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**ORIGINAL ARTICLE**

# Three-Dimensional Kinematical Analysis of Jump Serve In Volleyball: Muscle Fatigue Effects

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## ABSTRACT

**Background.** This study aimed to analyze core muscle fatigue effects on the kinematic parameters change during volleyball jump serve. **Methods.** The participants were sixteen experienced male volleyball players with average age, height, and body weight of 24.6 ± 1.8 years, 1.85 ± 1.6 m, and 79.5 ± 3.5 kg, respectively. This study utilized two high-resolution video cameras, a drone video, a lactate analyzer, and a radar speed gun. Meanwhile, the eight kinematics parameters analyzed at the approach, plant, and jump phases showed that the ball speed decreased significantly in the fatigue condition compared to the non-fatigue counterpart. **Results.** There was a significant difference in the jump phase duration, step length, and jump height variables for the fatigue and non-fatigue conditions during the jump serve in volleyball. Furthermore, the six kinematics parameters analyzed in the maximal shoulder external rotation phase showed a significant difference in fatigue and non-fatigue conditions found in the shoulder external rotation and trunk tilt backward parameters. Meanwhile, the maximum angular velocity phase at the upper limb joint during the jump serve showed that the variable shoulder internal rotation decreases significantly in the fatigue condition compared to the non-fatigue counterparts. Also, in the trunk rotation and trunk tilt forward, a significant decrease in the upper limb joint's maximum angular velocity was observed in the fatigue condition during the volleyball jump serve. **Conclusion.** Fatigue reduces players' performances during jump serve in volleyball, leading to slower ball speed and changes in body segment movements.

**KEYWORDS:** ***Volleyball, Sports Biomechanics, Core Muscle, Fatigue, Jump Serve*.**

## INTRODUCTION

Volleyball was initially created for recreational sports but is now a competitive sport. In addition, volleyball is a team sport where individual players must be able to master skills and tactics, supported by a high physical fitness level, both in attacking and defensive conditions (1). Therefore, these players must master six basic skills: receiving, passing, setting, blocking, and spiking. The jump's height is the main performance in the volleyball game's characteristics and is essential for a successful jump serve performance. Typically, jumps are used during a spike, block, and service actions. The jump serve is a technique performed by throwing the ball with both hands upwards from the court's baseline, followed by a lower body ground reaction force while jumping as high as possible to hit the ball in the air towards the

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opponent's field (2). The jump serve is characterized by high toss, multistep approaches, take-off, maximal jump, and the full swing of both arms (3). Recently, the jump serve has become a dangerous offensive weapon for the top volleyball teams, as a great spike server can produce several aces over a match (4). An analysis of the services performed at the 2005 Men's European Volleyball Championship showed the Spanish team used the jump serve more often at a 72% execution rate, compared to other serve types, while the French and Dutch teams used the serve at execution rates of about 63% and 58%, respectively. According to the International Volleyball Federation (FIVB), the average jump serve frequency increased from 63% at the 2004 Olympic men's tournament to 82% at the 2008 counterpart (5).

A study by MacKenzie (6) regarding the spike vs. the jump serve for collegiate volleyball players showed similar speeds for male athletes (male jump serve 19.7 m/s and male spike 22.4 m/s), but lower speeds for the female jump serve (13.2 m/s), compared to the spike (17.8 m/s). Meanwhile, a study on elite international volleyball spikers' front row spikes reported a mean impact ball speed of 27 m/s. In the jump serve, the ball position at impact is determined by the server's toss.

The stages in a volleyball jump serve are categorized above. During the approach phase, horizontal speed is developed and subsequently slowed down by planting one foot in front of the body (7). The dynamic arm swing allows for greater momentum and ground reaction force to be generated. As stated in previous studies, the spike action is divided into three phases (the approach, plant, and jump) to enable a detailed analysis of the players' performances. Meanwhile, the previous studies' results showed that the main aspects influencing jumping performance are approach velocity, trunk countermovement, upper body support, arm swing, and knee extension angular velocity (8). The lower leg's muscles are previously stretched after setting the foot through a cycle of shortening stretches, while the joint angle is reduced and the body is lowered to increase the distance during acceleration.

