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Original research papers

DIRECTION AND VELOCITY OF THE BALL IN VOLLEYBALL SPIKE DEPENDING ON LOCATION ON COURT

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Abstract
Introduction. The aim of this study was to determine the correlations between the direction and velocity of the ball in volleyball spike. We adopted the hypothesis that the direction of an attack is dependent upon the arrangement of the pectoral girdles in the phase of flight. ***Material and methods.*** The research was carried out for four different types of attacks: from the left side of the court down the line (A) and in the cross-court direction (B) and from the right side in the same directions (C and D). Sixteen young volleyball players from a Sports Championship School run by the Polish Volleyball Federation were examined. ***Results.*** The analysis of the results showed different ball velocities in different attacks. The velocity was the lowest in attack B and the highest in attack D. ***Conclusions.*** The direction of attack was produced by hitting the ball in a non-central manner and by aligning the glenohumeral joints diagonally to the net.

Key words: biomechanics, ball direction, volleyball spike, cinematographic method

Introduction

Kinematic research has found that the effectiveness of an attack in volleyball is to a large extent determined by the velocity of the ball [1, 2]. Another significant factor is the choice of the appropriate direction of the attack [3, 4]. The biomechanical criterion of effectiveness (accuracy) is met when the ball is directed into the opponent's weak area.

The biomechanics of the technique of an attack in volleyball and the differences in expertise in the technique have been previously analysed [5, 6]. The effect of the take-off phase on the height of the jump was also analysed [7, 8], as was the influence of the kinetics of the player's body during flight on the velocity of the ball [8, 9]. Previous studies, however, have not investigated the relationships between the direction of the flight of the ball and the kinematics of the body during an attack [8, 10]. Hitting the ball with maximum strength into the hands of blockers usually results in the loss of a point. Therefore, directing the ball in an appropriate direction is, apart from the velocity of the attack, the principal factor determining whether an attack will be successful. In light of the above, the purpose of this study was to determine the correlations between the direction of the ball and ball velocity. The hypothesis that the direction of an attack is dependent upon the arrangement of the pectoral girdles in the phase of flight was adopted.

Material and methods

All of the participants consented to being recorded. Sixteen male students from the Sports Championship School in Spała run by the Polish Volleyball Federation participated in the study. Their characteristics were the following: average height was 196.1 ± 7.03 cm, average mass was 86.4 ± 9.51 kg, average age was 18.3 ± 0.95 years, and average training experience was 6.7 ± 1.14 years. The individuals examined had approximately the same level of sport technique.

A cinematographic method was applied, and the analysis was carried out in a three-dimensional space with the use of the APAS 2000 program. Strike attempts were recorded with the use of two digital cameras (JVC GR-810) with a frequency of 60 Hz and the shutter set at 1/250 s. The cameras were set diagonally in relation to the plane of movement behind the subject. For scaling, a rectangular frame with dimensions of 1.5 x 1.5 x 2 m was applied. Data were smoothed with the embedded Butterworth filter [11] with a value of 8 Hz for axes Ox and Oy and the value of 6 Hz for axis Oz.

Before the measurements, the subjects warmed up for 30 minutes, by running, stretching, and doing ball exercises. First, they hit the ball in pairs, and then they performed spike attempts. During the research, subjects first performed attacks from the left side of the court from the attack area (of the front court). Attacks were firstly directed along the spike line (x direction) and subsequently in the diagonal direction. Solo blocking, which was stationary in relation to the width of the court, was performed by a co-practising individual and was intended to help the researched individual direct the ball in a defined direction and create similarity between research conditions and actual match situations. Prior to performing an attack, the subjects knew the direction in which the attack was to be performed. After the settings of the cameras were changed, the subjects performed similar attacks from the right side and from the back court. In this manner, four types of attempts were performed: A, a left side attack directed along the spike line, in which the players jumped from the attack area; B, a left side attack directed along the diagonal line, in which the players jumped from the attack area; C, a right side attack directed along the spike line, in which the players jumped from the defence area; and D, a right side attack directed along the diagonal line, in which the players jumped from the defence area.

