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Tennis flat forehand drive stroke analysis: three dimensional kinematics movement analysis approach

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Abstract

The purpose of this study was to analyze the ability of the flat forehand drive stroke with a three-dimensional kinematics analysis approach in tennis. The method used was quantitative descriptive, while the subjects were 18 male tennis players (age 27 ± 3.7 years, height 169 ± 7.4 cm, body weight 71.5 ± 8.3 kg). This instrument uses three video cameras, one set of calibration, motion analysis software, manual markers and a radar speed gun. The results of this study showed that of the shoulder internal rotation, wrist flexion, trunk and hip rotations for players who have skills shows greater results when compared to the novice players. In addition, the skills player group produce ball speed that is greater than the novice players. The results of this study concluded that the series of motion starting from the hip joint rotation, the maximum external-internal shoulder rotation contributed greatly to the racket speed in generating greater ball momentum. Meanwhile, the shoulder internal velocity is the key to producing the racket maximum speed. The recommendation from the results of this study for further research is to compare the performance of forehand and backhand strokes in the elite group with a three-dimensional analysis approach.

Keywords: *Sport biomechanics, Tennis, Forehand drive, Kinematic analysis*

INTRODUCTION

Tennis is one of the most popular sports, especially among the middle to upper class community. Ball stroke technique is the basic foundation that must be mastered by novice players (Iwamoto et al., 2013). The strokes in tennis are classified into three parts, namely ground strokes, volleys and overhead strokes (Genevois et al., 2014). Furthermore, groundstrokes can be divided into several types, including forehand drive, drop shot, backhand drive and half volley (Smeeton et al., 2013). One of the easiest drive strokes for beginners to learn is the forehand drive, both strokes with flat and spin techniques (Rota et al., 2012). This is because the motion of the forehand stroke for beginner

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players is relatively easy in trying to return the ball from the opponent due to the condition of the racket which is free from the body (Reid & Duffield, 2014). By learning the right forehand drive technique, players are able to develop effective and efficient strokes to get points from the baseline of the court (Soubeyrand et al., 2017). The coordination and harmonization of the chain of motion from various body segments during the forehand drive stroke will affect the quality of the stroke result. Forehand drive flat and spin by producing a fast ball is the main stroke technique in modern tennis game (Collins et al., 2020). According to the results of study conducted by Rogowski et al., (2011), it shows that the number of forehand drives stroke is 25% more, when compared to backhand drives in matches during the Grand Slam event in 2016. Forehand drive generates faster ball momentum after impact than the backhand drive stroke (Yeh et al., 2019).

One of the main principles of the fast flat forehand drive stroke is "the summation of speed principle", which is the harmonization pattern and coordination of the chain of motion from proximal to distal at the center of the axis of rotation of the joints of the body, especially at the upper extrimity (Gordon, 2006).

From the aspect of biomechanical studies, the movements and positions of various variations of joint motion that are inefficient and ineffective can reduce the speed, accuracy and rotation of the ball, and can even increase the risk of injury (Martin et al., 2020). This is in accordance with the results of research conducted by Rogowski et al., (2014) which showed that wrist flexion and forearm supination contributed 10-20% of the power when hitting the ball. So that the focus of the force of the forehand drive is more directed at the forearm, elbow, wrist and shoulder to improve the quality of the stroke motion that is effective and efficient (Knudson & Bahamonde, 2001).The forehand drive technique is divided into four phases, namely the preparation, backswing, impact and the follow-through. During the implementation of these four phases, the movement must be a complete of motion carried out simultaneously. In the

