American Journal of Sciences and Engineering Research

E-ISSN -2348 – 703X, Volume 7, Issue 4, 2024

Biomechanics Analysis of Volleyball: A Review

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ABSTRACT: *Biomechanics is vital in volleyball to learn how previous methods have affected movement and to create brand-new methods that are even more effective. Running spike jump (RSJ) is a fundamental skill in the volleyball game, which includes one leg (RSJ-1L) or two legs (RSJ-2L). Spiking in volleyball typically entails a three-step run-up, a countermovement leap, and a straight-down hit on the ball on the other side of the net. A jump serve requires the server to leap from behind the end line, strike the ball in the air while still inside the court, and land in the service zone. Kinovea is a free and open-source video analysis tool that allows researchers to track and analyze critical parameters like shoulder angle, elbow angle, wrist angle, jump height, ball velocity, and hand velocity during specific volleyball actions. A wide range of kinematics and shoulder harm risks are associated with various spike approaches, which result in varying injuries.*

Keywords: *biomechanics; volleyball; spike jump; kinematic; overhead.*

I. INTRODUCTION

Whether on the individual or national stage, successful athletic endeavors inspire academics, coaches, and athletes to seek new ways to improve training and performance (Chaconas et al., 2017). Players and coaches may learn a lot about their strengths and weaknesses by looking at data collected about their actions during training and games (Singh, 2019). The most common method of this sort of analysis is using video-based sensors that take stills and videos of athletes in action during practice and competition (Rana & Mittal, 2020).

For overhead volleyball, a spike is one of the most potent techniques (Baena-Raya et al., 2021). More than 40,000 spikes may be performed by a top volleyball player who practices between 16 and 20 hours each week (Wunder, 2020). Those specializing in attacking the ball are more prone to shoulder discomfort and dysfunction (McGuine et al., 2020). Since many of the abilities in volleyball require the player to make overhead contact with the ball, it is known as an overhead sport. The kinetics and kinematics of each sport's talent differ, even if other games like handball, tennis, and baseball are considered overhead sports. Vulnerable players often utilize an overhead approach to propel their volleyballs down the court and toward the other team's net side of the court. Reeser et al. (2013) found that spike and float serve actions in volleyball have stronger shoulder abduction and horizontal adduction than baseball pitching and tennis serving. Volleyball players had a higher chance of developing infraspinatus syndrome than athletes in other overhead sports because of their unique scapular mechanics.

It is necessary to conduct biomechanical studies to learn how previous methods have affected movement and to create brand-new methods that are even more effective. Using portable inertial measurement units (GMUs) has completely altered the landscape of sports kinematics research. Kinematics analysis employing wearable sensors can offer real-time feedback to the players on their adopted approaches in their particular sports, allowing them to perform efficiently (Rana & Mittal, 2020). Volleyball, handball, baseball, tennis, the javelin throw, and the shot put all rely heavily on the overarm motion (Bergün et al., 2009). Backswing phase

 Received-22-07-2024, Accepted- 06-08-2024

angle, angular velocity, and angular acceleration significantly differed between volleyball and handball players across all three planes. Several research studies analyze the motions of volleyball and handball, but no studies compare their kinematics. Bergün et al. (2009) indicated that the angle in the transverse plane, the angular velocity in the vertical plane, and the angle, angular velocity, and angular acceleration in the sagittal plane significantly differed between volleyball and handball players. Several kinematic factors of the movement and the ball speed after the hit may be used to measure the success of the spike, which relies on physical and psychological qualities (Challoumas & Artemiou, 2018). Researchers have found that spike performance is affected by sex (Fuchs et al., 2019), amount of expertise and technique (Shih & Wang, 2019), as well as injury avoidance (Zahálka et al., 2017).

The kinematics of the volleyball spike are different between men and women, and the height of the spike jump depends on the speed at which the ball is thrown (Oliveira et al., 2020). Variations in volleyball spikes exist according to experience level, technique, and the impact of injuries, all of which need further investigation (Oliveira et al., 2020). However, Seminati et al. (2015) claim that the backswing style approach is a possible preventive treatment for persistent shoulder diseases has yet to be verified (Oliveira et al., 2020).