In the analysis, we used the coordinates of the points that defined the location of the following: the attacking hand, the left and right humeral joints, the ball, and the net (2 points, each situated on the upper edge of the outside of the net). We then calculated the vectors of the net, the girdle of the upper extremities (line of the humeral joints), the movement of the attacking hand (the initial coordinates were taken from the frame of film prior to the ball being hit, and the final coordinates were obtained from the frame after it was hit), and the movement of the ball (the initial coordinates were taken from the frame after the ball was hit, and the final coordinates were obtained from the 10th frame after the ball was hit). Angles between vectors were calculated with the use of the definitions of the scalar product (1, 2) and the values of the scalar product of vectors (3):

$$\vec{a} \circ \vec{b} = |\vec{a}| \cdot |\vec{b}| \cdot cos < (\vec{a}; \vec{b}) \qquad (1),$$

$$\vec{a} \circ \vec{b} = a_x b_x + a_y b_y \; \vec{a} \circ \vec{b} = a_x b_x + a_y b_y \qquad (2),$$

therefore

$$cos < (\vec{a}; \vec{b}) = \frac{\vec{a} \circ \vec{b}}{|\vec{a}| \cdot |\vec{b}|} = \frac{a_x b_x + a_y b_y}{|\vec{a}| \cdot |\vec{b}|} \qquad (3).$$

The geometry of the ball which was hit was determined on the horizontal plane 0_{xz} by the angles describing the mutual spatial relations between the vectors of the location of the net and the glenohumeral joints and the vectors of movement of the attacking hand and the ball (Figure 1). The angles were defined as follows: α_1, the direction of attack, set between the vector of the movement of the ball and the vector of the location of the net; α_2, the direction of movement of the hand in relation to the vector of movement of the ball; β_1, the location of the line of the glenohumeral joints in relation to the net; β_2, the direction of movement of the ball in relation to the line of the humeral joints; and β_3, the direction of movement of the attacking hand in relation to the line of the humeral joints.

For attempts C and D, the arrangement of vectors exhibited axial symmetry in relation to attempts from the left side of the court. The angles α_1, α_2, and β_1 were determined in a symmetrical manner. The angles β_2 and β_3 were defined in the same manner for the attempts from the left and right side of the court. When α_1 is equal to 90°, the ball is moving perpendicularly to the net (attempts A and C); however, for the diagonal direction of attack (attempts B and D), this angle should be an acute angle. A positive α_2 value is observed when the attacking hand is resituated to the outside of the court in relation to the ball (Figure 1) and is caused by the movement of the ball into the centre of the court. A negative α_2 angle value indicates the opposite and causes significant inconsistency (Table 3). To perform statistical analyses, we increased the measured α_2 by 90°, which improved the value of Pearson's correlation coefficient. A similar course of action was adopted in the case of the angle β_1. Using the positional coordinates of the ball, we also calculated the maximum velocity of the ball.

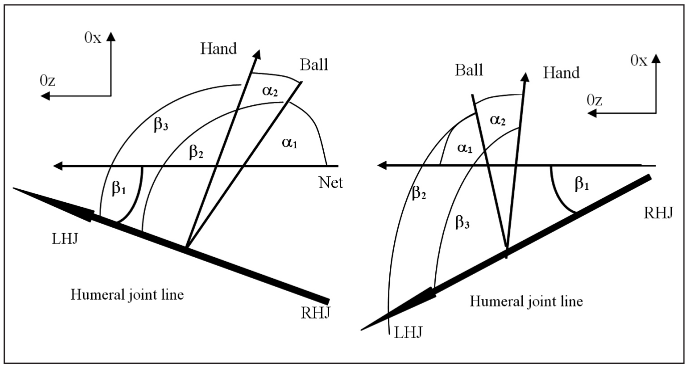

Figure 1. Angles determining ball geometry for attacks from the left and right side of court; LHJ – left humeral joint, RHJ – right humeral joint

Statistical analyses were carried out in the STATISTICA package using the Shapiro-Wilk and Levene tests. Differences between average values in groups were determined using ANOVA with repeated measurements. Significance was assessed using the Newman-Keuls test, and the strength of the correlation was determined using the Pearson coefficient. Significance of differences between groups and for the correlation coefficient was set at the level of $p \leq 0.05$.

