or physiotherapy. Ankle/knee pain history was used in the analyses regardless of which side it affected while only shoulder pain history in the dominant arm was used in the analyses. Players with ankle and knee pain history were included in the same group, firstly because their potential adverse effect on SS, VJH and AE was thought to be due to the negative impact they are both hypothesised to have on jump performance and secondly because sub-groups would have been too small for analyses.

Following the interview, each player had his height measured with a tape measure attached on the wall. Body mass, BMI, body-fat percentage (fat%), percentage lean mass (muscle%) and body-bone percentage (bone%) were measured with Tanita® BC-418MA Segmental Body Composition Analyser[7]. A tape measure was also used to measure each athlete's thigh circumference (half-way between the anterior superior iliac spine and the superior aspect of the patella) and calf circumference (5cm distal to the tibial tuberosity) both on the left side. The following tests were performed by a physician in both shoulders of each athlete to screen for shoulder impingement: Hawkins-Kennedy, Jobe, palm-up, infraspinatus and lift-off [8-12]. Athletes who had at least one positive test on their dominant side were included in the 'shoulder impingement' group.

For an illustration and explanation of these tests the reader is referred to our previous article[12].

After a volleyball-specific 15-minute warm-up, each player was instructed to perform a vertical jump mimicking the volleyball spike jump and reach the highest possible point with their dominant hand on a post, which had a tape measure attached ('jump-and-reach' test). An observer standing next to the post on a ladder recorded the reach point for each athlete. The best of three attempts was selected and represented each player's VJH.

Subsequently, the maximum SS of each player was measured with a speed radar (Supido® Multi Sports Personal Speed Radar) which was placed close to the end line just outside of the playing court directly opposite the players, who were instructed to spike the ball set by the setter as forcefully as possible 'down-the-line' towards the radar.

All players, regardless of team role (incl. setters and liberos), performed 3 spikes at the position they usually spike according to their team role ('outside' players from position '4', 'opposite' players from position '2' and 'middle' players from position '3') and the highest SS of each player was recorded. All non-spiking players (liberos and setters) chose to spike at the left corner (position '4') of the court.

Finally, team performance reports of four official matches between the two teams that were obtained by the team statisticians were used to calculate the AE of players with spiking roles ('outside', 'opposite' and 'middle' players). AE was calculated by the ratio of (number of successful attacks) / (number of total attacks) for each player, where number of total attacks = number of successful attacks + number of unsuccessful attacks. A successful attack was defined as an attack that won a point without the opposing team setting the ball for a counter-attack. 'Tips' and 'roll shots' were included in the analysis. Videos of two matches were subsequently watched and AE of each spiking player was calculated manually to confirm the accuracy of the data of the team performance reports.

The data for each team was collected before (interview and examination), during (SS) and after (AE) a single training session towards the end of the championship by a single examiner and an assistant.

Statistical Analysis

Statistical analysis was performed using R 3.2.2. When assessing the correlation of any two variables, initially normality was tested for each variable using the Shapiro Wilk Normality test[14]. Where both variables were found to be normally distributed, their correlation was tested using Pearson's correlation coefficient, otherwise Spearman's rank correlation coefficient was used. Both Pearson's and Spearman's coefficients are denoted by 'r'. Where possible, non-normal distributed variables were logarithmically transformed to achieve normality as Pearson's correlation test achieves a higher statistical power than non-parametric tests. Strength of correlation was defined based on the value of 'r' as follows: 0-0.19 very weak, 0.20-0.39 weak, 0.40-0.59 moderate, 0.60-0.79 strong and 0.80-1 very strong. Results were considered to be significant at the 5% critical level ($P<0.05$) and are presented at two decimal places.

3. RESULTS

The demographics and anthropometrics of the sample are shown in table 1.

Pain history (shoulder and ankle/knee) and characteristics (mean±sd and range) of SS, AE and VJH are presented in table 2.