II. BIOMECHANICS ANALYSIS OF VOLLEYBALL

2.1. Running Spike Jump

Running spike jump (RSJ) is a fundamental skill in the volleyball game. Common RSJs for the spike assault in volleyball include the RSJ with one leg (RSJ-1L) and the RSJ with two legs (RSJ-2L). The present investigation contrasts the RSJ-1L and RSJ-2L regarding their kinematic and kinetic properties. When comparing the RSJ-1L and RSJ-2L, the former had a faster three-step approach running velocity, a greater vertical ground reaction force (GRF), and a more significant ankle, knee, and hip joint moment, while the latter had a lower vertical leap, a shorter last step length and push-off time, more minor knee and hip joint flexion angles at the initial foot-contact, and a smaller knee range of motion. Incorporating the results of the present study into volleyball training helps players better comprehend the biomechanical nuances of spike leaps (Tai et al., 2021).

Previous studies have reported kinematic differences in flight time, jump height, and ball velocity in the front-row spike between the short-set and high-set ball (Obara et al., 2022) and suggested that vertical jump ability (Fuchs et al., 2019) and technical coordination (Slovák et al., 2022) were the primary factors influencing the performance of the three-step approach RSJ (Bhasi & Sadanandan, 2022). In order to improve the take-off velocity of the center of mass (COM) and jumping performance, increasing the approach running velocity prior to a jump can increase the stretch-shortening cycle (SSC) (Tai et al., 2021), which in turn increases the effectiveness of subsequent neuromuscular force production and muscular concentric contraction (Fuchs et al., 2021). Volleyball relies heavily on the skill of spiking. Spiking in volleyball typically entails a three-step run-up, a countermovement leap, and a straight-down hit on the ball on the other side of the net. Quickly running up to the net, launching themselves into the air, and slamming the ball with all their might from the highest point define the RSJ as a hallmark of the volleyball smash. Spiking the ball high and short in the front row as part of an offensive plan are two of the most fundamental volleyball skills, and both are frequently practiced with the RSJ (Tai et al., 2021).

Volleyball's reliance on the spike as a fundamental tactic stems from the importance of the spiking skill (Tai et al., 2021). The study hypothesized that the running spike-jump (RSJ)-2L would be superior to the RSJ-1L in terms of its ability to transfer the horizontal approach running velocity to vertical velocity at take-off. Based on these findings, it is clear that the RSJ-1L and RSJ-2L use distinct approaches to executing a spike jump concerning approach run velocity, final step length, push-off time, and specific joint kinematics and kinetics. Compared to the RSJ-2L, the RSJ-1L may be considered a lower-extremity movement with a higher loading. The current study's findings can be utilized to modify volleyball training by increasing awareness of the biomechanical distinctions between spike leaps. For specialized volleyball techniques, players and coaches should think about how to load the RSJ-1L and RSJ-2L during training (Tai et al., 2021).

Body segments are linked by a kinetic chain, which distributes energy from one body segment to the next during movement, such as throwing (Chu et al., 2016). In overhead throwers, the legs and core carry more

than half of the kinetic energy to the upper extremities (Kibler & Sciascia, 2019). Varying degrees of shoulder rotation range of motion (ROM) are common among athletes who throw, although the connection between ROM and volleyball performance metrics is unclear. The stride, pelvic rotation, upper torso rotation, elbow extension, shoulder internal rotation, and wrist flexion are all standard parts of a general throwing action (Dutton et al., 2020). There is a wide range of kinematics and shoulder harm risks associated with various spike approaches, which results in varying injury risks depending on the technique used by the athlete. Giatsis et al. (2022) compared and contrasted the Traditional Technique (TT), also known as the Elevation Style, and the Alternative Technique (AT), also known as the Backswing Style, while spiking the ball in volleyball. These two approaches were first presented by (Giatsis et al., 2022), but no systematic quantitative study has been done.

