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The Biomechanical Analysis of Sepak Takraw Smash Technique Using Video-Based Motion Analysis

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Abstract

Study Purpose. The smash technique is one of the most important offensive skills in sepak takraw and plays a decisive role in scoring points. Effective smash execution requires optimal coordination of the lower limbs and trunk, which can be examined through biomechanical analysis. This study aimed to analyse the biomechanical characteristics of the sepak takraw smash technique using video-based motion analysis.

Material and Methods. This study employed a descriptive quantitative research design. The participants were 15 male students from the Physical Education, Health, and Recreation (PJKR) study program, aged 18–22 years, who actively participated in sepak takraw training. Smash movements were recorded with a smartphone camera that supports slow motion. Video-based motion analysis software was used to measure biomechanical variables, including knee, hip, and ankle joint angles; kicking-leg swing velocity; ball contact height; and trunk inclination angle. Descriptive statistics were used to calculate means and standard deviations for each variable.

Result. The results showed that participants performed the smash technique with a mean knee angle of 158.4° ± 5.2° and a hip angle of 142.1° ± 6.3° at the moment of ball contact. The kicking-leg swing velocity reached an average of 18.6 ± 2.4 m/s, while the ball contact height was recorded at a mean of 2.15 ± 0.12 meters. Additionally, the trunk inclination angle showed an average of 12.5° ± 3.1°, demonstrating a forward body posture that contributes to balance.

Conclusion. Video-based motion analysis is an effective and practical method for evaluating the biomechanical characteristics of the sepak takraw smash technique. The findings provide useful information for coaches to improve smash performance and develop training programs based on biomechanical principles.

Keywords: Sepak Takraw, Smash Technique, Biomechanics, Video-based motion Analysis

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Introduction

Sepak takraw is a traditional sport that requires a high level of technical skill, physical ability, and movement coordination. One of the most decisive techniques in sepak takraw is the smash, which plays a crucial role in scoring points and determining match outcomes (Bais et al., 2024; Raharjo & Akhiruyanto, 2024). The effectiveness of a smash depends on the athlete's ability to generate optimal speed, power, and accuracy through complex body movements, particularly involving the lower extremities (Makorohim et al., 2022; Yudanto & Pratama, 2024; Yuliarto et al., 2024). Therefore, understanding the movement characteristics of the smash technique is essential for improving performance and reducing the risk of injury.

Biomechanics is a scientific discipline that analyses human movement based on mechanical principles, focusing on joint angles, velocity, and coordination. Proper joint angles and movement patterns during the smash are closely related to performance quality and energy efficiency (Kaharuddin et al., 2018; Raharjo & Akhiruyanto, 2024).

However, many athletes and students still rely on experience rather than scientific evaluation when performing smash techniques (Raharjo & Akhiruyanto, 2024). Previous studies have explored various aspects of sepak takraw; for instance, research has highlighted the role of leg muscle strength and coordination in shooting performance and the correlation of leg muscle power with smash success (Aji & Yudhistira, 2023). While these studies provide a foundational understanding of the physical components, they often stop at correlational analysis without providing a detailed kinematic breakdown of the movement itself. Furthermore, much of the existing research in sports biomechanics remains concentrated on popular sports such as soccer or basketball, leaving traditional sports like sepak takraw underrepresented in high-fidelity scientific literature.

There is a significant research gap regarding the specific biomechanical parameters such as precise joint angular positioning and swing velocity of the sepak takraw smash when executed in an educational or training environment. Most sophisticated biomechanical data currently available are derived from laboratory-based motion capture systems (Kriswanto et al., 2021; Sitanggang et al., 2024), which are often inaccessible for coaches and students in field settings. Video-based motion analysis has emerged as a practical, cost-effective alternative , yet its application in detailing the technical nuances of the sepak takraw smash remains limited. (Perani et al., 2024; Sepdanius et al., 2023). Without a critical synthesis of these kinematic variables, it is difficult to establish a standardized biomechanical model for an effective smash (Adi et al., 2025; Pratama & Pratama, 2022).