Of the 10 athletes with ankle/knee pain history, 4 had knee pain history (2 past, 2 present) and 6 ankle pain history (4 past, 2 present). Two players had both ankle/knee pain history (one right ankle – past, and the other left knee - past) and dominant shoulder pain history (both present).

During the four matches between the two teams, a total of 15 sets were played and 638 attacks were performed by 13 players (range 12 – 201, mean 49.1). Four (4) players did not play during the 4 games and the 5 non-spiking players did not perform any attacks. All 5 non-spiking players played at spiking positions at some point in their career therefore they were all included in tests and analyses for VJH and SS. Manual calculation of each player's AE from the two videos watched confirmed that the recorded AE in the equivalent team performance reports was 100% accurate.

Table 3 provides a summary of all associations tested in our study with results of correlation tests and exact p-values for significant relationships.

Data for VJH and SS were used from all 22 athletes. Only the 13 spiking players who performed attacks during the 4 games were used for AE.

VJH appeared to have a significant positive correlation with SS ($r=0.52$, $P<0.01$; figure 1) but not with AE. When the relationship between SS and AE was assessed, the test returned a very weak correlation between the two ($r=0.06$, $P=0.42$; figure 2). From the scatterplot we observed that there is a downward trend in AE for SS > 90 $km \cdot h^{-1}$ which yielded a statistically significant negative correlation when an additional test was performed ($P=0.01$).

When anthropometric and demographic factors were tested against VJH, SS and AE, the following significant positive correlations were detected: a) weekly hours of resistance training Vs SS (r=0.80, *P*<0.01; figure 3a); b) bone% Vs SS and muscle% Vs SS (r=0.64 and r=0.56, *P*<0.01 and *P*<0.01 respectively; figures 3b and 3c); c) height Vs SS (r=0.46; *P*=0.024); and d) age Vs AE (r=0.52, *P*=0.03; figure 3d). Despite the last positive correlation between age and AE, testing years of volleyball experience against AE returned a non-significant result (r=0.38, *P*=0.11). Weekly hours of volleyball practice had a positive correlation with SS, however this was not statistically significant (r=0.35, *P*=0.05). The association between weekly hours of volleyball practice and VJH was re-tested for spiking players only (as non-spiking players perform fewer/no jumps during training) and the result was also non-significant (*P>0.05*). Similarly, re-testing all correlations of SS in spiking players only had no impact on the statistical significance of any of the correlations.

Injury associations

Athletes with shoulder pain history (n=6) had a lower mean SS (*P*=0.03) but not AE (*P*=0.50) than those without shoulder pain history (n=16). Those with (n=10) and those without (n=12) shoulder impingement had a similar mean SS and AE (*P*=0.69 and *P*=0.75 respectively).

Comparing volleyball athletes with (n=10) and without (n=12) ankle/knee pain history, there were no significant differences in SS or AE (*P*>0.05); however, the former group had a significantly greater mean VJH (*P*=0.02).

4. DISCUSSION

In our study, VJH appeared to be a significant predictor of SS but not AE in high-level, male volleyball players. SS>90 km·h^{-1} were found to be associated with significantly lower AE compared to SS<90 km·h^{-1}. VJH did not have any significant correlations with any demographic or anthropometric factors, while SS had strong positive correlations with frequency of resistance training, height, bone% and muscle%. AE had a significant positive correlation with age.

We believe that the most striking finding of the present study is the significantly lower AE with SS>90 km·h^{-1} compared with speeds<90 km·h^{-1}. Our assumption is that greater SS may be the result of the player striking the ball in a more forward position at smaller angles of shoulder forward flexion (rather than above their heads at 180 degrees of forward flexion) which directs the ball to the ground in a steeper and faster downward motion. Ball impact at a more forward position implies that the arm and hand have travelled longer from the cocking position during the acceleration phase of the overhead movement and therefore acquired a greater speed, which they transmit to the ball. However, this implies a lower ball contact height which significantly increases the chances of the spike being stopped by the opponents' block. In this respect, studies with larger samples are needed to confirm or disprove this association.

