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ORIGINAL ARTICLE

Effect of Fatigue on Biomechanical Variable Changes in Overhead Badminton Jump Smash

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ABSTRACT

Background. The badminton forehand overhead jump smash is one of the high speed and powerful motions among various racket sports. **Objectives.** The purpose of this study is to analyze the effect of fatigue on the kinematic variable movement changes during overhead jump smash in badminton. **Methods.** This study is descriptive quantitative research with the pre-test and post-test design methods used to obtain data from 15 male badminton players, aged 19.4±1.6 years, height 1.73 ± 0.12 m, and weight 60.8 ± 3.7 kg. The study used three high-resolution handy-cams, motion software Frame DIAZ IV, and 14 point manual markers to analyze body segments' movement when carrying out a jump smash. Furthermore, an ergo treadmill was used to test the players' level by running. **Results.** The results showed that the shuttlecock velocity was faster during pre-fatigue (188 km/h) than under the condition (145 km/h). A significant difference showed in the angle of shoulder internal rotation (p=0.048) and wrist palmar flexion (p=0.037) at the instant of maximal shoulder external rotation phase. Furthermore, there were significant differences in the shoulder's internal angular velocity (p=0.042), elbow extension (p=0.035), forearm supination (p=0.024), and wrist Dorsi dorsiflexion.040). **Conclusion.** In conclusion, fatigue reduces players' performances during jumping smash in badminton, thereby leading to slower shuttlecock speed and changes in body segment movements.

KEYWORDS: ***Sport Biomechanics, Badminton, Jumping Smash, Fatigue, Kinematic.***

INTRODUCTION

Badminton is a racket sport 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 consists of fast accelerations, decelerations, and many explosive shifts with changes of direction over short distances (1). The international standard duration of single matches ranges from 25 to 110 minutes, with each point's length varying from a few seconds to several minutes (2). Many rallies are decided in less than 10 seconds, and the intense actions during match play need rapid movements of high intensity related to repetitive motions within a short duration (3). Elite players need to perform at their maximum speed, agility, flexibility, endurance, and strength limits. The sports is a combination of high-intensity short rallies (anaerobic system) as well as longer, and moderate (aerobic system) sustaining efforts used to promote recoveries (4). During a match, players are required to maintain a high level of intensity for as long as possible.

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Energy expenditure depends on players' morphological factors and displacement efficiency. Agus reported that 60 - 70 % of the energy yield during games is derived from the aerobic system. In comparison, 30 % is obtained from the anaerobic, with a great demand on the galactic and, to a lesser degree, the lactic (5). Players tend to adapt their movements using biomechanical factors of efficiency, enabling them to respond to the full set of visual information. This game requires quick changes of direction, jumps, lunges at the net, and rapid arm movements from various postural positions (6).

The badminton forehand overhead techniques are divided into three strokes: drop, clear, and smash. The stroke comprises clear, shoot, break, block, lift, push, and net (7). Also, the overhead smash movement is categorized into two groups, including the standing and jumping smashes (8). Among the many badminton strokes, a powerful smash is an especially necessary means of gaining points to win the game. The dominant skill in double matches is the forehand overhead jumping smash, which accounts for 1/5 the attacks during a match (9). Jumping the smash technique produces a shuttlecock velocity that can disable the opponent's movement and contribute to the higher score attainment of 39.8% or more (10). Also, the speed of a shuttlecock due to the smash technique tends to exceed those of other racket sports, such as tennis, squash, and soft tennis. A Chinese athlete, Tan Boon Heong, proved that the shuttlecock's velocity is up to 493 km/hour, during the trial of a new racket product (Yonex ArcSaber Z-Slash) in 2013 (11). Moreover, the velocity produced by the player of China men's doubles in Sudirman Cup 2005, Fu Haifeng, reached 332 km/hour (11). Meanwhile, the velocity produced from a jumping smash movement of an Indonesian named Taufik Hidayat, during the men's single in the 2006 World tournament, was approximately 305 km/hour (12).