Results

The average values of ball velocity varied among attempts; they were the highest in attempt D and were 2.38 m/s (approximately 9%, $p < 0.01$) higher for attacks from the second line. These values were significantly ($p < 0.05$) different than those from both of the attempts performed from the first line of the court. No significant differences were found in the direction of ball movement (Table 1).

Table 1. Resultant velocity of ball hit in particular types of attack (A – 1st line attack along spike line, B – 1st line attack along diagonal line, C – 2nd line attack along spike line, D – 2nd line attack along diagonal line)

	Type of attack			
	A	B	C	D
V_p [m/s]	24.57 ± 2.53^{dd}	24.32 ± 3.42^{d}	26.04 ± 2.7	27.63 ± 2.54

^{d} – $p \leq 0.05$ – significantly different from attack D;
^{dd} – $p \leq 0.01$ – significantly different from attack D.

The average values of α_1 indicate that the subjects directed the ball nearly perpendicularly to the net in attempts A (82 ± 10°) and C (81 ± 7.5°). In attempts B and D, the ball moved at an angle of approximately 45° in relation to the net (Table 2). ANOVA revealed significant differences in the values of α_1 ($p < 0.001$) due to the direction of the attack along the spike line and along the diagonal line (Table 2). For attempts performed in the diagonal direction, α_1 was 8° ($p < 0.05$) larger in condition D than in condition B.

Table 2. Average, minimum, and maximum values of angles describing geometry of ball hit (explanation of angles is shown in Figure 1)

Parameters	Type of attack			
	A	B	C	D
α_1 [º]	$82 \pm 10^{bbb\ ddd}$ min = 58 max = 96	$43 \pm 10.1^{ccc\ d}$ min = 29 max = 60	81 ± 7.5^{ddd} min = 68 max = 92	51 ± 10 min = 41 max = 78
	Difference between the directions of attack***			
α_2 [º]	2 ± 16.3^{b} min = −20 max = 45	11 ± 8.7^{c} min = −8 max = 29	1 ± 10 min = −15 max = 16	12 ± 13.2 min = −19 max = 35
	Difference between the directions of attack**			
β_1 [º]	$9 \pm 15.7^{bbb\ ddd}$ min = −27 max = 37	45 ± 13.4^{ccc} min = 15 max = 65	16 ± 13.2^{ddd} min = −5 max = 43	39 ± 17.2 min = 22 max = 94
	Difference between the directions of attack***			
β_2 [º]	89 ± 18.1 min = 63 max = 141	92 ± 12.7 min = 68 max = 113	97 ±15.4 min = 66 max = 126	90 ± 19.9 min = 65 max = 145
β_3 [º]	90 ± 12.8 min = 56 max = 106	$80 \pm 11.2^{cc\ ddd}$ min = 60 max = 96	98 ± 12.2 min = 77 max = 122	102 ± 21.8 min = 74 max = 169
	Difference between line of attack***			

^{a} – p ≤ 0.05; ^{aa} – p ≤ 0.01; ^{aaa} – p ≤ 0.001 – significantly different from attack A;
^{b} – p ≤ 0.05; ^{bb} – p ≤ 0.01; ^{bbb} – p ≤ 0.001 – significantly different from attack B;
^{c} – p ≤ 0.05; ^{cc} – p ≤ 0.01; ^{ccc} – p ≤ 0.001 – significantly different from attack C;
^{d} – p ≤ 0.05; ^{dd} – p ≤ 0.01; ^{ddd} – p ≤ 0.001 – significantly different from attack D;
** – p ≤ 0.01; *** – p ≤ 0.001 – significantly different from direction and line of attack.