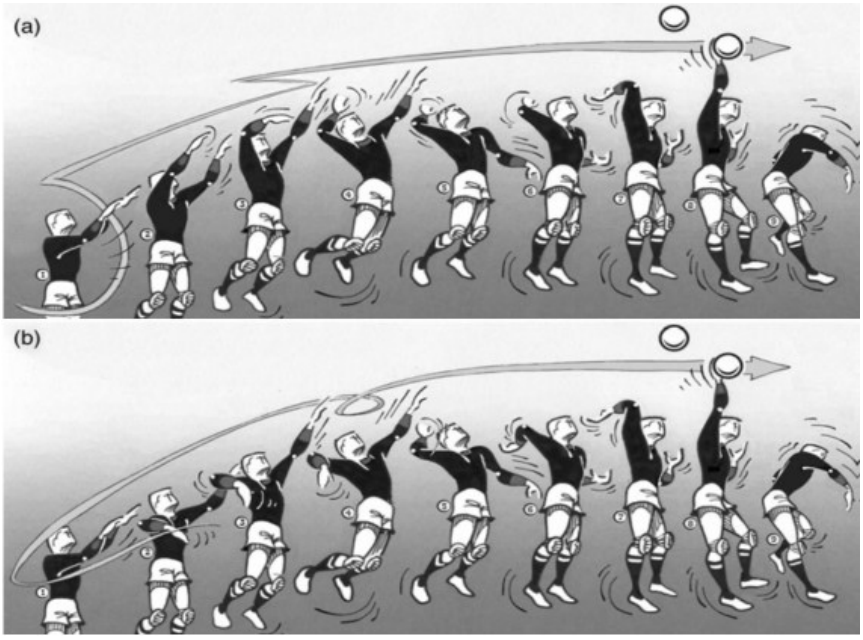

Figure 1: Traditional Spike Technique (a) Elevations style and (b) the Backswing style

2.2. Jump Serve

Aspirational athletic accomplishments, whether on the part of an individual or a nation, inspire scholars, sports scientists, and athletes to develop more effective approaches to training and performance analysis (Borms et al., 2020). The volleyball jump serve is the most challenging service to do. Players and fans alike are mesmerized by the jump serve because of the beautiful, dynamic talent it demonstrates. Today's jump serve is one of volleyball's most entertaining and aggressive talents (Bhasi & Sadanandan, 2022). The jump serve is a spectacular volleyball serve that provides players and viewers with an additional dose of the thrilling, dynamic talent that fascinates the sport. When players throw the ball out of their hitting hand, they have more freedom of movement regarding their hitting arm and trunk posture, allowing them to produce a more extended lever arm and generate more hit velocity (Bhasi & Sadanandan, 2022). Because of the increased speed and topspin, the ball drops quickly and has a shorter flight duration. An ace is frequently the consequence of a powerful jump serve, as the receiving player may not have enough time to position themselves properly or be unable to maintain control of the ball after it has been hit.

A jump serve requires the server to leap from behind the end line, strike the ball in the air while still inside the court, and land in the service zone. The ball contact of the jump serve occurs within the court, unlike when comparing other serves by standing behind the end line. This technique shortens the distance the served ball must travel while increasing its velocity toward the receiving court (Bhasi & Sadanandan, 2022). Athletes load up their legs, which involves shifting their weight forward to convert horizontal speed into upward acceleration. Given the biomechanical significance of the approaches, this study examined the correlation

between a few vital kinematic characteristics and the speed of the ball in a jump serve.

As a result of the mechanical stimulation of sports motions, the shoulders of athletes who throw regularly undergo significant morphological modifications. The increased arm retroversion caused by throwing torsional stress can further contribute to the ER gain, as can the loosening of the anterior capsule, which is associated with the large amplitudes in the late cocking phase (Telles et al., 2021). Experts in kinesiology use biomechanics as a primary tool to solve everyday difficulties in human movement (Singh, 2019). Evidence suggests that the angle of the wrist joint of a volleyball player's counter-spiker has no noticeable effect on their performance, while evidence suggests that the angle of the elbow joint of a volleyball counter-spiker has no noticeable effect on performance (Singh & Singh, 2017). The statistics show that the correlation between the shoulder angle of a volleyball player's counter spike and their performance is weak (Singh & Singh, 2017).