The player performing a jumping smash needs maximum power of the leg, arm, abdominal, and hand muscles supported by physical components for complex movements (13). Jumping smash is a series of continuous movement coordination of the body as a whole. Meanwhile, the coordination is effected by the skeletal muscle, which provides stimulation to the somatic motor neurons, thereby inducing movements in all body segments (14), which also leads to a change of position, also known as motor segment (15). A durable and long muscle contraction in a continuous smash movement during a tournament tends to decrease the energy resources in the body, thereby, leading to fatigue (16). Conversely, this decrease affects the muscle's contraction strength and speed, thus delaying the stimulation order (17). Therefore, a slower and less controlled movement is an indication that the player is in a fatigue condition (18).

Fatigue is defined as the inability of a person to produce adequate power needed to carry out a specific activity (14). It leads to the reduction of power generation, neuromuscular coordination, the precision of motion control, proprioception, joint stability, contraction, and the increase in reaction time, with a significant reduction in muscle function (19). In summary, the occurrence of fatigue in central muscles adversely affects the neuromuscular coordination, precision motion control, as well as the stability of the proximal joint. This effect is transferred to distal joints, which leads to the dysfunction of the kinetic chain, thereby producing a destructive impact on the core and lower limb muscles (2). Several factors affect a person's ability to maintain or restore postural control, such as damage to the nervous system, inefficient optic nerves, stress, vestibular mechanism, and fatigue (8).

Muscle fatigue is generally defined as the reduced ability of a person to generate adequate power due to the chain of events cut off from the central nervous system to the muscle fibers (20). This overall feeling of tiredness is classified into peripheral and central fatigue. Peripheral fatigue occurs in the muscles and involves a particular group of movements, which leads to dysfunction in the neuromuscular region, excitation-contraction mechanism, stimulated emission by the transverse tubules, the release of calcium, and contraction stimulating components that generate power (21). However, the central fatigue related to the upper part of the brain invokes the alpha motor neurons and affects the whole body (2). Therefore, in peripheral fatigue, movement command does not change or increase, while in the central, it decreases, thereby leading to the reduction of muscle tension (4). Fatigue is one of the disruptive factors of neuromuscular control. For instance, those that occur in the lower limb muscles and joints, such as the ankle, tend to change muscle stability and reduce its ability to produce responses for balance and stability. This condition leads to instability and the loss of balance while landing. Jumping smash needs the perfect combination of three factors, namely timing, power, and control (22). Furthermore, a player puts a greater force on the take-off foot to propel upward with a velocity vertical to the center of mass (9). The repeated jumps and deviations in jumping and landing techniques during the games are becoming the primary causes of muscle fatigue (23).

The study related to biomechanics, especially on the overhead smash technique, is still limited. However, several studies have been carried out on other types of sports with high similarity in the series of movement mechanism of overhead smash technique such as in-service, throwing, bowling, and pitching in tennis, handball, cricket, and baseball, respectively (24). S. Sakurai et al. (2000) studied smash and jump performances of elite and collegiate players and noted that elite players generally achieved a higher angular velocity of elbow movement taken to mean radio-ulnar pronation. While the movement times from the preparation phase to the point of contact were less than those of collegiate players (25). An estimation of the joint contributions made to the shuttle's velocity in the badminton smash attributed 53% of the final output to shoulder rotation and radio-ulnar pronation. The standing and jump smash, tend to produce superior racquet-head angular and shuttlecock velocities (26).

Studies carried out in tennis serve (27), overarm throw in baseball (28), overhead throw in handball (29). Forehand squash (30) shows that the expansion of movement space in the upper extremity provided a significant contribution to the velocity and acceleration of body segment movements that affect the maximum ball velocity (5). The studies showed that the action of palmar flexion at wrist joint or snap contributed to the impact of a shuttlecock by 20%. Also, the movement of forearm pronation supination significantly influences the velocity of shuttlecock by 10% (31). The dominant role of shoulder joint actions, especially during the maximal external rotation followed by internal shoulder rotation, are the significant factors affecting a ball velocity in tennis serve movement with an exceeding contribution of 40% (32).