For the values of α_2, ANOVA revealed that attacks with different directions of attack differed significantly from one another ($p \leq 0.01$). These differences were significant for attacks performed from the first line. Although α_2 values were greater in D, no significant differences were recorded between conditions C and D, most likely due to the greater spread of the results (Table 2).

Statistical analysis confirmed significant differences between the directions of attack ($p < 0.001$) in angle β_1, describing the position of the girdle of the upper extremity in relation to the net. The A and C attacks were characterised by the parallel arrangement of the glenohumeral joints with the net. For diagonal attacks, the researched individuals arranged their glenohumeral joints diagonally in relation to the net. The values of β_2 were not significantly different between attempts (Table 2).

The analysis of the average values of β_3 (Table 2) indicate that in all types of attack, the attacking hand moved in a near-perpendicular direction in relation to the line of the humeral joints. The smallest value of the angle was achieved in attempt B.

A significant correlation between the geometry of the ball hit and its velocity was only found in test A for the angles α_1 and α_2. The direction of the attack (α_1) was positively correlated with the velocity of the ball ($p < 0.05$). The same tendency was observed for attempt B (Table 3), although the correlation did not reach statistical significance (r = 0.31). There was a slightly negative correlation for attacks from the right side.

Table 3. Pearson simple correlation coefficients for relationships between angles describing ball geometry (Figure 1) and ball velocity (vball) in particular types of attack (n = 16) and coefficients of partial correlations with exclusion of angle β_1 (n = 16)

Angles	r (simple correlation)				r (partial correlations) for attempt A
	A	B	C	D	
α_1	0.574*	0.31	−0.149	−0.036	0.581*
α_2	−0.735***	−0.318	0.308	−0.208	−0.759***
β_1	0.068	−0.311	0.135	0.086	
β_2	0.377	0.08	0.044	0.057	0.581*
β_3	0.390	0.337	0.308	−0.074	−0.712**

* – p < 0.05; ** – p < 0.01; *** – p < 0.001.

The angle α_2 was negatively correlated with the velocity of the ball only for A attacks from the front court ($p < 0.001$; Table 3). The remaining angles were not significantly correlated with the velocity of the ball (Table 3). Significant correlations were recorded only after the exclusion of the angle β_1 (Table 3), but, once again, only in the A attacks. The direction of flight of the ball in relation to the shoulder girdle (β_2) exhibited an increased positive correlation with the velocity of the ball, reaching a significance level of $p < 0.05$ (Table 3). As the angle between the direction of movement of the ball and the glenohumeral joints became smaller, ball velocity also decreased. Moreover, the ball had greater velocity in cases in which the attacking hand was moving more proximally (smaller β_3).

The correlation between the direction of the flight of the ball with the geometry of the arrangement of the body of the players was examined for all the attempts together (n = 64, Table 4). This means that a reduction of the angle α_1, which describes the movement of the ball in the diagonal direction, is connected with an increase in the value of the angles α_2 and β_1. The direction of movement of the attacking hand deviates from the direction of the movement of the ball, and there is an increasingly diagonal arrangement of the shoulder girdle in relation to the net.

Table 4. Pearson simple correlation coefficients for relationships between angles describing ball geometry (Figure 1) and attack direction (α_1) (n = 64) and coefficients of partial correlations with angle α_1 and effects of exclusion of α_1 on angles α_2 and β_1 (n = 64)

Angles	r	Excluded variable	
		α_2	β_1
α_2	−0.653***		−0.694***
β_1	−0.669***	−0.707***	
β_2	0.076	0.179	0.149
β_3	0.187	0.307*	0.294*

* – p < 0.05; *** – p < 0.001.

Statistical analysis revealed that the angle $\alpha_1$was significantly and positively correlated (r = 0.307; $p < 0.05$) with the direction of movement of the attacking hand in relation to the shoulder girdle (Table 4).