Several phases of spike migration have been identified by authors (Serrien et al., 2016), but Gupta et al. (2021) proposed the most comprehensive model, which included six phases: Seconds after the left foot takes off, both feet come into contact with the ground; this is known as the "Approach" phase (Gupta et al., 2021). The "Plant phase" is the period between the ground contacts of both feet and take off; the "Take-off" is the moment the feet leave the ground; and finally, "Landing" is the time between the initial contact and the last step (Gupta et al., 2021).

The ball's speed and the spike's direction were measured in six separate investigations (Seminati et al., 2015). The mean ball speed for healthy male elite players was 27.0 m/s and 19.0 m/s, respectively. A study by Seminati et al. (2015) found that male and female top Italian players using various spike methods (elevation style: 25.6 m/s compared to backswing style: 26.3 m/s) had equal ball speeds. There was a statistically significant difference in ball speed between the straight-ahead and crosscourt spikes for I Division NCAA female volleyball players. However, Jiang and Zhao (2022) found no change in ball speed between straight-ahead (15.5 m/s) and crosscourt (15.7 m/s) spikes for a comparable sample. Oliveira et al. (2020) observed a mean ball speed of 18.4 m/s for elite female players from Spain when spikes were driven to the backcourt (crosscourt, straight-ahead, or center spikes). Ball speed correlated with the shoulder-hip separation angle (r = 0.56), shoulder angular velocity (r = 0.66), and hip angular velocity (r = 0.47).

Coleman et al. (1993) found a strong connection (r =0.75) between the angular velocity of the spiking arm and ball speed (for various spike orientations during competitive matches). Only three investigations specifically examined the kinematic changes between spikes (Brown et al., 2014). During crosscourt spikes, top male players rotated their trunks more than during straight-ahead spikes (Δ=4°, CI-0.9-7.7, p=0.016). Crosscourt spikes were shown to have a more extensive range of shoulder rotation velocity (Δ=236°/s) than straight-ahead spikes (Δ=4236°/s). The I Division NCAA female volleyball players showed significant variations in the shoulder hip separation angle between straight-ahead and crosscourt spikes, with a p=0.043 and a calculated statistical power of 61.9%, respectively. There was no difference between the two spike orientations seen by Reeser et al. (2013) when they used a comparable sample.

III. KINEMATIC ANALYSIS SOFTWARE

Incorporating Kinovea software for motion analysis in volleyball biomechanics research can offer detailed insights into the kinematics of various movements, such as the volleyball spike. Kinovea is a free and open-source video analysis tool that allows researchers to track and analyze critical parameters like shoulder angle, elbow angle, wrist angle, jump height, ball velocity, and hand velocity during specific volleyball actions (Al-Tamimi, 2023; Bhasi & Sadanandan, 2022a; Kumar, R., & Kumar, 2020; Wahyudi et al., 2021; Yazdani et al., 2022; Yousif et al., 2023).

Kumar and Kumar (2020) performed the biomechanical analysis of the volleyball serve using Kinovea software. Researchers likely utilized this tool to examine key kinematic parameters involved in the serving technique. By analyzing factors such as shoulder rotation, arm speed, and ball trajectory, this study could have provided valuable insights into the biomechanics of the volleyball serve. Integrating findings from this study with the current research on rotator cuff exercises can help understand how shoulder stability and strength impact the serving motion, potentially leading to improvements in serve accuracy and power while reducing the risk of

shoulder injuries among volleyball players.

Similarly, Yousif et al. (2023) conducted a kinematic analysis of the blocking technique in volleyball using Kinovea software. This study may have focused on tracking joint angles, hand positioning, and timing during blocking. By examining the biomechanics of the blocking technique, researchers could have identified optimal movement patterns and joint coordination required for effective blocking. Integrating insights from this study with the discussion on rotator cuff exercises can aid in developing targeted exercise programs to enhance shoulder stability and strength, thereby improving blocking performance and reducing the likelihood of shoulder-related issues in volleyball players.