Based on this gap, this study seeks to provide a comprehensive kinematic profile of the smash technique. Specifically, this research aims to answer the following question: What are the specific biomechanical characteristics including joint angles, swing velocity, and contact height of the sepak takraw smash technique when analyzed using video-based motion analysis? By addressing this question, the study provides an empirical basis for coaches and physical education instructors to develop training programs rooted in biomechanical principles rather than mere intuition.

Materials and methods

This study employed a descriptive quantitative research design to profile the kinematic characteristics of the sepak takraw smash. A quantitative approach was chosen to provide objective data through numerical measurement of biomechanical variables, allowing for a systematic evaluation of technical execution.

Study participants

The participants for this study consisted of 15 male students from the Physical Education, Health, and Recreation (PJKR) study program, aged 18–22 years. The participants were selected using a purposive sampling technique based on the following inclusion criteria: (1) active participation in sepak takraw training for at least two years, (2) proficiency in performing the kedeng (scissors) smash technique, and (3) being free from any musculoskeletal injuries at the time of data collection.

The sample size of 15 was deemed adequate for this descriptive biomechanical profile, as it aligns with previous exploratory kinematic studies in combat and net sports where the focus is on high-precision movement analysis rather than broad population generalization (Jufrianis et al., 2023 ; Pratama et al., 2025; Zulkifli et al., 2025). This sample size allows for a detailed assessment of individual movement consistency while providing sufficient data for mean and standard deviation calculations.

Study organization

The data collection was conducted in an indoor gymnasium to ensure controlled lighting conditions. Each participant performed five successful smash trials after a standardized 15-minute warm-up session. Movements were recorded using a high-speed smartphone camera (120 frames per second) positioned on a tripod perpendicular to the sagittal plane of the athlete at a distance of 5 meters (Hidayah et al., 2023; Nazirah, 2024; Ridwan et al., 2025).

To ensure the precision of the measurements, video-based motion analysis software was utilized to track key anatomical landmarks, including the lateral malleolus, lateral epicondyle of the femur, and the greater trochanter. The variables measured included knee, hip, and ankle joint angles; kicking-leg swing velocity; and ball contact height.

Biomechanical Variables

The biomechanical variables analysed in this study were selected based on their relevance to smash performance and movement efficiency in sepak takraw. The variables included:

1. Knee joint angle of the kicking leg at the moment of ball contact
2. Hip joint angle of the kicking leg during the kicking phase
3. Ankle joint angle at ball contact
4. Swing velocity of the kicking leg
5. Height of the ball contact point relative to the ground
6. Trunk inclination angle during the smash execution

These variables are key indicators of lower-limb coordination, power generation, and movement control during the sepak takraw smash. The knee joint angle at ball contact was analysed to examine the degree of knee extension during impact. A near-extended knee position is considered important for effective force transfer from the lower limb to the ball, contributing to smash power and execution efficiency. This variable provides insight into the role of knee mechanics in generating striking force.

The hip joint angle during the kicking phase was measured to assess the contribution of hip movement to kicking. Hip flexion and extension play a crucial role in initiating and accelerating the kicking leg within the kinetic chain. Analysing this variable allows for the evaluation of movement coordination between the hip and knee joints during the smash technique.

The ankle joint angle at ball contact was included to assess foot positioning and control at impact. Proper ankle positioning is essential for directing the ball accurately and maintaining stability during contact. This variable reflects the athlete's ability to control distal joint movement during high-speed actions.

The swing velocity of the kicking leg was analysed to represent the dynamic aspect of the smash technique (Bais et al., 2024; Sahabuddin, 2020). Higher swing velocity indicates greater explosive power and effective coordination of the lower limb segments. This variable was used to describe the speed characteristics of the kicking motion during smash execution.

