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Original Article

Badminton overhead backhand and forehand smashes: a biomechanical analysis approach

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Abstract
Smash hit is a powerful weapon to score points in a badminton game. The world record for smash speed is held by Fu Haifeng, a Chinese doubles player who achieved the shuttlecock speed of 332 km/h at the June 2005 Sudirman Cup championship. Meanwhile, the fastest backhand smash was conducted by Taufik Hidayat, an Indonesian player who won a gold medal at the 2004 Athens Olympics and achieved the shuttlecock speed of 206 km/h. The purpose of study was to analyze the movement of overhead backhand and forehand smash stroke techniques in a badminton game using a biomechanical approach. The results were analyzed using a descriptive and quantitative approach. Furthermore, 18 male Indonesia badminton national team elite players with an average age of 24.4 ± 1.89 years, height of 1.77 ± 0.19 m, and weight of 66.35 ± 3.7 kg were used. The study was conducted using 3 handycams, a calibration set, a dartfish pro motion analysis software, an automatic shuttlecock launcher shooting machine, and a speed radar gun. The data normalization from the kinematics values of the shoulder, elbow, and wrist joint motion was calculated using the inverse dynamics method. In addition, a one-way ANOVA test was used to identify the differences in the kinematics of motion between two different groups (overhead forehand and backhand smashes). The obtained results showed that the shuttlecock speed during the forehand smash was greater than that during the backhand smash. During the maximal shoulder external rotation phase, two variables were found to have the best results during the forehand smash, i.e., the velocity of shoulder external rotation and wrist palmar flexion. During the maximum angular velocity phase, the velocity of shoulder internal rotation, elbow extension, and forearm supination was higher when making a forehand smash stroke. The main contribution to upper limb motion during overhead backhand and forehand smashes was the internal rotation velocity of the shoulder joint, elbow angular extension, and wrist falmar flexion.
Key Words*:* Badminton, overhead smash, kinematics analysis, three dimensions

Introduction

Badminton is a racket sport that is played by two or four players on a rectangular court with a high net across the middle. The game is characterized by multiple intense actions and specific movement patterns, which consist of fast accelerations, decelerations, and many explosive shifts with changes in direction over short distances. The international standard duration of single matches ranges from 25 to 110 min, and the time required to score each point ranges from few seconds to several minutes. Many rallies are decided in less than 10 s, and the intense actions during the match require rapid high intensity movements that are repetitively performed within a short time period (Rusdiana et al., 2020). According to Kuntze et al., (2010), stroke techniques are categorized into three types based on the racket position. Stroke techniques include underarm, sidearm, and overhead strokes. The most frequently used attack technique is the overhead smash stroke technique (Chow et al., 2014). Similarly, there are two types of smash technique skills, i.e., forehand and backhand smash. These are powerful attack techniques that are used to dominate the opponents and score as many points as possible; these techniques account for 39.8% of all scored points (Barreira et al., 2016). Furthermore, a smash is a fast stroke that relies on the strength, velocity, and flexion of the wrist with the shuttlecock swooping down towards the opponent's field area (Lam et al., 2020).

The average number of smashes executed in one match in the men's single category was 69 strokes, while in the women's singles category, 51 strokes were performed in All England Championship 2015 (McErlain-Naylor et al., 2020). The world record for smash speed is held by Fu Haifeng. This medalist paired with Cai Yun

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who achieved the shuttlecock speed of 332 km/h at the June 2005 Sudirman Cup championship (Martin et al., 2020a). Fu Haifeng and Cai Yun are Chinese professional men's doubles badminton players. They were men's doubles world champion in 2006, 2009, 2010 and 2011 (Li et al., 2016). The shuttlecock speed exceeds that of other racket sports and reaches 493 km/h. This speed was achieved by a Chinese player Tan Boon Heong while testing a new racket product (Yonex ArcSaber Z-Slash) in 2017 (Rusdiana et al., 2020). Meanwhile, the fastest backhand smash was conducted by Taufik Hidayat, an Indonesian player who won a gold medal at the 2004 Athens Olympics and who achieved the shuttlecock speed of 206 km/h (McErlain-Naylor et al., 2020).