Furthermore, the serve's success is determined by several factors, including arm swing, jump height, motion range on the upper body joint and core muscle strength (9). With respect to the jump serve frequency at international level of competition, Fuchs (10) reported an average number of jumps per game of 118-212 times. During a jump serve, a large number of jumps has a direct impact on muscle fatigue, primarily in the body's lower and core muscles, including the trunk and hip muscles, with the function of maintaining the spine and pelvis' stabilities, as well as supporting transfer of energy from large to small muscles, during activity (11). Hung (12) reported that core stability is the ability to control the body's position and motion to produce optimal movement. Becker (13) described core muscle stability as integrating local, single, and multi-joint muscles to provide bodily stability and produce efficient and effective movements.

During sport activity, fatigue causes decreased muscle power generation, neuromuscular coordination, precision motion control, joint stability, muscle contraction, and speed reaction time. Fatigue is defined as a person's lack of ability to produce the required energy or the inability to sustain energy produced to perform a targeted activity (4). Generally, muscle fatigue is defined as a reduction in a muscle's ability to generate power, due to disconnected coordination in the chain of motion from the central nervous system, to the muscle fibers (8). According to Ozmen (14), core muscle fatigue impacts decreased performance during jump headings in soccer. Ball speed decreases after impact due to decreased hip and trunk forward velocities and head extension angular velocity.

Similarly, a study by Bastiurea (15) on handball throwing showed a significant reduction in shoulder internal rotation, elbow extension angular velocity, and horizontal abduction shoulder velocity after conducting muscle fatigue treatment. Meanwhile, in badminton, significant reductions in shoulder internal rotation, forearm pronation, elbow extension, and wrist flexion angular velocity were observed after muscle fatigue treatment, and this negatively influenced the jumping smash performance. However, this differed, compared to a study by Vaverka (16) on table tennis, where a significant increase in ball speed during the forehand topspin stroke was reported, after arm muscle fatigue treatment with maximum weight training, and only the ball accuracy differed.

The purpose of this study was to analyze core muscle effects to kinematics parameter movement change on the volleyball jump serve performance using three-dimensional analysis.

## MATERIALS AND METHODS

**Method and Design.** This study used a descriptive method with a quantitative approach, using a one-group pretest and posttest design.

**Participants.** In this study, sixteen experienced male volleyball players, with an average and standard deviation age of 24.6 ± 1.82 years (age range from 21 to 25 years), height 1.85 ± 1.64 m (height range from 1.76 to 1.92 m), and body weight 79.5 ± 3.57 kg (height range from 74 to 83 kg), volunteered to participate in the study. The local Ethics Committee approved this study of the Faculty of Sport and Health Education, Universitas Pendidikan Indonesia, with the number F/UPI.046/2021.

**Fatigue Treatment.** As a treatment for core muscles fatigue in the body, various core training types, including flutter kicks, reverse crunch, feet crossovers, plank knee ins, scissor kicks, spiderman push-ups, side plank raises, mountain climbers, sit up cross punch exercise, were provided. All exercises were performed in one set until the point of fatigue was reached. Meanwhile, each player has fitted a heart rate (HR) monitoring System (Polar S 810İ Polar Electro OY, Finland) before fatigue exercise treatment. Each participant's resting HR and maximum HR values were also recorded.

**Statistic Analysis.** This study utilized the SPSS version 22.0 application software (SPSS Inc., Chicago, IL). Also, mean and standard deviation were calculated as initial data for further analysis on the normality (Chi-square method approach), homogeneity (Lavene's test method approach), and hypothesis testing. A one-way variance analysis was used to test the hypothesis at a significance level of $p < 0.05$. joints were performed using the Butterworth low-pass filter approach at a 15 Hz cut-off frequency, determined by residual analysis techniques.