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preparation phase, the legs are shoulder-width apart with a slight bend, both hands hold the racket in a position in front of the body with the racket head parallel to the chin position. In the second phase, grip the racket with your dominant hand, then rotate your shoulders open, swing the racket back, keeping your feet shoulder width apart and knees slightly bent. The shoulders are fully rotated, followed by a strong motion of the shoulder and wrist joints, so that the direction of motion of the racket is circular during the backward swing (Kawamoto et al., 2019). In the third phase, the impact stage is when the racket swings forward by adjusting the arrival of the ball, then continues the swing until the racket rises and over the shoulder while shifting the weight to the forefoot which results in "force production" which causes the kinetic chain to occur resulting in more racket speed (Blache et al., 2017). Shoulder internal rotation and wrist palmar flexion contribute significantly to racket speed before impact. In addition, the speed of the shoulder internal rotation is a factor that is the main indicator that differentiates the various ball speeds during service tennis (Christensen et al., 2016). Furthermore, in the fourth phase is the follow-through, this movement occurs after the impact is continued by the motion of the racket swing forward by straightening the arms and decreasing the speed of the upper body segment which results in speed and ball accuracy (Colomar et al., 2020). Although the forehand drive is the most common shot in tennis, research related to the forehand drive coordination chain using a three-dimensional analysis approach is very limited.

The success of a player is often determined by the mechanical efficiency of the executed strokes. Therefore, studies related to the kinematics of flat forehand drives not only help to understand the scientific aspects related to movement techniques, but will also improve the performance of the player optimally (Kwon et al., 2017). This study aims to describe the kinematic parameters of motion, especially on the shoulders, elbows, wrists, hips and trunk during the flat forehand drive between the

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skilled player group and the novice player group with a three-dimensional analysis approach in the tennis.

METHODS

Participants

Subjects in this study were 18 male tennis players (mean ± SD; age 27 ± 3.7 years, height 169 ± 7.4 cm, body weight 71.5 ± 8.3 kg) consisting of nine players who have skills with categories experience playing tennis for more than 5 years, while the other nine player are novice players group who have experience practicing tennis under 6 months. All participants gave their consent on the form that had been given previously and were confirmed not to be injured. Then, prior to the test the participants received a technical explanation related to the implementation procedure in a comprehensive manner. The data collection test was conducted in the indoor tennis court of the FPOK Universitas Pendidikan Indonesia. While the method used in this research is descriptive quantitative approach.

Test Procedure

Before starting the test, the participants did a warm-up for about 15 minutes, followed by carrying out flat forehand drive strokes using their own racket to make it more comfortable and quick to adapt. The player stands in the baseline position, then makes a flat forehand drive stroke perpendicular to the opponent's court quickly and accurately in the predetermined target area, the number of strokes made 10 times. Strokes that are off target or hitting the net are not considered for scoring.

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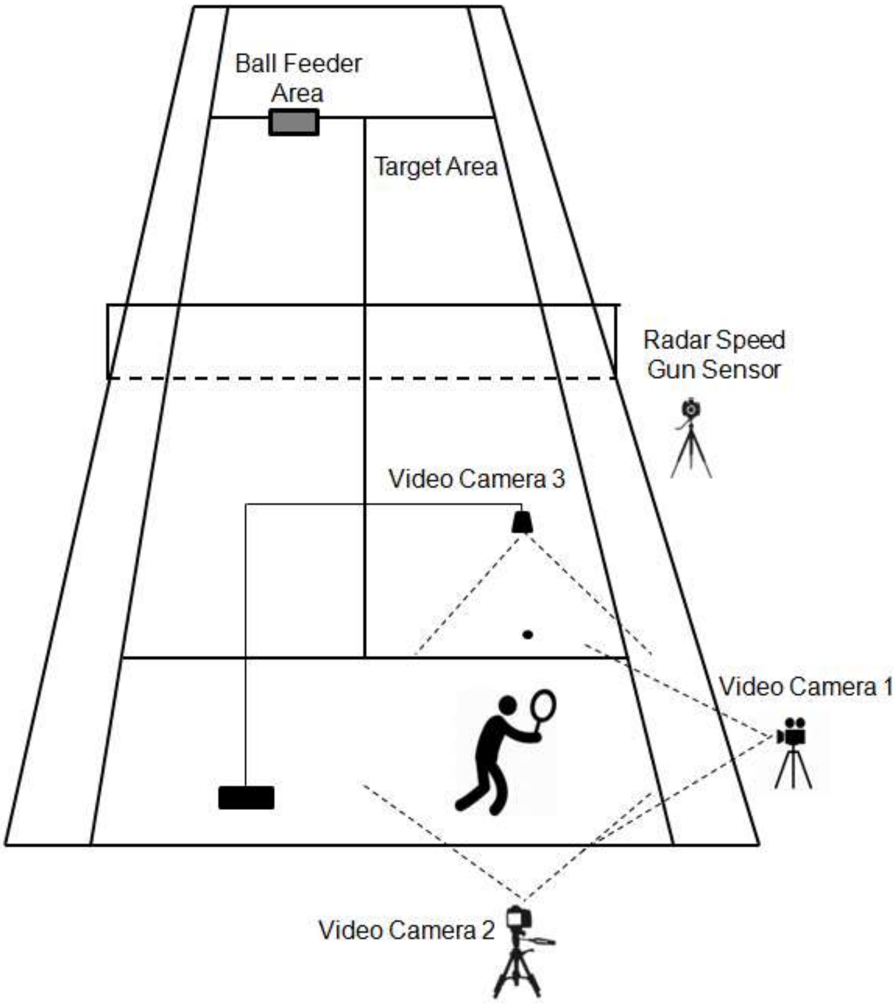