Furthermore, Wahyudi et al. (2021) utilized Kinovea for motion analysis in the volleyball setting technique. This study analyzed parameters such as shoulder angle, wrist movement, and ball placement during the setting action. By investigating the biomechanics of the setting technique, researchers could have gained insights into the role of shoulder stability and mobility in executing precise and efficient sets. Integrating findings from this study with the current research on rotator cuff exercises can inform the development of exercise interventions to improve shoulder function and enhance setting accuracy in volleyball players.

Bhasi and Sadanandan (2022) employed Kinovea, a motion analysis program. The jump serve velocity was correlated with several other kinematic characteristics using Pearson's product-moment correlation coefficient. Using Pearson's Correlation Coefficient, Bhasi and Sadanandan (2022) analyzed the data gathered from the video analysis. A positive correlation was observed between the ball's velocity and the athlete's take-off velocity, center of gravity (CG) height at ball contact, reach height, and distance jumped. Based on the principle of conservation of momentum, it has been hypothesized that players with a longer run-up in volleyball can leap higher. The average run-up for a volleyball player is four steps (Bhasi & Sadanandan, 2022).

Fuchs et al. (2021) indicated that there was a significant relationship between the volleyball spike jump (VSJ) and the squat jump (SJ) ($r = 0.88$, $p=0.001$), the countermovement jump (CMJ) ($r = 0.88$, $p=0.001$), and the countermovement jump (CMJA) ($r = 0.82$, $p=0.001$). Predictions of vertical-sprint jump height using regression with overall jump height as the single predictor were unreliable. Regression analysis of vertical-sprint jump height based on overall jumping performance was considerably enhanced using just one or two extra kinetic variables. In females, better models were identified for SJ; in men, better models were found for SJ and CMJA. More accurate and valuable data on sport-specific VSJ performance may be gleaned through these models, which give well-established and dependable general jump types that may be utilized for testing (Fuchs et al., 2021).

Ikeda et al. (2018) compared the kinematic data of the spike jump (SPJ) to the kinematic data of the standing long jump (SLJ) and the vertical jump (VJ) in order to better understand the factors that contribute to successful spike jump (SPJ) performance among female competitive volleyball players (VJ). The data indicated that SPJ height was linked to the vertical velocity at take-off, the horizontal velocity at the third step contact, and the horizontal velocity deceleration between the third step contact and take-off. Relationships among SPJ, SLJ, and VJ were all positive, but those between SPJ and SLJ were significantly closer and more supportive than those between SPJ and VJ. The hip, knee, and ankle muscles each contributed 39.7%, 21.1%, and 39.2% to the propelling phase of SLJ, while they each contributed 36.2%, 30.2%, and 33.6% to the accelerating phase of VJ. Take-off vertical velocity for SPJ was linked with hip work, ankle peak power in SLJ, and knee peak power in VJ. Since the significant generator for power output appears to rely on jump direction, these findings highlight the significance of improving horizontal and vertical leaping talents independently to increase the height of SPJ.

Chen and Huang (2008) compare the front- and back-row spiking velocities and displacements of female volleyball players. For this purpose, they employed two JVC9800 digital video cameras (120Hz) to record spiking action. A Kwon 3D motion system was utilized to examine the kinematic factors. The data showed that the resulting velocities of the CM were higher for the back-row spike during both approach and take-off. The horizontal displacement of the CM and the height of the leap were both more significant for the spike in the rear row than for the spike in the front. The front-row spike had a higher starting ball speed and angular velocity at the shoulder, elbow, and wrist than the back-row spike. Results from this research can help instructors better explain and demonstrate the volleyball spike technique.

IV. CONCLUSION

Several kinematic factors of the movement and the ball speed after the hit may be used to measure the success of the spike, which relies on physical and psychological qualities, including jump height, ball trajectories, speed of the ball, and direction of the spike and range of motion. There is a wide range of kinematics and shoulder harm risks associated with various spike approaches, which results in varying injury risks depending on the technique used by the athlete.

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