**Kinematics Parameters.** The volleyball jump serve movement is divided into three phases (i.e., the approach, plant, and jump phases) to analyze the players' performance in detail, as shown in Figure 1 (17).

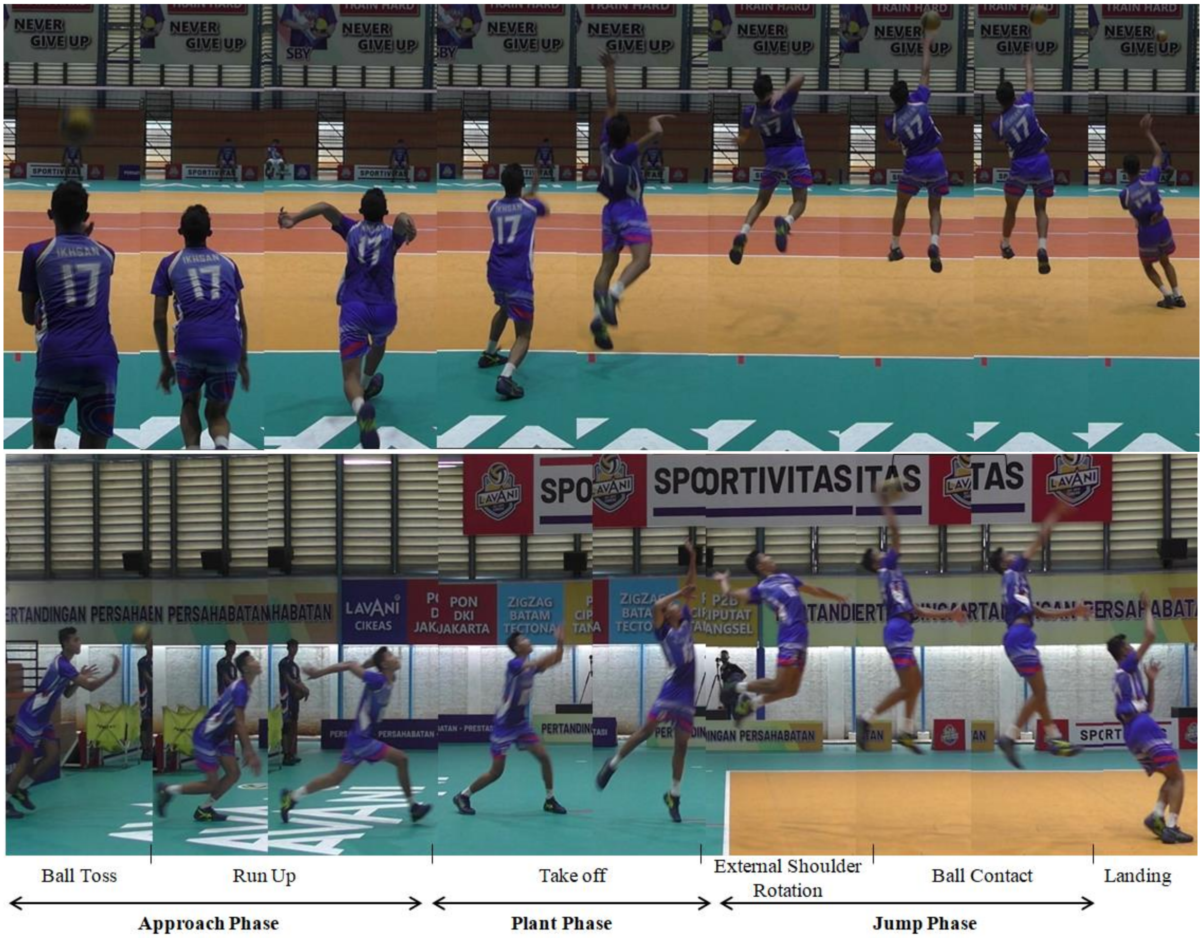


**Figure 1. The phase of the Mechanical Movement of the Volleyball Jump Serve Technique**

In this jump serve approach phase, the movement begins with a ball toss, followed by a run-up to the movement before take-off. Furthermore, in the plant phase, starting from take off to the maximum shoulder external rotation movements, and in the jump phase, starting from the shoulder internal rotation, ball contact until the landing moment. In contrast, the total spike duration movement starts from the ball toss to the landing moment.

To analyze the volleyball jump serve's kinematic parameters, a movement model design was formulated under the body's anatomical principle, as outlined below (Figure 2). The shoulder joint