The positive correlation between age and AE may be attributed to one of the following two reasons: older players are more experienced than and technically superior to younger players, therefore the success of their attack is expected to be higher. Alternatively, this positive association between age and AE could simply be a type II error due to our small sample size. Unfortunately no published studies looking at associations between demographic factors and AE have been identified in the literature, therefore further research with larger samples is warranted to provide further insights.

Regarding correlations between injury and volleyball performance, history of dominant shoulder pain was associated with a lower SS but did not have a negative effect on AE; shoulder impingement (symptomatic and asymptomatic) did not influence SS or AE. Athletes with knee or ankle pain history had a higher VJH than those without knee or ankle pain history, while SS and AE were similar between the two groups.

This last finding of higher vertical jumps in those with ankle or knee pain history was rather surprising; one would expect this group of athletes to perform more poorly in jumping due to lower limb pain and/or fear for worsening/recurrence of their injury. Not only was their VJH not compromised compared to those without history of ankle/knee pain, it was in fact greater. We speculate that lower limb pain/injury in this group of players may be a consequence of their higher vertical jumps, which may be predisposing them to ankle and/or knee pathology due to greater ground reaction forces on their joints upon landing. This assumption is in fact in agreement with an early study by Lian et al. (2003)[15] who found a greater risk of patellar tendinopathy in those with better jumping performance. Additionally, the contralateral unaffected lower limb may be compensating, taking on most of the work needed for a jump. In this regard, considering pain/injury in the lead-leg and trail-leg separately as well as observing take-off and landing techniques could provide further insights into the likely underlying reason, however sub-groups would have been too small for the former and the latter was beyond our scope[16,17].

Forthomme et al. (2005)[1] hypothesised that AE is proportional to SS and performed tests in 19 elite male volleyball players aiming to identify factors correlated with spike velocity. They found that the strength of the dominant shoulder internal rotators in concentric mode, the dominant shoulder external rotators/internal rotators peak torque ratio, the strength of the dominant elbow flexors and extensors, the height at which the ball is contacted, the weekly hours of resistance training and the BMI were significant predictors of SS, which is partly in agreement with our results. Our findings showing positive associations of frequency of resistance training and VJH with SS are in accordance with the aforementioned results by Forthomme et al. (2005)[1]. The discrepancy between the results of Forthomme et al. (2005)[1] describing a positive correlation between BMI and SS and the absence of any effects in our study is most likely due to the small samples of both studies and possibly due to the use of different statistical tests. Indeed, Forthomme et al. (2005)[1] do state that this latter positive correlation was somewhat surprising, as one would expect athletes with lower BMIs to perform a higher vertical jump, which appears to be an important predictor of SS. On the other hand, a higher BMI could potentially lead to higher SS as it could be the result of a high muscle mass (hence greater strength), or by increasing the momentum of the hand striking the ball, therefore transmitting larger amounts of kinetic energy to it. Our study failed to demonstrate a significant relationship between BMI and VJH but it did show a positive correlation between muscle% and SS.

With regard to anthropometric and demographic correlations with VJH, a recent study by Nikolaidis et al. (2016)[6] identified a number of factors that had strong correlations with VJH in youth female volleyball players: age at peak height velocity and isometric strength had positive correlations with VJH, while body mass, BMI and body fat% were correlated with VJH in a negative manner. Older ages of maturation were associated with higher vertical jumps. In our study fat% did exhibit a negative correlation with VJH but it did not reach statistical significance, which is most likely due to our small sample. Aouadi et al. (2012)[5] examined the associations between physical and anthropometric profiles and vertical jump performance in elite male volleyball players and identified lower limb length as an important predictor of counter-movement jump with arm swing, which mimics the spike jump in volleyball.

5. PRACTICAL APPLICATIONS

Based on our findings and the existing literature we suggest optimisation of spike technique as it might be more important than SS for attack success. Specifically, we suggest working on achieving a high ball contact height, for which VJH optimisation would play a very important role, as it has previously been shown to be a significant predictor of winning points in volleyball[18].