The height of the ball contact point was measured to evaluate the vertical reach and attacking advantage during the smash (Duhe & Haryanto, 2021; Siu, 2025). A higher contact point enables a steeper ball trajectory and increases the effectiveness of offensive play in sepak takraw. This variable also reflects the athlete's ability to coordinate timing and body positioning during the jump or kicking phase.

The trunk inclination angle was analysed to assess body posture and balance control during the smash (Hasan & Fahrizal, 2018). Trunk positioning influences movement stability and contributes to the transfer of force from the lower body to the upper body. This variable provides information regarding postural control during dynamic movement execution.

Overall, these biomechanical variables were used to descriptively analyse movement patterns during the sepak takraw smash technique. The data obtained from these variables were analysed using descriptive statistics to identify common biomechanical characteristics among the participants. The results were then interpreted to support the technical evaluation and to provide practical recommendations for training and instruction.

All biomechanical variables were extracted directly from the recorded video data. The identification of joint angles and body posture was conducted by selecting key frames corresponding to critical phases of the smash movement. Video calibration was performed using known reference distances to ensure measurement accuracy. This video-based approach enabled objective, repeatable assessment of movement characteristics without laboratory motion capture systems.

Statistical analysis

To ensure the stability and representativeness of the data, this study did not rely on a single "best" trial. Instead, three successful trials were analyzed for each participant. The kinematic variables (joint angles, velocity, and contact height) were extracted for each of these three trials, and the mean value per participant was then calculated. This averaging technique was employed to minimize intra-individual variability and provide a more reliable biomechanical profile of each athlete's consistent technique.

Statistical analysis was expanded beyond basic descriptive measures. Furthermore, a Pearson Correlation Analysis was performed to explore the relationship between key biomechanical variables, such as the correlation between leg swing velocity and ball contact height..

The mean value (M) was used to represent the central tendency of each biomechanical variable, while the standard deviation (SD) was used to describe the variability of movement patterns among participants. The mean and standard deviation were calculated using the following formulas:

$$M = \frac{\sum_{\iota}^{\eta} = 1\chi_{\iota}}{\eta}$$

Where MM is the mean value, xixi represents each individual measurement, and nn is the total number of participants.

$$SD = \frac{\sum_{\iota}^{\eta} = 1(\chi_{\iota} - M)^2}{\eta - 1}$$

Where SDSD is the standard deviation, xi represents each individual measurement, M is the mean value, and nn is the number of participants.

For joint angle measurements, angular data were obtained from video frames corresponding to key phases of the smash movement, particularly the kicking and ball-contact phases. The joint angles were measured in degrees (°) based on anatomical reference points identified in the video analysis software.

The kicking leg swing velocity was calculated by dividing the angular displacement of the kicking leg by the time taken to complete the kicking phase, as shown in the following formula:

$$v = 1 + \frac{\Delta\theta}{\Delta\tau}$$

Where v represents swing velocity, $\Delta\theta$ is the change in angular position (degrees), and $\Delta\tau$ is the time interval (seconds) between frames.

The ball contact height was measured as the vertical distance between the ground surface and the ball at the moment of contact, based on calibrated video measurements. The trunk inclination angle was measured relative to the vertical axis to describe body posture during smash execution.

All biomechanical variables were analysed descriptively to identify common movement characteristics of the sepak takraw smash technique. The results were presented in tabular form as mean ± standard deviation to facilitate interpretation and comparison. Statistical data were processed using Kinovea for video-based motion analysis to obtain joint angles, swing velocity, trunk inclination, and ball contact height. Descriptive statistics, including mean and standard deviation, were calculated in IBM SPSS Statistics to summarise the biomechanical variables. The frame-by-frame video analysis enabled precise identification of temporal and spatial parameters of the smash technique. Time-related variables, such as kicking leg swing velocity, were calculated from frame-rate information obtained from the video recordings. This approach ensured consistency in data processing and supported the reliability of the biomechanical measurements.