Backhand smash is an overhead stroke that uses the rear racket head. When executing the backhand smash, back of the body needs to be positioned towards the net by prioritizing the wrist joint flexion motion, which is directed to swoop backward (Sakurai & Ohtsuki, 2010). This is necessary because the transfer of body weight to the pedestal is the same as the position of the hand while holding the racket. The upper extremity rapidly rotates when the shuttlecock moves to the front of the player. This is followed by rotation of the hip, shoulder, and elbow joints (Li et al., 2016). Similar to the forehand smash, the shuttlecock needs to be hit at the highest possible position. Furthermore, a flexible and strong wrist flexion motion is essential for producing a hard and targeted stroke (Miller et al., 2013). The application of motion mechanics principles is essential for producing a smash that provides maximum strength, speed, and accuracy to dominate the opponent's movements and score points (Ooi et al., 2009). Owing studies on backhand smashes, to obtain broader insights, various studies tried to focus on almost the same motion patterns that are used in tennis (e.g., serve mash, backhand, and forehand drive techniques). According to Abian-Vicen et al., (2013), a one-handed backhand drive is supported not only by the velocity of the trunk rotation. It is also determined by the amount of momentum and force movement generated from the shoulder and wrist joints. This drive involves the motion of body segments such as the legs, hips, trunk, upper arms, forearms, and hands (Alexandros et al., 2013). The velocity of maximal shoulder external rotation and the backswing of the upper arm are the main factors in generating a greater force when making a backhand drive (Kolman et al., 2019). Genevois et al., (2014) have reported that in the advanced player group, the maximum speed of the racket is obtained from the strength of the upper arm force. Meanwhile, in the novice group, the maximum speed is obtained from the motion of the wrist and elbow. During the one-handed backhand drive, the velocity of hip rotation significantly contributes to that of the other upper limb joints (Wu et al., 2001). Meanwhile, the forehand smash requires harmonious coordination of body motions from the strength generated by the trunk, shoulders, arms, and wrists (Mavvidis et al., 2005). To produce an effective smash, the biomechanics principles should be implemented in the phase of motion sequences. These include the preparation phase, backswing, forward swing, racket impact with the shuttlecock, and follow-through motion phase (Phomsoupha & Laffaye, 2014). Nesbit et al., (2006) have identified the importance of wrist flexion, forearm pronation, and upper arm rotation. In addition, the "kinetic chain movement" principle will produce an effective and efficient smash. The study of Taha et al., (2016) have reported that these joints and segments have an affect one another the movement. When one is in motion, it creates a chain of events that affects the movement of neighboring joints and segments. Furthermore, the optimal performance in conducting a forehand smash depends on the motion of the body segments that work in a harmonious motion chain sequence (Abian-Vicen et al., 2013). Based on the background explanation, this study aims to analyze the movement of overhead backhand and forehand smash techniques in badminton in three dimensions using the motion biomechanical approach.

Materials and Methods

Method and Design

The method used is a descriptive and quantitative approach. A descriptive method aims to systematically and accurately describe facts accurately about certain symptoms that are the center of attention.

Participants

The sample used included 18 male elite badminton players (with the average age of 24.4 ± 1.8 years, height of 1.77 ± 0.19 m, and weight of 66.3 ± 3.7 kg) who joined Indonesia National Team. Purposive sampling was used. All participants gave their written consent on the form that was previously given to them. All participants confirmed that they were not injured. Before the test, the participants received technical explanations related to the implementation procedures in a comprehensive manner.

Procedures

Before the test, the participants warmed up for approximately 15 min. This was followed by performing overhead backhand and forehand smashes using their racket to become more comfortable and faster adapt to the test. Subsequently, all participants were asked to execute 8 forehand and 8 backhand smash strokes to determine the mean velocity value in km/h.

The ball speed was measured using a radar speed gun with a shutter speed of 200 Hz. The radar speed gun was placed near the net at a distance of 45 cm outside the field line. In addition, video camera 1 was placed at the right side of the field at a distance of 2.5 m perpendicular to the position where the subject was standing. Video camera 2 was positioned behind the field line parallel to the subject area at a distance of 3 m from the player's position. Video camera 3 was placed above the subject in a perpendicular position parallel to the subject area. The three video cameras were set by the users according to the needs of the study characteristics. The following settings were used: frame rate of 250 Hz, shutter speed of 250 s, and exposure time of 1/1200 s. Meanwhile, calibration and data processing (analyzed in three dimensions) were conducted using the direct linear transformation structure method developed by Aziz Abdel (Hong et al., 2014).

Kinematics Parameters

To obtain the kinematic parameters of an overhead smash motion, a model is developed based on the anatomical principles of the body (Figure 1).