Additionally, increasing ball spin would give the ball a more curved, downward trajectory which would increase the effectiveness of the attack by reducing the chances of spiking the ball 'out' and making defence by the opponents a lot more difficult. Finally, spiking faster sets gives the opponents much less time to set up a good block and choosing the direction of the spike so that it avoids the opponents' block would also be expected to enhance AE.

Our study has important limitations that cannot be overlooked. Firstly, our small sample does not allow for any definitive conclusions to be made due to the high risk of type II errors. In addition, sub-group analyses were limited and results may not be accurate due to the very small number of athletes in each sub-group (shoulder pain history, ankle/knee pain history). Finally, we did not adjust for important factors that have direct effects on a player's AE, such as quality of sets received and quality/effectiveness of opposing block and defence.

To the best of our knowledge, this is the first study reporting on specific variables correlated with AE. At the same time, we identified strong correlations between demographic and anthropometric factors and VJH and SS, with our results being largely in accordance with the already existing relevant literature. In the future, larger observational studies are warranted to reach more definitive conclusions about correlations among different volleyball skills and their associations with anthropometric and demographic factors.

6. CONCLUSIONS

The volleyball attack is the skill winning the greatest number of points during a game and its success is therefore an important predictor of victory. In our study, we assessed the correlations among the three most important characteristics of the volleyball attack (VJH, SS and AE), as well as their associations with anthropometric and demographic factors. Our findings suggest positive correlations between SS and a) VJH, b) muscle%, c) bone%, d) height and e) frequency of resistance training. AE was correlated with age, while spike velocities beyond certain magnitudes may be compromising AE. Based on our findings, we suggest that coaches and players should place more emphasis on optimising their spike technique rather than SS.

For more definitive conclusions on performance-related volleyball skills to be reached with confidence, larger observational studies are warranted that will accurately examine the relationships and associations of volleyball actions with athletes' characteristics to better guide performance optimisation programs.

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Tables

Table 1. Demographic and anthropometric characteristics of our sample. sd: standard deviation

Demographics - Anthropometrics		
	Mean±sd	**Range**
Age (years)	25.8±6.2	17-36
Volleyball experience (years)	13.2±7.2	3-25
Weekly volleyball practice (hours)	12.6±3.4	8-18
Weekly resistance **training (hours)**	2.8±2.2	0-7
Height (m)	1.92±0.08	1.73-2.08
Body mass (kg)	88.2±11.3	65.4-109.3
BMI (kg/m^2)	23.7±2.3	17.7-28.4
Fat%	12.1±3.5	5.0-17.1
Bone%	3.8±0.4	3.1-4.6
Muscl%e	72.9±9.9	55.0-91.8
Thigh circumference (cm)	54.8±5.5	42-64
Calf circumference (cm)	38.3±2.8	32-43

Table 2. Prevalence of shoulder pain history and ankle/knee pain history, and basic statistical values of spike speed, attack effectiveness and vertical jump height. sd: standard deviation.

		Right	Left
Shoulder pain history	Past	3	0
	Present	3	0
Ankle/knee pain history	Past	2	2
	Present	2	4
		Mean±sd	**Range**
Spike Speed (kmh^{-1})		84.1±14.1	65-119
Attack effectiveness (%)		51.6±12.1	37-65
Vertical Jump Height (cm)		69.4±8.5	53-84

Table 3. Results of correlation tests (r) and *P* values between variables. 95% CI are shown in parenthesis. Statistically significant associations are shown in bold. Negative “r” values denote negative correlations. * higher mean vertical jump height in those with ankle/knee pain history; ** lower mean spike speed in those with shoulder pain history.

