

**ANALYSIS OF BALL CONTACT ANGLE AND JUMP HEIGHT BIOMECHANICS
IN VOLLEYBALL SMASH MOVEMENTS AMONG
SPORTS EDUCATION STUDENTS**

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Abstract

This study aims to analyze the biomechanics of the volleyball smash (spike), focusing on ball contact angle and jump height among Sports Education students at Universitas Muhammadiyah Kalimantan Timur (UMKT). The smash is a key attacking technique consisting of run-up, take-off, hit, and landing phases. This research used a quantitative descriptive method involving three active male students representing different training experience levels (<1 year, 2 years, and 3 years). Video recordings at 1080p 60 FPS were processed using Kinovea software (version 24.1.1) to measure jump height parameters and ball contact angle relative to a standard 243 cm net height. The results showed mean values for standing height (173 cm), height before jump (148.40 cm), height after jump at contact (220.79 cm), net jump height (72.39 cm), and ball contact angle (164.23°). While net jump height was relatively similar across subjects (71.35 cm–73.43 cm), students with longer training experience achieved significantly higher contact reach points (238.02 cm) and more optimal control. Training experience enhances neuromuscular coordination and technical efficiency in smash execution.

Keywords: Biomechanics; Smash; Ball Contact Angle; Jump Height; Physical Education

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INTRODUCTION

Volleyball is a rapidly developing sport in higher education, particularly among physical education students. Achieving peak performance requires mastery of basic techniques, good physical conditioning, and optimal motor coordination. One of the most critical offensive techniques in volleyball is the smash (spike), which aims to generate points through aggressive attacks (Muñoz-González et al. (2019). The success of a smash depends heavily on physical attributes such as leg muscular power, upper body strength, and neuromuscular coordination (Ismael 2024). In addition, mastering basic techniques is strongly influenced by physical fitness and motor coordination among students (Jafar et al., 2023).

Based on preliminary observations conducted on 10 students of the Sports Education Study Program at Universitas Muhammadiyah Kalimantan Timur (UMKT), only 3 students were able to perform an effective smash. The remaining 7 students experienced failed smash attempts primarily

due to improper ball contact, poor body coordination, inaccurate jump timing, and insufficient hitting power. Vertical jump height has a strong relationship with the position of the ball contact point, which directly affects the resulting attack angle (Kuryanto et al., 2024). Furthermore, movement coordination and arm angle during ball contact act as crucial factors in determining spike speed, direction, and accuracy (Zahálka et al., 2017). Coordination within the kinetic chain plays an essential role in reaching peak jump height and generating ball speed (Wang et al., 2024). Leg muscle explosive power contributes significantly to vertical jump height and spike quality (Dos'Santos et al., 2018). Moreover, biomechanical evaluation shows a strong correlation between ball contact angle and jump height during spike execution (Ismael, 2024).

Students often experience difficulties in basic biomechanical aspects when performing a smash (Situmorang & Raharja, 2025). Biomechanical theory explains that smash performance is governed by key factors including contact angle, jump height, and arm swing speed (Dos' Santos et al., 2018). An optimal attack angle significantly improves ball accuracy and attack effectiveness (Pradana & Darmanto, 2025). While previous studies have examined general biokinetic and kinematic relationships in elite or trained athletes (e.g., Garcia et al., 2022; Ismael, 2024), a research gap remains regarding how skill acquisition level in physical education pedagogy influences these parameters during field execution. The novelty of this study lies in its specific focus on evaluating the interaction between ball contact angle and vertical reach across distinct training maturity stages (<1 year, ~2 years, and 3 years) within a physical education curriculum framework using 2D high-frame-rate video motion tracking (Kinovea). This approach provides tailored pedagogical insights to bridge theoretical biomechanics with diagnostic instructional strategies for physical education educators and student-athletes (Ismael, 2024).

METHODS

This study employed a quantitative descriptive design. According to Sahputra et al. (2021), a descriptive approach is used to describe and explain phenomena based on field data without manipulating the variables under investigation. This design provides a systematic, objective, and factual overview of biomechanical variables expressed numerically. The study focused on analyzing ball contact angle and jump height during smash execution using Kinovea video analysis software.

Participants were three active male students from the Sports Education Study Program at UMKT. In sports biomechanics and kinematics analysis, small-N designs (1–3 participants) utilizing objective digital measuring instruments prioritize internal validity, movement control, and visual accuracy per individual over large sample sizes (Widiantari et al., 2025). Inclusion criteria specified active enrollment, prior coursework/training in volleyball, technical capability to perform smashes, absence of musculoskeletal injuries, and voluntary consent. Participants represented three training duration levels: less than 1 year, approximately 2 years, and 3 years of active volleyball playing.

To avoid fatigue effects that could alter biomechanical execution and kinematic consistency,

each participant performed 3 to 5 trials of volleyball smashes with a standardized 2-minute rest interval between trials. The trial with the optimal execution and clearer video frame alignment per participant was selected for kinematic processing.

Video recording protocols were standardized to minimize perspective distortion and parallax errors. A digital camera recording at 1080p resolution (60 FPS) with an optimized fast shutter speed setting (1/1000s) was used under bright ambient lighting to prevent motion blur during high-velocity upper-limb movements at ball impact. The camera was mounted on a rigid tripod positioned at a fixed distance of 6 meters perpendicular (sagittal plane view at a 90° angle relative to the approach and jumping line) from the participant and net zone. The tripod height was locked at 1.35 meters from the ground surface.