The exclusion of angle β_1 caused a significant correlation among between the angles α_1 and α_2 (r = –0.694; p < 0.001) and α_1 and β_3 (r = 0.294; p < 0.05). Increases in angle α_2 caused a decrease in angle α_1. As a result, increases in the angle between the vector of movement of the attacking hand and the vector describing the orientation of the shoulder girdle (β_3) were correlated with increased angles in the direction of the movement of the ball.

Discussion

The velocity of the ball achieved by the researched individuals was comparable with data in literature for players at university level attacking from the left side of the court without the presence of a blocker [4, 12]. However, it is important to note that performing an attack without obstacles is much easier and makes it possible to attack in an arbitrary direction. In comparison with the results obtained for senior level players, the velocity of the ball was slower when it was struck by junior level players, on average, by more than 2 m/s [2, 8]. These results can be explained by the superior technique of the seniors and their higher levels of strength.

For attacks in the direction along the spike line, the ball did not move perfectly perpendicularly to the net, which is not surprising. An attempt to direct the ball perfectly parallel to the side line of the court (α_1 = 90°) has a greater risk of resulting in the ball being hit beyond the side line of the court [14]. Therefore, in the case of the researched individuals, the values of α_1 were smaller than 90° in attacks performed along the spike line.

Different values of α_1 for attacks in the diagonal direction compared to the direction along the spike line were not surprising. There was a significantly greater value of the angle in the D attempt than in the B attempt, likely due to the greater distance between the net and attacking player in attempt D (attack from the defence line). However, for attack B, the ball was hit significantly closer to the net, and this allowed the ball to be directed at a much more acute angle in relation to the net.

The values of α_2 fluctuated around zero in the A and C attempts, proving the directions of movement of the ball and the striking hand were approximately parallel when the ball was hit. In this model, this condition indicates the occurrence of a central collision. It may be presumed that during an attack along the diagonal direction, setting the appropriate path for the ball is achieved by hitting the ball on the side and not its centre of mass. This assumption is proved by α_2 values of 11° in the B attempt. A significant difference in α_2 of 9° between the A and B attempts confirms this line of reasoning. The identical difference for attacks performed from the back court was equal to approximately 11°. Although it was not characterised by statistical significance, the values of α_2 for attacks directed along the diagonal line suggest non-central hitting.

The direction of the movement of the attacking hand in relation to the body was defined by angle β_3 between the vectors of the movement of the attacking hand and the vector of the position of the shoulder girdle. Due to the limited scope of mobility of the upper extremity in the humeral joint, there is a limited range of the directions of movement in which the attacking hand can move during the activity of attacking [15]. When the player's back is arched as they prepare to hit the ball, the upper extremity is positioned with sub-maximal bending of the elbow joint and maximal abduction of the humeral joint. The hand is at the back and behind the head. In these cases, it is only possible to perform movements with great velocity directed forwards. An attempt to change the direction of movement of the hand towards the centre or the side will be associated with a significant decrease in velocity, which, in turn, decreases the effectiveness of an attack. In attempt B, which took place on the left wing of the court, to direct the ball diagonally in relation to the net, the researched individuals had to resituate the attacking hand proximally. As a result, the effect of non-central hitting of the ball was achieved. It is worth pointing out that a difference of approximately 10° between the observed direction of movement of the attacking hand and the perpendicular direction matches the average value of the angle α_2 in this attempt. The interpretation of the results for the C and D attempts is more difficult because of the different initial directions of the flight of the ball. During attacks from the left side, the ball initially moves from the right side to the left, whereas the direction of movement is the opposite for attacks from the right side. These initial differences may make it necessary for the researched individual to adopt a different direction of movement of the attacking hand. The initial movement of the ball, however, was not analysed.

In simple terms, it is possible to assume that the direction of the movement of the attacking hand will oscillate around the perpendicular in relation to the shoulder girdle. The results relating the velocity of the ball and the direction of movement of the attacking hand (Table 3) indicate that the ball can be hit with greater velocity when the hand is moving towards the proximal and can be partially attributed to the ability to use the strength of the muscles of the chest [15]. This situation, however, only applies to attempt A.