comprises three movements, internal-external shoulder rotation (A), shoulder abduction-adduction (B), and horizontal shoulder abduction-adduction (C). Meanwhile, the elbow joint comprised one motion characteristic, the elbow flexion extension (D). The next movements are the trunk tilt forward-backward (E), trunk tilt left and right sideways (F), and hip and trunk rotation (G).

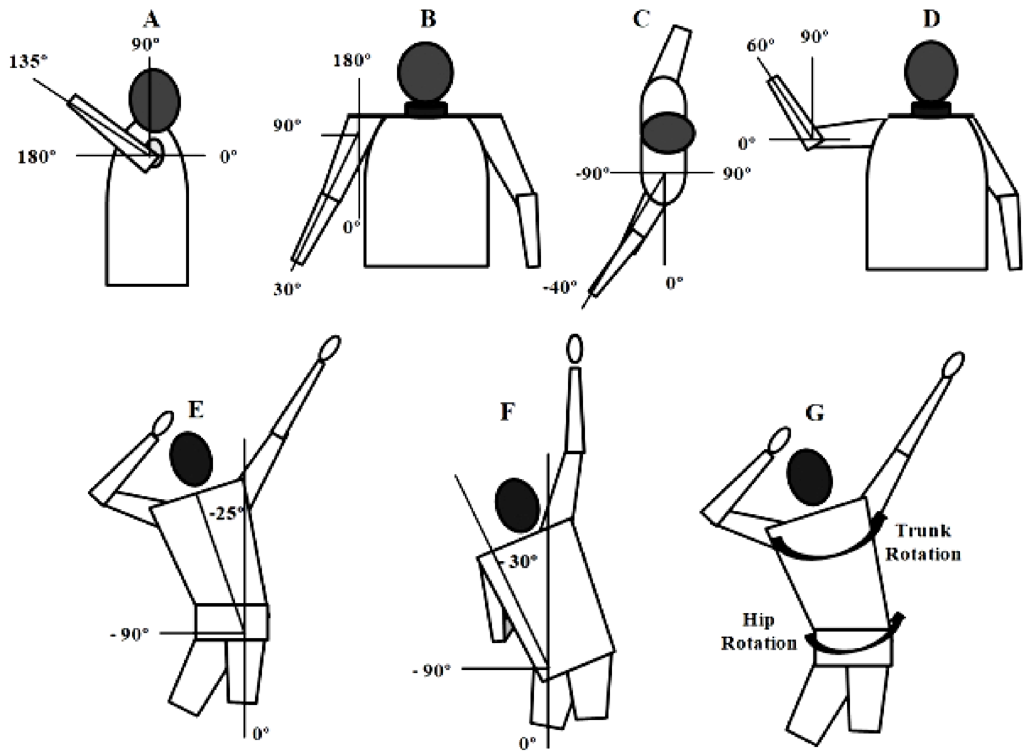


**Figure 2. Kinematic Parameters of the Upper Limb Joint Movements**

**Instruments.** This study utilized two high-resolution digital video cameras (Sony Handycam HC-V400 Full HD, Japan), a drone video camera (DJI Phantom 4 Pro, China), One set of three-dimensional calibration, 3D motion software analysis (Dartfish Pro, Switzerland), a set of manual markers, a lactate analyzer (Accutrend plus kit GCT, Germany), Heart rate monitoring System (Polar S 810İ Polar Electro OY, Finland), as well as a radar speed gun (Bushnell Speed gun 101911, Italia).