Kinovea software (version 24.1.1) was utilized to measure kinematic indicators. Kinovea provides high validity and reliability in measuring joint angles and distances in sports performance (Puig-Diví et al., 2019; Pueo et al., 2020). Measured indicators included: (1) Ball contact angle (°): Arm extension angle formed at impact; (2) Jump height parameters (cm): Height before jump, height after jump at contact point, and net jump height (peak height minus initial standing height). Videos were analyzed in Kinovea 24.1.1 calibrated against a standard 243 cm men's net height reference. Descriptive statistics (mean, standard deviation, minimum, maximum) and correlation patterns were processed using Microsoft Excel (Fadilah & Raharja, 2025).

RESULTS AND DISCUSSION

Results

Data collection categorized the three active students based on training duration: less than 1 year (Figure 1), approximately 2 years (Figure 2), and 3 years (Figure 3).

Student Active for Less Than 1 Year

The first subject was a beginner student with less than one year of experience and no athletic background. Analysis revealed height after jump at contact point reached 201.65 cm, while height before jump was 129.26 cm. Measured against the 243 cm men's net height reference, net jump height was 72.39 cm, and ball contact angle reached 171.6°.



Figure 1. Kinematic analysis of smash execution for student active less than one year

Student Active for Approximately 2 Years

The second subject had played volleyball for approximately two years, demonstrating better movement coordination than beginners. Analysis showed height after jump at contact reached 222.70 cm, while height before jump was 151.35 cm. With a 243 cm net reference, net jump height was 71.35 cm and ball contact angle measured 150.0°.



Figure 2. Kinematic analysis of smash execution for student active approximately two years

Student Active for 3 Years (Athlete)

The third subject had three years of active volleyball training. Demonstrating superior technical stability and coordination, this subject achieved a height after jump at contact of 238.02 cm and height before jump of 164.59 cm. With a 243 cm net reference, net jump height was 73.43 cm and ball contact angle measured 171.1°.



Figure 3. Kinematic analysis of smash execution for student active three years

Despite having the lowest body height (170 cm), the 3-year experienced student achieved the highest reach point (238.02 cm) and highest net jump height (73.43 cm). All parameter comparisons across subjects relative to the 243 cm net height are summarized in Table 1.

Table 1. Biomechanical Variables of Volleyball Smash Across Experience Levels

Biomechanical Variable	Figure 1 (<1 Year)	Figure 2 (2 Years)	Figure 3 (3 Years)	Mean
Body Height (cm)	175.00	174.00	170.00	173.00
Height Before Jump (cm)	129.26	151.35	164.59	148.40
Height After Jump (cm)	201.65	222.70	238.02	220.79
Net Jump Height (cm)	72.39	71.35	73.43	72.39
Ball Contact Angle (°)	171.60	150.00	171.10	164.23

Table 1 presents the descriptive statistics of the research variables. The overall group mean for body height was 173 cm, height before jump was 148.40 cm, height after jump at contact point was 220.79 cm, net jump height was 72.39 cm, and ball contact angle was 164.23°. Net jump height was relatively equal across all subjects (71.35 cm to 73.43 cm), showing similar leg explosive power capabilities. However, maximum reach height increased directly with experience. Continuous training experience enhances biomechanical execution, jump reach, and hitting angle effectiveness (Proja et al., 2023).

Discussion

Biomechanical analysis of smash performance among UMKT Sports Education students demonstrates the clear influence of training duration on movement quality. The smash requires sequential kinetic energy transfer from lower extremities through the trunk to the arm (Oliveira et al.,

2020; Zahálka et al., 2017). While vertical jump height was similar across participants, reach height at ball contact varied. Success depends not only on jump capability but also on anthropometric characteristics, timing, and approach run kinematics (Kumar & Kumar, 2020; Nishimura et al., 2023). Longer training duration refines neuromuscular coordination, stabilizing landing and takeoff mechanics while optimizing leg muscular power (Garcia et al., 2022; Chandra & Mariati, 2020; Ramadani et al., 2026). Explosive leg power directly relates to vertical jump performance in jumping sports (Heriansyah et al., 2025).

In addition to jump reach, ball contact angle is vital. Proper contact angles produce steeper ball trajectories into the opponent's court (Anwar et al., 2020). Body position and arm swing angle directly govern ball trajectory and speed (Heriansyah et al., 2025). Biokinematic coordination and explosive body power strongly influence overall attack quality (Ismael, 2024). Long-term practice builds kinetic consistency and technical mastery (Situmorang & Raharja, 2025; Pradana & Darmanto, 2025). Therefore, volleyball coaching should balance physical conditioning with structured biomechanical technique development (Oliveira et al., 2020; Fuchs et al., 2019).

CONCLUSION

In conclusion, volleyball smash effectiveness among UMKT Sports Education students depends on a combination of jump height, ball contact angle, and motor coordination. Experience enhances kinetic chain efficiency, enabling players to reach higher contact points (up to 238.02 cm) and achieve effective hitting trajectories. Training programs should combine physical conditioning with targeted biomechanical refinement of step approach, timing, and arm contact angles.

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