This study aims at analyzing the effect of fatigue on the kinematic variable movement changes during overhead jump smash in badminton games.

MATERIALS AND METHODS

Participants. Data were obtained from 15 male badminton players purposively selected with overhead jumping smash technique aged 19.4 ± 1.6 years, height 1.73 ± 0.12 m, and weight 60.8 ± 3.7 kg. This study is descriptive quantitative research with the pre-test and post-test design methods used to obtain data from participants with over eight years' experience. The subjects were fully informed on the protocol before participating in this study, which was conducted following the recommendations of the ethics research committee of the Faculty of Sport and Health Education, Universitas Pendidikan Indonesia.

Instruments. This study used two high-resolution handy-cams (Sony HXR-MC2500, Japan), a unit of the high-speed camera (Fastec Imaging TS5-H, USA), 14 point manual markers, a set of 3 dimension calibration, a motion analysis software (Frame DIAZ IV, Japan), Cosmed direct gas analyzer Fitmate MED (COSMED Srl-Italy), a heart rate sensor (Polar H10, Finland), fly power shuttlecock shooting machine (BGH 800, Indonesia) and a speed radar gun (Bushnell 101922, Germany).

Procedures. Camera 1 was perpendicularly placed on the top subject area at a distance of 5m to record the shoulder and hip joints movement during jump smash. Camera 2 was placed on the right side of the subject area. At the same time, the third was perpendicularly stationed behind to obtain a comprehensive depiction of the whole upper body joint movements. A shuttlecock shooting machine launcher was perpendicularly placed in the opposite area of the subject to gain a more stable accuracy and speed of the shuttlecock, as shown in Figure 1.

The participants were instructed to warm up for 15 min. After a 3 min resting period, they were asked to perform jump smashes by hitting the shuttlecock as fast as possible towards the opponent's court area. Shuttlecock velocities were measured using a radar gun Bushnell 101922, manufactured in Germany. The mean value of the six hits was also calculated, and shuttlecock velocity was measured in km/h.

Furthermore, all subjects were fitted with a heart rate monitoring system Polar H10 Polar Electro Oy, Finland), and asked to perform a fatigue test on a treadmill. The warm-up session had a starting speed of 8 km·h−1, which continued to 10 km·h−1, and increased by two km·h−1 every 3 min (14, 20). The test ended when the subjects were exhausted. Subsequently, all questions were asked to continuously and rapidly hit the shuttlecock 6 times to determine the mean velocity value in km/h.

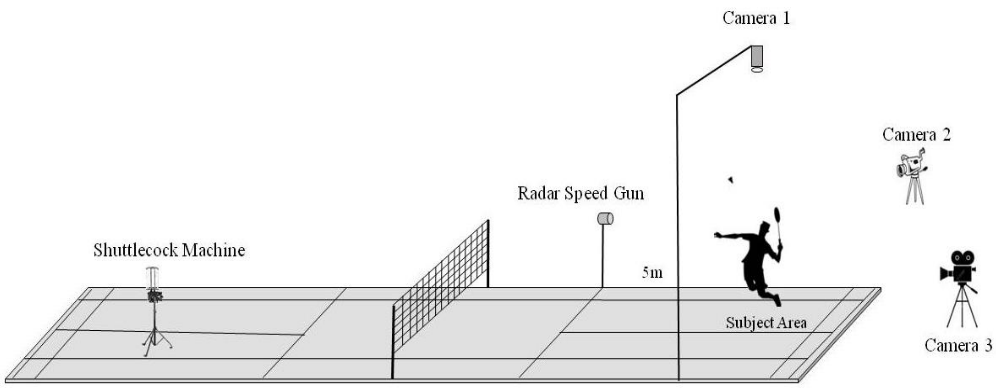

Figure 1. The Scheme of the Data Collection Process

Statistical Analysis. Data were analyzed using the SPSS program version 21.0 for Windows with descriptive statistics performed to determine the mean ± SD. A paired sample t-test was applied to identify differences between pre-fatigue and fatigue conditions in terms of maximal shuttlecock velocity during jump smash at a 95% degree of confidence. The position-time data were filtered with a fourth-order Butterworth low-pass filter at a cutoff frequency of 13.5 Hz.