**Procedure.** The ball speed was measured using a radar speed gun with a 100 hz shutter speed, placed near the net at a distance of 45 cm outside the field's sideline. Meanwhile, all jump serves were captured using three high-definition digital video cameras. To capture the jump serve performance's movement, all three video camera handicaps were operated at a 120 Hz nominal frame rate, with a 1/2000s shutter speed, and each was placed on a rigid tripod, mounted at a 1.5 m height. Video camera 1 was placed on the field's right side, at a distance of 3.5 m perpendicular to the serve line, while video camera 2 was positioned behind the service line, perpendicular to the player's position, at a distance of 6m from the court's back line.

Meanwhile, video camera 3 was mounted on a drone positioned perpendicularly above the subject's head at a 9 m distance from the subject area. The subjects were instructed to warm up and practice the normal jump service to obtain kinematic data. Subsequently, each subject was asked to perform a maximum jump serve, and only 5 successful jumps serve performances were recorded and used for further data analysis. In addition, calibration and data analysis were performed in three dimensions, using the direct linear transformation (DLT) calibration structure method developed by Abdel Aziz and Karara (18).

## RESULTS

Table 1 shows the average, standard deviation, and significance values of the kinematic parameters in the approach, plant, and jump phases during the volleyball jump serve.

The eight kinematics parameters analyzed at the jump serve approach phase (starting from the ball toss, running up to the movement just before take-off), plant phase (from take off to the maximum shoulder external rotation movements), jump phase (from shoulder internal rotation, ball contact until landing moment), and the total spike duration movement starts from the ball toss to the landing moment showed a significant decrease in ball speed during the fatigue condition (11 m/s), compared to the non-fatigue counterpart (20 m/s) with a p-value of 0.037. Furthermore, the data showed a significant difference in the jump phase duration (P = 0.041), step length (P = 0.038), and jump height (P = 0.034) variables in the under fatigue and non-fatigue conditions during the volleyball jump serve.

Table 2 shows the kinematic parameters' average, standard deviation, and significance values during the volleyball jump serve in the maximal shoulder external rotation phase. The six kinematics parameters analyzed in this phase showed a significant difference between the fatigue and non-fatigue conditions that occurred in the parameters of the shoulder external rotation (p = 0.042) and trunk tilt backward (p = 0.033) during the volleyball jump serve.

Table 3 shows the kinematic parameters' average, standard deviation, and significance values, in the maximum angular velocity at the upper limb joint, during volleyball jump serve. According to the table, a significant reduction in the shoulder internal rotation variable occurred in the fatigue condition (1623º/s), compared to the non-fatigue counterpart (2161º/s), with a p-value of 0.052. Also, in the fatigue condition, a significant decrease in the upper limb joint's maximum angular velocity was found in the trunk rotation (p = 0.087) and trunk tilt forward variables (p = 0.029), compared to the non-fatigue counterpart, during the jump serve.

**Table 1. During Volleyball Jump Serve, Kinematics Analysis Parameters in the Approach, Plant, and Jump Phases.**

| Kinematics Parameter | Means ± SD | | P-Value |
|---|---|---|---|
| | Fatigue | Non-Fatigue | |
| **Ball velocity (m/s)** | 11 ± 1.7 | 20 ± 1.5 | 0.037* |
| **Approach Phase Duration (s)** | 0.54 ± 0.03 | 0.52 ± 0.02 | 0.852 |
| **Planting Phase Duration (s)** | 0.22 ± 0.01 | 0.22 ± 0.03 | 0.767 |
| **Jump Phase Duration (s)** | 0.70 ± 0.05 | 0.61 ± 0.07 | 0.041* |
| **Total Spike Duration (s)** | 1.47 ± 16.41 | 1.41 ± 0.06 | 0.812 |
| **Step Length (cm)** | 201.5 ± 13.16 | 262.4 ± 15.24 | 0.036* |
| **Jump Height (cm)** | 78.54 ± 4.23 | 75.17 ± 5.13 | 0.038* |
| **Spike Height (cm)** | 293.25 ± 6.05 | 279.54 ± 6.18 | 0.229 |