The observed perpendicular direction of the flight of the ball in relation to the girdle of the upper extremity was not a surprise given the assumptions made about the attempts. The researched individuals, knowing the direction in which the attack was to be performed, dealt with this task in the most efficient manner possible. As a result, the attacking hand and the ball were both directed approximately in a perpendicular direction in relation to the line of the humeral joints, and their arrangements in relation to the net determined the direction of the attack.

According to the values shown in Table 2, a large difference in α_2 in the A attempts was observed, in which it ranged from –20° to 45°. The analysis of individual results showed that both of these extreme cases were characterised by a non-typical performance of the attack. In the case in which α_2 was –20°, all other angles had normal values: α_1 = 89°, β_1 = 24°, β_2 = 113°, and β_3 = 93°. As a result of a the diagonal arrangement of the lines of the glenohumeral joints in relation to the net (β_1 = 24°), the researched individual was not able to direct the ball ahead of himself while meeting the required assumptions of the attempt in terms of performing an attack in the direction along the spike line. The direction of the movement of the attacking hand in relation to the line of the glenohumeral joints (β_3 = 93°) would have caused the player to strike the ball straight into the individual blocker. Therefore, to maintain the defined direction of an attack along the spike line (α_1 = 89°), the player could set the direction for the ball only by means of hitting the ball non-centrally, causing α_2 to be –20°. In the second case, the angle α_2 was 45°, and the remaining angles had the following values: α_1 = 66°, β_1 = –27°, β_2 = 39°, and β_3 = 84°. In this attempt, the researched individual also set the line of the glenohumeral joints diagonally in relation to the net but towards the outside of the court (β_1 = –27°; Figure 1). The arrangement of the humeral joints changed from a parallel one in relation to the net, which is characteristic of an attack along the spike line, to a diagonal one. In this situation, it is difficult and risky to direct an attack in a parallel manner to the side line of the court. Therefore, the researched individual had to hit the ball with a greater angle (66°) to complete the task of bypassing the blocker on the outside.

Although neither of these cases is typical for the assumed characteristics of an attack in the direction along the spike line, they provide valuable data for analysis because they show the comparative constancy of angle β_3. Thus, the researched group proved that they had the ability to change the direction of movement of the attacking upper extremity in the humeral joint, described by the angle β_3.

Interpreting the results with respect to the tactics of volleyball, one may arrive at the conclusion that the players, knowing prior to an attack the direction in which they were to hit the ball, direct the ball mainly by aligning the line of their humeral joints. The direction of the flight of the ball may also be modified by changing the direction of movement of the attacking hand in relation to the girdle of the upper extremity and by moving the attacking hand on the ball in the course of hitting the ball. These factors can help opponents set up their defence because they can predict the direction of an attack based on the alignment of the attacking player. Due to the limitations of the conditions imposed in this study, the players were not able to make very wide movements of their attacking upper extremities in the humeral joint. The direction of movement of the attacking hand in relation to the line of the glenohumeral joints was similar in the diagonal and perpendicular attacks. Taking these observations into consideration, training should involve exercises that increase the mobility of the glenohumeral joints and the development of tactics that force players to take advantage of these joints in setting the direction of the flight of the ball. Developing the abilities described in the current article will make it more difficult for the opponent to predict the intentions of an attacking player.

The data obtained suggest that setting a diagonal direction of the ball during attacks from the left side of the court (the A and B attempts) is connected with a decrease in the velocity of the flight of the ball. For attacks from the right wing (the C and D attempts), an identical change in the attack direction made it possible for the researched individuals to hit the ball with greater velocity.

For attempts from the left wing of the court in the direction along the spike line, the velocity of the ball increased as the direction of the flight of the ball became more perpendicular to the net. Central strikes of the ball were also more likely in the more perpendicular attacks.

The researched individuals directed the ball principally by arranging the girdle of the upper extremity and secondarily by performing non-central hitting of the ball.

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