Kinematic Parameter. This parameter is used to determine the characteristics of a jumping smash mechanism, models relevant to the principles of movement anatomy, as shown in Figure 2. It consists of shoulder joints, which are categorized into three characteristics, namely internal-external shoulder rotation (A), shoulder abduction-adduction (B), and shoulder horizontal abduction-adduction (C). The elbow joints consist of two movement characteristics, including elbow flexion-extension (D) and forearm pronation-supination (E). The wrist joints consist of two movement characteristics, namely palmar-dorsiflexion (F) and radial-ulnar flexion (G). This is followed by the upper torso and pelvis rotations (H), trunk tilts forward and backward (I), and nose tilts sideways to the left and right (J).

RESULTS

The followings are the explanations of the data analysis results related to the difference of shuttlecock velocity and the kinematic of motion changes under fatigue and non-fatigued conditions during overhead jumping smash in badminton.

Table 1 shows that three out of ten variables of a kinematic parameter in the instant maximal shoulder external rotation phase had significant differences under fatigue and non-fatigued conditions. The parameters include the shuttlecock velocity (p=0.035), angle of shoulder external rotation (p=0.048), and wrist palmar flexion (p=0.037).

Table 2 shows that four out of seven kinematic parameters in the maximum angular velocity phase gained significant differences under fatigue and non-fatigued conditions. The parameters include the shoulder internal rotation (p=0.042), elbow extension (p=0.035), forearm supination (p=0.024), and wrist dorsiflexion (p=0.040).

Figure 3 shows a significant difference in change associated with the angle of external shoulder rotation (-162° vs. -134°) and its internal angular velocity (1623°/s vs. 2111°/s) in fatigue and non-fatigued conditions. Hereafter there is a significant difference in the angle change of forearm pronation (14° vs. 1°) and the angular velocity of its supination (442°/s vs. 694°/s) under fatigue and non-fatigued conditions.

Table 3 shows that only the shoulder horizontal abduction variable had a significant difference in the shuttlecock release under fatigue and non-fatigued conditions.

DISCUSSION

Badminton is a sport that requires several overhead shoulder movement, following the abduction and external rotation of the proximal-to-distal sequence. Among the sport's numerous strokes, a powerful smash is essential to obtain adequate points to win a game. The crash tends to score directly or cause the opponent to be in passive defense. Therefore, the smash technique has better efficacy compared to others in the badminton attack that may lead to the following (1) directly scoring (2) favorable scoring opportunity, (3) inhibiting an opponent's attack, and (4) transforming a situation from defense to offense. However, numerous factors tend to affect quality. Some practical, relevant parameters include positioning, stance, racquet swing speed, striking height, racquet angle, string tension, and grip. This study provides several biomechanical principles to the badminton smash, with suggestions on ways to improve performance and shuttle velocity. These include increasing the range of motion of joint actions to allow more significant acceleration and use of muscular force, the utilization of proximal-to-distal sequencing, and the stretch-shortening cycle.