Figure 1. Schematic of field data collection from the back view

Figure 1 explains the position of the video camera and the field scheme, the position of the feeder standing at the intersection of the center service line of the opponent's field. To measure the speed of the ball using a radar speed gun with a shutter speed of 100 *hz* which is positioned near the net with a distance of 45 cm outside the field line. Video camera 1 is placed on the right side of the field with a distance of 1.5 meters perpendicular to the position of the subject standing. Then, the video camera 2 is positioned behind the field line parallel to the subject area with a distance of 2 meters from the player's standing position.

Furthermore, the position of the video camera 3 is placed above the position of the standing subject that is vertically perpendicular to the position of the subject area. The three video cameras are user-controlled

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according to the needs of the research characteristics, namely the frame rate is 100 *hz*, shuttle speed is 250s and exposure time is 1/1200s. Meanwhile, for the purposes of calibration and data processing, the three-dimensional analysis is carried out using the Direct Linear Transformation Method Calibration Structure approach developed by Blace (Blache et al., 2017).

Research Instruments

The instrument in this study used three video cameras (Panasonic Handycam HC-V100 Full HD, Japan), a three-dimensional calibration set, a 3D motion analysis software set (Frame DIAZ IV, Japan), a set of manual markers and a radar speed. gun (Bushnell Speed gun 101911, Italy).

Kinematic Parameters

To analyze the kinematics of the flat forehand drive technique, it is divided into four phases, namely preparation, backswing, impact and follow-through according to Figure 2 below. (Knudson & Bahamonde, 2001).

Figure 2. Series of flat forehand drive stroke motion images

Meanwhile, to determine the mechanical characteristics of the flat forehand drive stroke, make a model according to anatomical principles (Rusdiana et al., 2020).