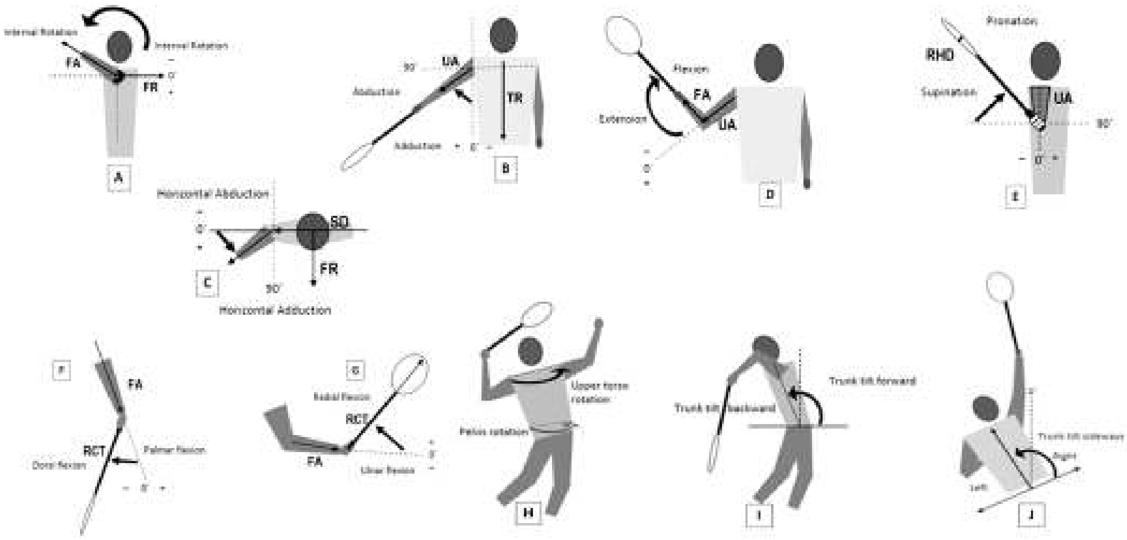

Fig. 1. Kinematic parameters of the upper limbs joint (source: Rusdiana, 2020))

Initially, the shoulder joint performs three movements, i.e., internal–external rotation (A), abduction–adduction (B), and horizontal abduction–adduction (C). Furthermore, the elbow joint performs two movements, i.e., flexion–extension (D) and forearm pronation–supination (E). The wrist joint performs two movements, i.e., palmar–dorsiflexion (F) and radial–ulnar flexion (G). The next movements are upper torso rotation and pelvis rotation (H), trunk tilt forward and trunk tilt backward (I), as well as trunk tilt left and right sideways (J).

Instruments

The instruments used were three video cameras (Panasonic Handycam HC-V100 Full HD, Japan), a three-dimensional calibration, a 3D motion analysis software (Frame DIAZ IV, Japan), one set of manual markers, a shuttlecock shooting machine (Plypower 143, Indonesia), and a radar speed gun (Bushnell Speed gun 101911, Italy).

Data Analysis

This study used the SPSS version 22.0 software (SPSS Inc., Chicago, IL). The average and standard deviation were calculated as initial data to further calculate normality, homogeneity, and hypothesis tests. To test the hypothesis, a one-way analysis of variance approach was used. This analysis helped to calculate the level of difference between backhand and forehand overhead smashes with the significant difference of 0.05. The three-dimensional coordinate data of the markers affixed to each part of the player's joints were adjusted using the Butterworth low-pass filter method approach. This adjustment was performed with a cut-off frequency of 15 Hz and determined by the residual analysis technique (Iino & Kojima, 2011).

Results

Table 1 shows the data for the difference in ball speed and changes in the kinematics of motion during backhand and forehand smashes.

Table 1. Kinematic parameters during maximal shoulder external rotation

Kinematic Parameter Analysis	Backhand	Forehand	p-Value
	Mean ± SD	Mean ± SD	
Shuttlecock velocity (km/h)	168 ± 6.9	274 ± 6.1	0.042*
Shoulder external rotation (º)	-128 ± 2.9	-176 ± 3.5	0.046*
Shoulder abduction (º)	116 ± 1.3	123 ± 1.7	1.865
Shoulder horizontal adduction (º)	12 ± 0.71	15 ± 0.68	1.443
Elbow flexion (º)	84 ± 1.5	101 ± 1.4	0.887
Radio-ulnar Pronation (º)	9 ± 0.7	13 ± 1.3	2.426
Wrist palmar flexion (º)	-21 ± 1.5	-49 ± 1.9	0.041*
Trunk tilt backward (º)	23 ± 2.1	27 ± 2.8	2.339
Trunk tilt sideways left (º)	18 ± 0.9	24 ± 1.2	1.371

**Significant differences at the 0.05 level*

Table 1 shows significant differences in three variables of the nine kinematic parameters analyzed in the maximal shoulder external rotation phase. These variables include shuttlecock velocity (p = 0.042), shoulder external rotation (p = 0.046), and wrist palmar flexion (p = 0.041). These results show that the three variables for the forehand smash have greater values than those for the backhand smash.