***Significant at P < 0.05**

**Table 2. Kinematic Parameters in the Maximal Shoulder External Rotation Phase, During the Olleyball Jump Serve**

| Kinematics Parameter | Means ± SD | | P-Value |
|---|---|---|---|
| | Fatigue | Non-Fatigue | |
| **Shoulder external rotation (º)** | -122 ± 3.5 | -169 ± 4.2 | 0.042* |
| **Shoulder abduction (º)** | 101 ± 1.2 | 106 ± 1.4 | 0.203 |
| **Shoulder horizontal adduction (º)** | 7 ± 0.83 | 9 ± 0.96 | 0.312 |
| **Elbow flexion (º)** | 94 ± 1.1 | 102 ± 1.3 | 0.956 |
| **Trunk tilt backward (º)** | 16 ± 3.5 | 29 ± 3.1 | 0.033* |
| **Trunk tilt sideways left (º)** | 19 ± 1.4 | 21 ± 1.6 | 0.229 |

***Significant at P < 0.05**

**Table 3. Kinematic Analysis Parameters on the Maximum Angular Velocity at the Upper Limb Joint, During the Volleyball Jump Serve**

| Kinematics Parameter | Means ± SD | | P-Value |
|---|---|---|---|
| | Fatigue | Non-Fatigue | |
| **Shoulder internal rotation (°/s)** | 1623 ± 3.5 | 2161 ± 4.2 | 0.052* |
| **Trunk rotation (°/s)** | 561 ± 1.2 | 782 ± 1.4 | 0.087* |
| **Hip rotation (°/s)** | 421 ± 0.8 | 429 ± 0.9 | 0.203 |
| **Elbow extension (°/s)** | 873 ± 1.1 | 995 ± 1.3 | 0.112 |
| **Trunk tilt forward (°/s)** | 162 ± 3.5 | 199 ± 3.1 | 0.029* |
| **Trunk tilt sideways left (°)** | 185 ± 3.5 | 199 ± 3.1 | 0.198 |

***Significant at P < 0.05**

## DISCUSSION

**Ball Velocity.** This study's results showed a significant decrease in the ball speed during the fatigue condition (11 m/s), compared to the non-fatigue counterpart (20 m/s), during the volleyball jump serve. It is similar to the results of a study by Ahmed (19) on the pitcher's throwing in baseball, where the ball speed experienced a significant decrease of about 23%, in the fatigue condition, compared to the non-fatigue counterpart (128.9 km/h). Rusdiana (20) also reported a significant difference in ball speed of 80 km/h and 125 km/h during the jump heading in soccer, in fatigue and non-fatigue conditions, respectively. According to Ziv & Lidor (21), the maximal ball speed had a significant positive correlation with the absolute stride length during a pitch (r = 0.69) but not with the relative stride length (% body height, % lower extremity length, and % maximal open legs' width). In handball throwing, the transfer of impulses from the proximal to distal segments, including the hip, shoulder, elbow, wrist, and middle hand, is an important factor in achieving maximum ball velocity. According to Yanagisawa & Taniguchi (22), 67% of ball velocity at ball release is explainable by the summation effects from the velocity of elbow extension and internal rotation at the shoulder. Meanwhile, Dinç & Ergin (23) shows a significant correlation between timing the maximal pelvic angle with ball velocity, indicating the best throwers.