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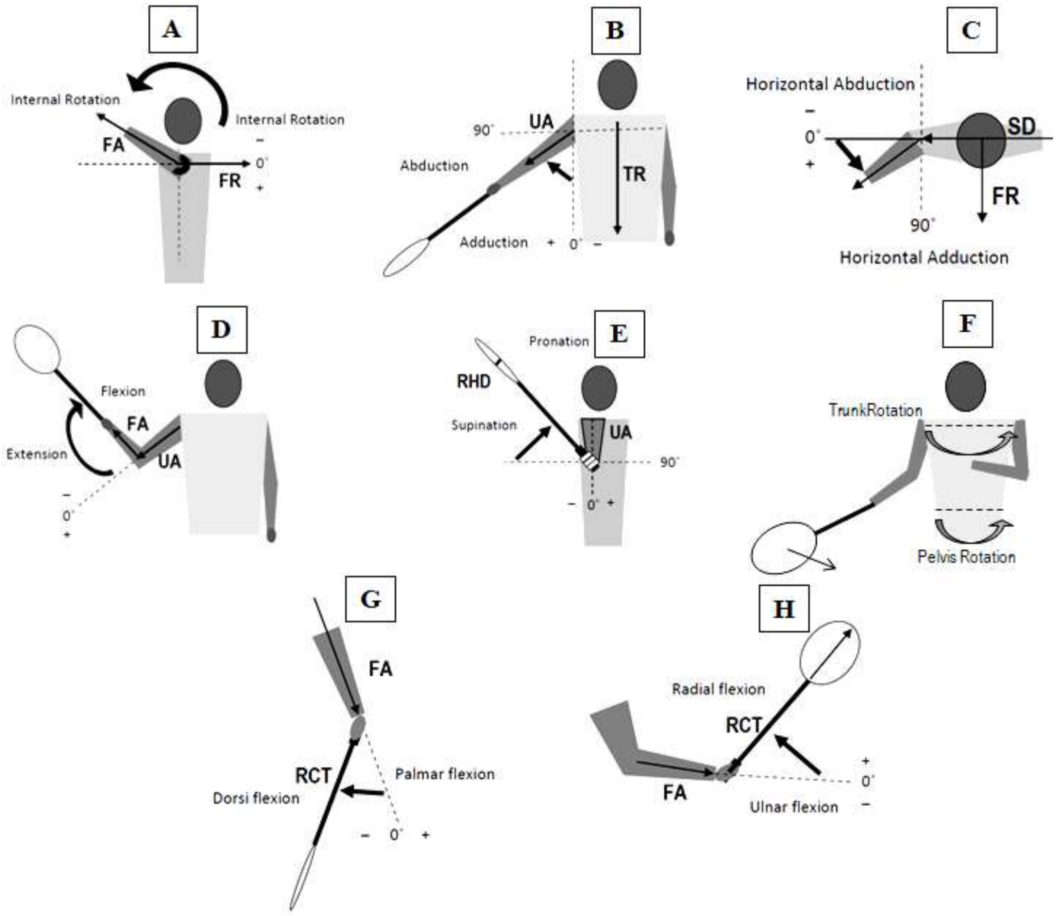

Figure 3. Kinematic parameters movement of the flat forehand drive

The movement consists of the shoulder joint, there are three characteristics of movement, namely internal-external shoulder rotation (A), shoulder abduction-adduction (B) and horizontal shoulder abduction-adduction (C). In the elbow joint, the elbow joint consists of two characteristics of movement, namely elbow flexion-extension (D) and forearm pronation-supination (E). Next is the trunk rotation and pelvis rotation (F). The wrist joint consists of two characteristics of movement, namely the wrist palmar-dorsi flexion (G) and the wrist radial-ulnar flexion (H) which is illustrated in Figure 3 above.

Statistical Analysis

This study uses the SPSS version 21.0 application (SPSS Inc., Chicago, IL). Average and standard deviation are calculated as initial data for further calculations, namely normality test, homogeneity and

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hypothesis testing. To test the hypothesis, a one-way analysis of variance test approach was used, which consisted of two groups, namely skilled and novice player groups.

RESULTS

The following is an analysis of data related to differences in ball velocity and changes in the chain of motion kinematics during the flat forehand drive stroke movement between the skilled player group and the novice player group in table 1 and 2.

Table 1. Kinematics data of shoulder, elbow and wrist joints between skilled and novice player groups in the preparation, maximal backswing, impact, and follow-through phases

Variables	*Preparation (Mean ± SD)*		*Maximum Backswing (Mean ± SD)*		*Impact (Mean ± SD)*		*Follow-Through (Mean ± SD)*	
	Skilled	***Novice***	***Skilled***	***Novice***	***Skilled***	***Novice***	***Skilled***	***Novice***
Shoulder Abduction-Adduction (°)	22±2.7	28±3.8	42±5.2	60±5.8	33±6.3	32±5.8	13±4.3	9±3.9
Shoulder Horizontal Abduction-Abduction (°)	4±2.1	1±1.9	9±2.2	13±2.7	14±1.9	10±1.8	99±8.5	78±8.9
Shoulder Internal-External Rotation (°)	43±6.4	22±5.9	-38±4.8	-20±5.2	43±7.3	-4±4.9	114±8.9	108±9.4
Elbow Flexion - Extension (°)	93±5.7	82±6.1	80±7.3	83±8.6	42±4.8	63±7.4	88±7.2	68±7.9
Forearm Supination-pronation (°)	79±6.3	72±5.8	57±3.6	49±3.8	20±1.7	43±2.5	107±8.7	84±8.2
Wrist Flexion - Extension (°)	-11±3.2	-5±2.4	-21±1.5	-17±2.1	-25±2.8	-42±3.1	4±1.4	-10±1.8
Wrist Radial Ulnar (°)	1±1.7	3±1.3	10±1.4	10±1.6	12±2.2	8±2.4	-3±1.2	-1±1.3

Table 1 shows the mean and standard deviation data for preparation, maximum backswing, impact and follow-through during the flat forehand drive stroke between the skilled player group and the novice player group.