	Vertical Jump Height	**Spike Speed**	**Spike speed (without setters and liberos)**	**Attack Effectiveness**
Vertical Jump Height	-	***r* = 0.52; *P* = 0.006 (0.118, 0.789)**	***r* = 0.56; *P* = 0.019 (0.112, 0.821)**	*r* = 0.11; *P* > 0.05 (-0.474, 0.620)
Spike Speed	-	-		*r* = 0.06; *P* > 0.05 (-0.579, 0.718)
Age	*r* = 0.07; *P* > 0.05 (-0.362, 0.478)	*r* = 0.38; *P* > 0.05 (-0.114, 0.673)	***r* = 0.51; *P* = 0.034 (0.046, 0.798)**	***r* = 0.52; *P* = 0.03 (0.041, 0.883)**
Volleyball experience	*r* = 0.02; *P* > 0.05 (-0.445, 0.418)	*r* = 0.30; *P* > 0.05 (-0.218,0.673)	*r* = 0.41; *P* > 0.05 (-0.103,0.755)	*r* = 0.38; *P* > 0.05 (-0.242, 0.785)
Weekly volleyball practice	*r* = 0.15; *P* > 0.05 (-0.330, 0.611)	*r* = 0.35; *P* = 0.05 (-0.092, 0.686)	***r* = 0.49; *P* = 0.047 (0.006, 0.812)**	*r* = 0.17; *P* > 0.05 (-0.462, 0.669)
Weekly resistance **training**	*r* = 0.19; *P* > 0.05 (-0.261, 0.613)	***r* = 0.80; *P* = 0.000004** (0.612, 0.898)	***r* = 0.78; *P* = 0.0002 (0.547, 0.913)**	*r* = 0.26; *P* > 0.05 (-0.368, 0.693)
Height	*r* = 0.33; *P* > 0.05 (-0.109, 0.658)	***r* = 0.46; *P* = 0.02 (0.036, 0.748)**	*r* = 0.47; *P* > 0.05 (-0.014, 0.775)	*r* = 0.20; *P* > 0.05 (-0.394, 0.677)
BMI	*r* = -0.09; *P* > 0.05 (-0.493, 0.344)	*r* = 0.25; *P* > 0.05 (-0.163, 0.630)	*r* = 0.47; *P* > 0.05 (-0.015, 0.775)	*r* = 0.28; *P* > 0.05 (-0.317, 0.722)
Fat%	*r* = -0.33; *P* > 0.05 (-0.661, 0.104)	*r* = 0.11; *P* > 0.05 (-0.519, 0.346)	*r* = 0.04; *P* > 0.05 (-0.448, 0.512)	-
Bone%	*r* = 0.25; *P* > 0.05 (-0.190, 0.609)	***r* = 0.64; *P* = 0.0007 (0.234, 0.855)**	***r* = 0.76; *P* = 0.0003 (0.447, 0.910)**	-
Muscle%	*r* = 0.28; *P* > 0.05 (-0.156, 0.630)	***r* = 0.56; *P* = 0.003 (0.115, 0.825)**	***r* = 0.73; *P* = 0.0008 (0.388, 0.897)**	-
Thigh circumference	*r* = -0.21; *P* > 0.05 (-0.623, 0.262)	-		-
Calf circumference	*r* = -0.10; *P* > 0.05 (-0.500, 0.336)	-		-
Shoulder pain history	*P* > 0.05	***P* = 0.02****		*P* > 0.05
Ankle/knee pain history	***P* = 0.02***	*P* > 0.05		*P* > 0.05

Figure Captions

Figure 1. Scatterplot of vertical jump height vs spike speed (Spearman's, r=0.52, P=0.03).

Figure 2. Scatterplot of spike speed vs attack effectiveness (Spearman's, r=0.06, *P*=0.42).

Figure 3. Scatterplots of a) weekly hours of resistance training vs spike speed (Spearman's, r=0.80, P<0.01), b) bone% vs spike speed (Spearman's, r=0.64, *P*<0.01), c) muscle% vs spike speed (Spearman's, r=0.56, *P*<0.01) and d) age vs attack effectiveness (Pearson's, r=0.52, *P*=0.03).