Table 2. Kinematic analysis parameters in the maximum angular velocity

Kinematic Parameter Analysis	Backhand	Forehand	p-Value
	Mean ± SD	Mean ± SD	
Shoulder internal rotation (°/s)	1722 ± 4.2	2459 ± 5.4	0.038*
Upper torso rotation (°/s)	926 ± 1.8	1021 ± 1.6	1.675
Pelvis rotation (°/s)	672 ± 1.8	729 ± 0.9	1.566
Elbow extension (°/s)	872 ± 2.3	1628 ± 3.1	0.022*
Forearm Supination (°/s)	819 ± 2.7	1048 ± 1.3	0.037*
Wrist dorsi flexion (°/s)	891 ± 3.6	984 ± 4.1	0.872
Trunk tilt forward (°/s)	389 ± 2.8	414 ± 3.1	0.919

***Significant differences at the 0.05 level**

Table 2 shows significant differences in three variables of the seven kinematic parameters analyzed in the maximum angular velocity phase during the forehand smash. These variables include the speed of the shoulder internal rotation (p = 0.038), elbow extension (p = 0.022), and forearm supination (p = 0.037). These results show that the three variables for the forehand smash have greater values than those for the backhand smash.

Discussion

The obtained results showed significant difference in the maximum speed of the shuttlecock produced during the forehand smash compared to that during the backhand smash. Previous studies showed a positive contribution between shuttlecock speed and wrist angular velocity when making backhand and forehand smashes. Meanwhile, the sequence pattern of upper limb joint rotation at the beginning of the backswing phase up to the moment of impact is similar between the two smash techniques. The shoulder joint rotation velocity was higher than that of the elbow joint. The wrist flexion angular velocity was smaller than the elbow angular velocity. This is consistent with (Creveaux et al., 2013), where the upper limb motion sequence starts from the rotation of the shoulder, elbow, and wrist joints during backhand drives in tennis. According to Rota et al., (2014), one major contribution of racket speed is obtained from the forearm supination rotation motion. Rogowski et al., (2014) stated that the combination of shoulder internal rotation and forearm supination provides approximately 53% support for the shuttlecock speed during an overhead forehand smash. This result is related to the backhand smash technique. This observation shows that forearm supination and upper arm lateral rotation provide the maximum bearing capacity to the speed of the racket swing before the impact occurs (Fu et al., 2017).

A series of motion patterns from overhead forehand and backhand smashes require linear and circular velocity as well as an acceleration of the body movement, shuttlecock, and racket swing. There are few studies on badminton that explain the movement of forehand and backhand overhead smash stroke techniques. However, the study by (Gordon, 2006) analyzed the contribution of upper limb joint rotation velocity during the tennis serve. The authors stated that the backward maximal shoulder external rotation produces initial momentum that is required to achieve a larger forward shoulder internal rotation force (Maeda et al., 2017).

Furthermore, the joint velocity during elbow extension is significantly higher, especially during the forehand smash. This is consistent with the study on tennis serve conducted by Reid et al., (2013). It has been reported that elbow joint provides positive support for racket speed. During the elbow extension motion, the faster it rotates, the higher is the produced force of the motion of the upper arm and racket. This occurs before the impact of the racket on the shuttlecock, as shown in Figure 4. Furthermore, the elbow extension motion contributes approximately 30% to the racket speed (Martin et al., 2020b). Another joint rotation that affects racket speed is the arm velocity during the radio–ulnar pronation motion (Gordon, 2006). This motion is mainly observed in the group of players with high technical skills. Meanwhile, in novice players, this motion is usually almost non-existent. Therefore, it is not surprising that professional players produce shuttlecock speeds that are much greater than those of amateurs.

Conclusion

The obtained results show that the shuttlecock speed during the forehand smash is greater than that during the backhand smash. During maximal shoulder external rotation, for the forehand smash, there are significant differences in three variables including shuttlecock velocity, shoulder external rotation, and wrist palmar flexion. Furthermore, shoulder internal rotation, elbow extension, and forearm supination at maximum angular velocity were higher when performing the forehand smash. Shoulder internal rotation and elbow joint velocity as well as forearm supination significantly contribute to the shuttlecock speed when performing the two-stroke technique.

The main contribution of upper limb motion during overhead backhand and forehand smashes was the internal rotation velocity of the shoulder joint, elbow angular extension, and wrist palmar flexion.

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Conflict of Interest

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

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