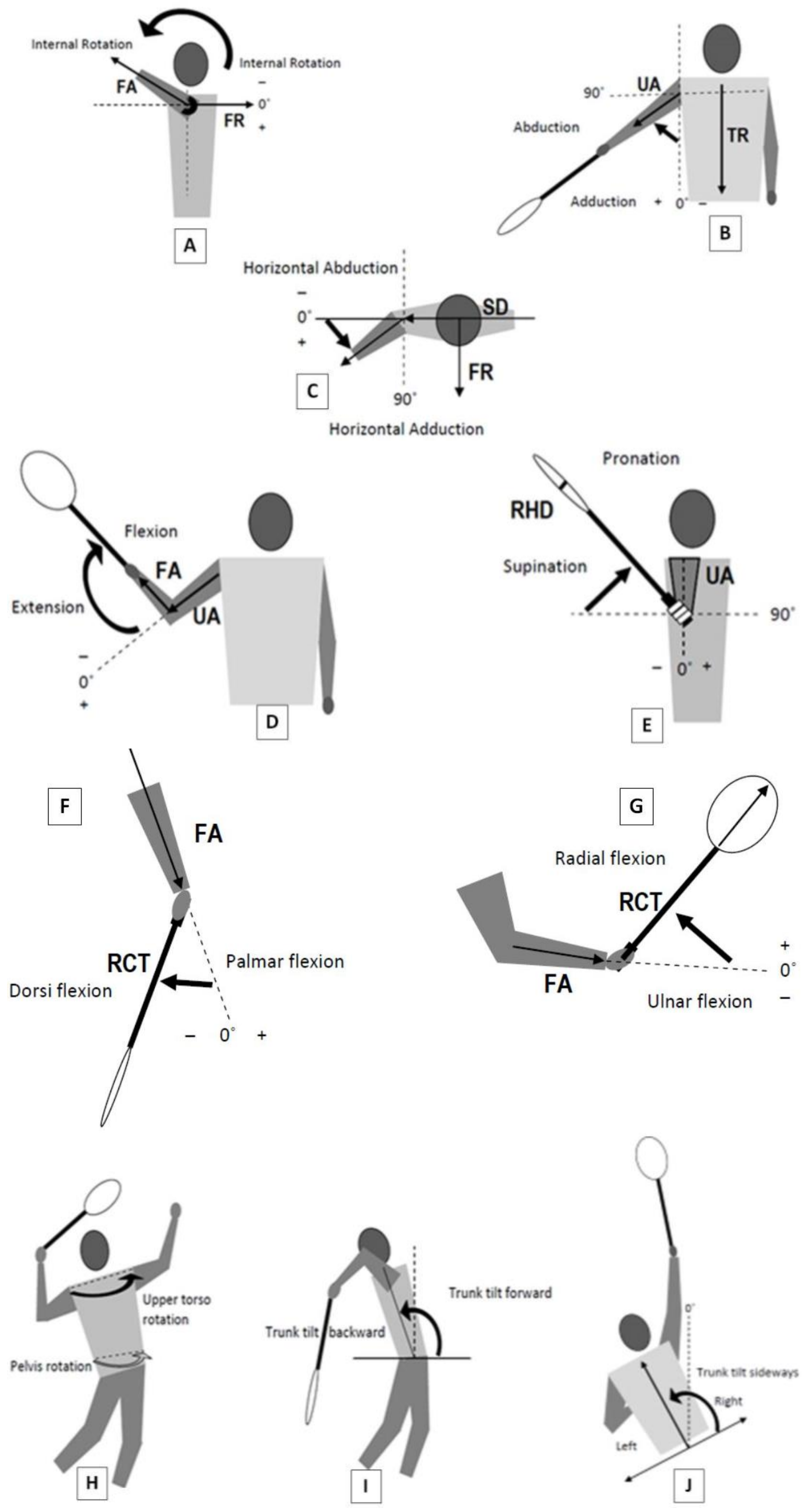

Figure 2. The Kinematic of Motion Parameters on the Upper Body Joints (Rusdiana et al., 2016)

Table 1: Kinematic Parameters in the Instant of Maximal Shoulder External Rotation Phase

Kinematic Parameter Analysis	Means ± SD	
	Fatigue	Non Fatigue
Shuttlecock velocity (mk/h) *	145 ± 5.7	188 ± 3.5
Jump height (cm)	43 ± 6.8	46 ± 5.1
Shoulder external rotation (deg)*	-162 ± 3.5	-134 ± 42
Shoulder abduction (deg)	101 ± 1.2	106 ± 1.4
Shoulder horizontal adduction (de)	7 ± 0.83	9 ± 0.96
Elbow flexion (deg)	94 ± 1.1	102 ± 1.3
Forearm pronation (deg)	14 ± 1.1	1 ± 1.3
Wrist palmer flexion (deg) *	-21 ± 2.1	-47 ± 2.4
Trunk tilt backward (deg)	21 ± 3.5	24 ± 3.1
Trunk tilt sideways left (deg)	19 ± 1.4	21 ± 1.6