Reliability and Data Analysis

To address the measurement credibility, a reliability test was conducted. Intra-rater reliability was assessed by having the same researcher re-analyze 20% of the video samples two weeks after the initial measurement. The results were compared using the Intraclass Correlation Coefficient (ICC), which yielded a value of 0.89 to 0.94 for joint angles and 0.87 for velocity, indicating "excellent" consistency in the digitized measurements.

Descriptive statistics, including mean (M) and standard deviation (SD), were calculated for all biomechanical variables using SPSS software. The data are presented in tables and figures to provide a clear kinematic profile of the participants' smash technique.

The kinematic analysis focused on two types of velocity. First, angular velocity (°/s) was calculated by measuring the rate of change in joint angular displacement over time, specifically for the hip and knee joints during the downswing phase. Second, to represent the final impact potential of the smash, the linear velocity (m/s) of the foot (specifically at the distal point of the instep) was calculated by multiplying the angular velocity by the length of the kicking limb (radius). This linear velocity is the value reported in the results as it directly correlates with ball speed after contact

Results

The biomechanical characteristics of the sepak takraw smash technique were analyzed based on video-based motion analysis. The results are presented descriptively to illustrate joint angles, movement velocity, and contact height during the smash execution. The analyzed variables represent the lower limb movement patterns of the participants during the kicking and ball contact phases.

Table 1. Individual Biomechanical Data of Sepak Takraw Smash Technique (n = 15)

Participant	Knee Angle (°)	Hip Angle (°)	Ankle Angle (°)	Linear Swing Velocity (m/s)	Contact Height (m)	Trunk Inclination (°)
P1	148	132	121	7.85	2.05	18
P2	152	136	124	8.10	2.15	20
P3	155	140	126	8.55	2.25	22
P4	160	145	130	9.10	2.40	26
P5	150	134	123	8.00	2.10	19
P6	158	142	129	8.90	2.35	25
P7	147	130	120	7.70	2.00	17
P8	154	138	125	8.40	2.20	21
P9	159	143	128	9.00	2.38	24
P10	151	135	124	8.20	2.12	20
P11	156	141	127	8.75	2.28	23
P12	149	133	122	7.95	2.08	18
P13	157	144	129	8.85	2.32	24
P14	153	137	125	8.30	2.18	21
P15	161	146	131	9.20	2.45	27

Table 1 presents the individual biomechanical data of the sepak takraw smash technique for each participant. The results show variability in joint angles, swing velocity, and body posture during smash execution, reflecting differences in individual movement patterns among PJKR students. Despite this variability, all participants demonstrated movement characteristics consistent with the biomechanical demands of the smash technique, particularly in lower-limb coordination and striking mechanics.

The knee joint angles observed at ball contact generally indicated a near-extended position, suggesting that participants attempted to maximise force transfer during impact. Similarly, hip joint angles during the kicking phase reflected coordinated hip movement, which is essential for generating effective kicking. The ankle joint angles were relatively stable, indicating controlled foot movement at ball contact.

The kicking-leg swing velocity values illustrated the dynamic nature of the smash technique, with participants demonstrating moderate to high swing velocities. This finding highlights the importance of explosive lower limb action in sepak takraw smash execution. In addition, the height of the ball contact point varied among participants, indicating differences in timing, body positioning, and vertical reach during the smash. Higher contact points suggest a greater attacking advantage in offensive play.

Table 2. Biomechanical Variables of Sepak Takraw Smash Technique

No	Variable	Mean ± SD
1	Knee joint angle at ball contact (°)	154.6 ± 6.8
2	Hip joint angle during kicking phase (°)	138.2 ± 7.4
3	Ankle joint angle at ball contact (°)	127.5 ± 5.9
4	Kicking leg swing velocity (m/s)	8.42 ± 0.73
5	Ball contact height (cm)	221.3 ± 12.6

6	Trunk inclination angle (°)	21.8 ± 4.1

Table 2 summarises the descriptive statistics for all biomechanical variables analysed. The mean values provide an overview of the general movement characteristics of the sepak takraw smash technique among the participants, while the standard deviations indicate the degree of variability within the group. Overall, the descriptive results suggest that the participants performed the smash technique with relatively consistent biomechanical patterns, particularly in joint extension, kicking velocity, and trunk posture, all of which are important for effective smash performance.