**Approach Phase.** In the approach phase, during the jump serve's ready position, the server stands about 5 m behind the end line and holds the ball in the serving hand. The jump serve description for a right-handed server is given below. For a left-handed server, the foot and hand positions are expected to be on the opposite side (24). The ball toss occurs off the right foot, and the ball is tossed with the right arm, elbow extended, and body leaning forward. Subsequently, the ball is for the serve from the left foot, preferable at a high point of release above the server's head because longer ball contact gives better control over the toss. Long step onto the left foot is performed to start the run-up (25). In the run-up, the step from the left foot back onto the right foot is the longest and often covers a distance of up to 80% of the server's standing height. Thus, an increase in this step's length implies the server is more skilled and has more time and distance to decelerate the forward velocity and prepare for upwards take-off. A study by Reeser (7) showed that longer step is related to a faster run-up, which is related to a higher jump and faster serve, to prepare for trunk rotation into the serve.

**Jump Phase.** The arm swings upward are completed before the extension of the legs, because the arm swing contributes to ground reaction forces early in the take-off, before leg extension occurs (26). However, the end of the arm's upward motion can also transfer vertically. The final left foot plant occurs prior to take-off. As the foot is planted well ahead of the right foot at an angle to the end line, the arm swing nearing completion transfers momentum to the rest of the body for take-off.

Meanwhile, as the leg is extended, the trunk is also extended to maximize the ground forces. The timing of joint movements during take-off comprises shoulder flexion, trunk extension, and hip and knee extension. Özdal (27) reported that ankle plantar flexion is the final movement to increase jump height, as the calf muscles contribute significantly to jump height.

At take-off, the center is raised in the body by the full trunk and leg extension, raising the arms to a near-vertical position. A skilled jumper can attain 60% of the total jump height by increasing the height of the center of mass at take-off (28). Meanwhile, the mean horizontal velocity at take-off was 3.23 m/s. However, in this study, the mean values for top servers were horizontal velocities of 4.20 m/s at the right foot plant and 3.65 m/s vertical velocities at take-off, while the center of mass velocity at ball impact ranged from -0.33 to 2.76 m/s, indicating some servers hit the ball on the way down and others hit on the way up, as also observed by Reeser (7), in front row spiking. The movement of the upper extremities happens entirely during this phase. The ball moves to a significant height of up to 10 m, then drop to a player contact position of about 2 m on the court.

## CONCLUSION

In this study, the eight kinematics parameters analyzed at the approach, plant, and jump phases showed a significant decrease in ball speed during fatigue compared to the non-fatigue condition. Furthermore, the data showed a significant difference in the jump phase duration, step length, and jump height variables during the fatigue and non-fatigue conditions in the volleyball jump serve. The six kinematics parameters analyzed in the maximal shoulder external rotation phase showed a significant difference in fatigue and non-fatigue conditions found in the shoulder external rotation and trunk tilt backward parameters during the volleyball jump serve. Subsequently, The six kinematic parameters analyzed in the maximum angular velocity phase at the upper limb joint during the jump serve showed a significant reduction in the variable shoulder internal rotation during fatigue compared to the non-fatigue counterparts. In addition, a significant decrease in the upper limb joint's maximum angular velocity was found in the trunk rotation and trunk tilt forward variables, during fatigue conditions, compared to the non-fatigue counterparts, during the volleyball jump serve.

## APPLICABLE REMARKS

- This study is used as basic information in selecting volleyball athletes.
- Athletes and coaches need real-time biomechanics analysis data of the serve volleyball technique.


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## AUTHORS' CONTRIBUTIONS

Study concept and design: B. Acquisition of data: A.R. Analysis and interpretation of data: B. Drafting the manuscript: A.R. Critical revision of the manuscript for important intellectual content: S. Statistical analysis: A.R. Administrative, technical, and material support: S. Study supervisionA.R.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest regarding the publication of this study.

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