***Significance of difference at level 0.05**

Table 2. Kinematic Parameters in the Maximum Angular Velocity

Kinematic Parameter Analysis	Means ± SD	
	Fatigue	Non Fatigue
Shoulder internal rotation (deg/s) *	1623 ± 3.5	2111 ± 4.2
Upper torso rotation (deg/s)	761 ± 1.2	782 ± 1.4
Pelvis rotation (deg/s) *	421 ± 0.83	429 ± 0.96
Elbow extension (deg/s) *	776 ± 1.1	985 ± 1.3
Foream supination (deg/s) *	442 ± 1.1	694 ± 1.3
Wrist dorsi flexion (deg/s)*	413 ± 2.1	855 ± 2.4
Trunk tilt forwars (deg/s)	185 ± 3.5	199 ± 3.1

***Significance of difference at level 0.05**

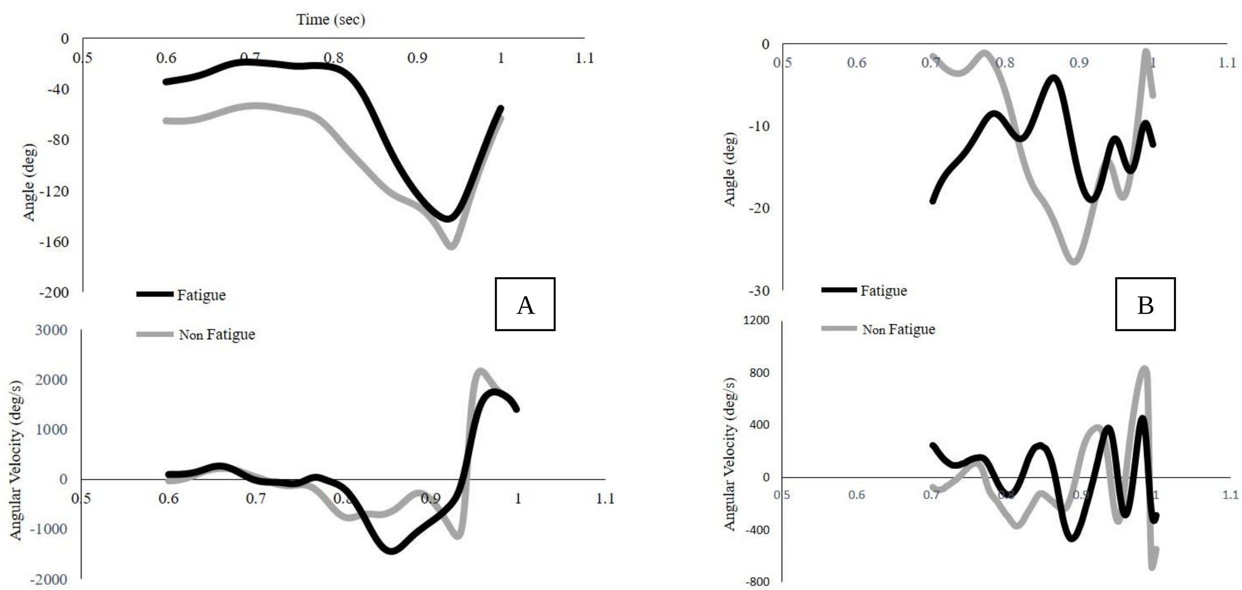

Figure 3. The Maximum Change of Angle and Angular Velocities of the Shoulder Internal Rotation (A) and the Change in Angular Velocity of the Forearm Pronation Supination (B).