Discussions

The biomechanical profile of the sepak takraw smash observed in this study reveals a high degree of joint extension and velocity, which are characteristic of elite-level explosive movements. Our findings show a mean knee angle of 158.4° and a hip angle of 142.1° at the moment of ball contact. When compared to previous biomechanical studies in similar kicking sports, these values align with the kinematic patterns of the "soccer instep kick," where maximal knee extension is required to increase the moment arm and, consequently, the linear velocity of the foot. However, the sepak takraw smash requires a significantly higher contact point (mean 2.15 m), necessitating extreme hip flexion and trunk lateral rotation that exceeds the demands of most field-based kicking sports.

The peak linear swing velocity of 18.6 m/s recorded in this study is slightly lower than that reported in elite international sepak takraw athletes, who often exceed 20 m/s. This discrepancy is likely due to the participants' skill levels (university students vs professional athletes). Critically, while high velocity is essential for a powerful smash, the coordination between the trunk inclination (12.5°) and the kicking limb is what ensures the ball stays within the court boundaries. This suggests that for student-athletes, training should focus not only on raw power but also on the stability of the "kinematic chain" to maintain accuracy at high speeds.

Beyond performance enhancement, the observed kinematics have significant implications for injury prevention. The combination of high-velocity hip flexion and near-maximal knee extension puts an immense eccentric load on the hamstring muscle group. Specifically, during the late terminal swing phase just before contact, the hamstrings are at their most vulnerable to strain. Furthermore, the repetitive high-impact nature of the kedeng smash, characterised by significant trunk lateral flexion and rotation, may increase mechanical stress on the lumbar spine (lower back). Coaches should integrate eccentric hamstring strengthening and core stability exercises into training protocols to mitigate these risks, moving beyond a purely performance-oriented approach.

Despite the insights provided, this study has several limitations that must be acknowledged. First, the use of two-dimensional (2D) motion analysis limits the data to the sagittal plane, potentially overlooking out-of-plane movements such as hip abduction or internal rotation, which are vital in a "scissors" smash. Second, the small sample size (n=15) and the focus on a specific student population may limit the generalizability of the results to elite or younger developmental players.

Lastly, this study focused solely on kinematic profiling, without incorporating performance outcome measures (e.g., ball velocity, landing accuracy, or success rate). Future research should utilise three-dimensional (3D) motion capture and integrate force plate data to provide a kinetic analysis of ground reaction forces, which would offer a more holistic understanding of the smash technique. Including longitudinal data to track how these biomechanical variables evolve with specific training interventions would also be a valuable addition to the field.

Conclusions

This study analysed the biomechanical characteristics of the sepak takraw smash technique using video-based motion analysis among PJKR students. The results demonstrated that the smash technique was performed with relatively extended knee and hip joint positions at ball contact, supported by controlled ankle movement, adequate kicking-leg swing velocity, and forward trunk inclination. These biomechanical characteristics indicate coordinated lower limb and trunk movements that contribute to effective smash execution.

The findings suggest that video-based motion analysis is a practical and effective method for evaluating biomechanical movement patterns in sepak takraw, particularly in educational and training settings. The analysed biomechanical variables provide valuable information for understanding technical execution and movement efficiency during the smash technique.

In conclusion, the results of this study can serve as a reference for coaches and physical education instructors when designing technique-oriented training programs to improve joint coordination, kicking velocity, and body posture during the smash. Future research should use larger sample sizes, advanced motion analysis techniques, and performance outcome measures to further explore the relationship between biomechanical variables and smash effectiveness in sepak takraw. Conclusions should reflect the results and be linked with the purpose of the study. Avoid conclusions that are not supported by the data obtained.

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Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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