Table 3. Kinematic Parameters in the Instant of Shuttlecock Release

Kinematic Parameter Analysis	Means ± SD	
	Fatigue	Non Fatigue
Shoulde abduction (deg)	23 ± 3.5	27 ± 4.2
Shoulder horizontal abduction (deg)*	14 ± 1.2	37 ± 1.4
Elbow extension (deg)	78 ± 1.1	81 ± 1.3
Wrist palmar flexion (deg)	5 ± 1.1	8 ± 1.2
Trunk tilt forward right (deg)	17 ± 3.5	21 ± 3.1

***Significance of difference at level 0.05**

The results showed that the shuttlecock velocity was faster on pre-fatigue (188 km/h) than under fatigue condition (145 km/h). This result is similar to the study conducted by P. Abián et al. (2017), which stated that there is a decrease in the speed of the ball after treatment intervention through the circuit training in handball throw that was also in line with the findings of Ferraz et al. (2012) in soccer, kicking with a specific circuit used five times to provoke fatigue.

This study also showed that several factors lead to a decrease in shuttlecock speed during jump smash with a reduction in body segment rotation. These include the shoulder internal angular velocity, elbow extension, forearm supination, and wrist dorsiflexion at the instant of maximal shoulder external rotation phase. The series of movement patterns associated with the overhead jump smash requires both linear and angular velocity and acceleration of the body movement, shuttlecock, and racket swing. A few studies explain the mechanism of action related to the forehand overhead stroke technique, especially in the jumping smash. However, M. Hiroshima et al. (2006), while analyzing the contribution of the upper body joints' angular velocity in a tennis serve, stated that a maximum shoulder external rotation is a first moment used to produce a higher speed of its internal rotation. Therefore, this enables the acquisition of a higher ball velocity (31). S. M. Fong et al. (2019) reported that internal shoulder rotation made the most significant contribution (up to 66%) to shuttlecock velocity or racket-head speed in the badminton smash or tennis serve. Furthermore, badminton needs a lot of overhead shoulder movement, in the abduction and external rotation, as well as in the proximal-to-distal sequence. X. Zhao, and Y. Gu (2019) published a biomechanical study of the badminton strokes of international players. They reported that, in the forehand smash, the elbow's extension movement almost ceased before impact. M. Á. Gomez et al. (2014) also showed that the elbow extension ended before impact. However, it was initially thought that much of the badminton smash's power was generated through what was termed the 'wrist snap' (palmar flexion). The majority of the early research emphasized the importance of internal shoulder rotation and radio-ulnar pronation while dismissing the contribution of palmar flexion.

This study result is relevant to the findings of (32) in tennis serve, which stated that elbow joints contribute to the ball's velocity. In the elbow extension movement, the faster the rotation, the stronger the push from the upper arm, enabling the forward racket to swing before the impact with the shuttlecock. The research results show that the flexion and extension movements on the elbow joints contribute up to 30% on the velocity of the racket swing. The angular velocity of other joints that play a vital role is the pronation-supination elbow joints (32). The movement of these joints, especially the angular velocity of the lower arm supination before impact with the shuttlecock, significantly contributes to the speed of the shuttlecock and racket (32). This movement is seen when the player is highly skilled. Therefore, it is not surprising when a professional produces a much higher shuttlecock velocity than their juniors.

CONCLUSION

In conclusion, the velocity of a shuttlecock associated with a jumping smash is higher in the non-fatigue condition than the fatigue. The muscle fatigue is closely related to the physiological definition, which stated that it is a decrease of response to the coming stimulation. When fatigue occurs, players find it challenging to control the direction of the shuttlecock. Furthermore, there are significant differences found in the fatigue condition parameter such as rotation velocity in the internal shoulder, wrist palmar flexion, and decrease in forearm supination, which reduces the shuttlecock's speed, compared to the non-fatigue condition during overhead jumping smash in badminton.

APPLICABLE REMARKS

- The results of this study are useful for players and coaches to analyze jumping smash motion mechanics comprehensively.
- The parameter of rotation velocity of the upper body in fatigue condition is decreasing, which reduces the speed of the shuttlecock during overhead badminton jumping smash.

CONFLICTS OF INTEREST

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

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