Table 2. The mean, standard deviation and significance value of the maximum change in joint angle, maximum joint angular velocity, forward swing speed and ball speed during the flat forehand drive stroke between the novice player group and the skilled player group

Variables	***Novice Player Group***		***Skilled Player Group***		***Sig. (p)***
	Mean	***± SD***	***Mean***	***± SD***	
Ball Speed (m/s)	20.4	2.8	29.8	2.4	5.245*
Forward Swing (sec)	0.42	2.1	0.31	1.6	4.429*
Maximum Angle Change (°)					
Shoulder Abduction (°)	32.5	5.4	59.7	5.9	3.785*

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Shoulder Adduction (°)	15.2	2.6	16.4	2.1	0.233
Shoulder Horizontal Abduction (°)	34.7	2.4	68.5	2.5	3.465*
Shoulder Horizontal Adduction (°)	26.4	2.1	29.4	2.3	0.098
Shoulder Internal Rotation (°)	44.7	3.8	69.4	4.1	5.642*
Shoulder External Rotation (°)	26.2	2.2	29.3	2.0	1.015
Elbow Flexion (°)	22.3	1.6	23.5	1.4	0.086
Elbow Extension (°)	45.3	3.9	56.2	2.8	0.857
Forearm Pronation (°)	11.4	1.3	39.6	2.1	3.652*
Forearm Supination (°)	17.8	2.1	19.9	1.8	0.255
Wrist Flexion (°)	24.8	1.8	28.4	2.0	1.432
Wrist Extension (°)	13.1	0.9	11.3	0.7	0.054
Wrist Radial (°)	12.9	0.5	11.6	0.4	0.028
Wrist Ulnar (°)	11.4	0.4	12.2	0.2	0.043
Maximun Joints Angular Velocity *(°/s)*					
Shoulder External Rotation (°/s)	437.4	62.4	4.786	65.3	1.334
Shoulder Internal Rotation (°/s)	793.7	83.5	951.4	98.5	3.245*
Forearm Pronation (°/s)	124.5	14.8	159.4	15.3	0.873
Forearm Supination (°/s)	113.3	11.5	121.6	12.5	0.911
Elbow Flexion (°/s)	224.5	87.5	249.2	89.5	0.682
Elbow Extension (°/s)	287.5	95.6	302.5	59.7	1.258
Wrist Flexion (°/s)	145.6	11.5	175.5	12.1	4.124*
Wrist Extension (°/s)	187.4	10.8	198.6	11.2	0.998
Wrist Radial (°/s)	98.4	6.9	112.2	7.2	0.749
Wrist Ulnar (°/s)	105.3	7.7	117.5	6.5	0.088
Trunk Rotation (°/s)	545.0	82.9	778.0	78.4	3.458*
Hip Rotation (°/s)	340.5	40.6	505.2	61.5	3.448*

* *Significant differences at alpha 0.05*

Table 2 shows the average and standard deviation values of the maximum joint angle change, maximum joint angular velocity, forward swing speed and ball velocity during flat forehand drive stroke between the novice player group and the skilled player group. The ball velocity between the novice player group (20.4 $m.s^{-1}$) and the skilled player group (29.8 $m.s^{-1}$) showed a significant difference (p = 5.245). Meanwhile, the forward swing time between the novice player group (0.42s) and the skilled player group (0.31s) also showed a significant difference (p = 4.429). The rotation

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speed of shoulder internal rotation, wrist flexsion, trunk rotation and hip rotation between the novice player group and the skilled player group showed a significant differences (respectively; p = 3,245, p = 4.124, p = 3.458 and p = 3.448).

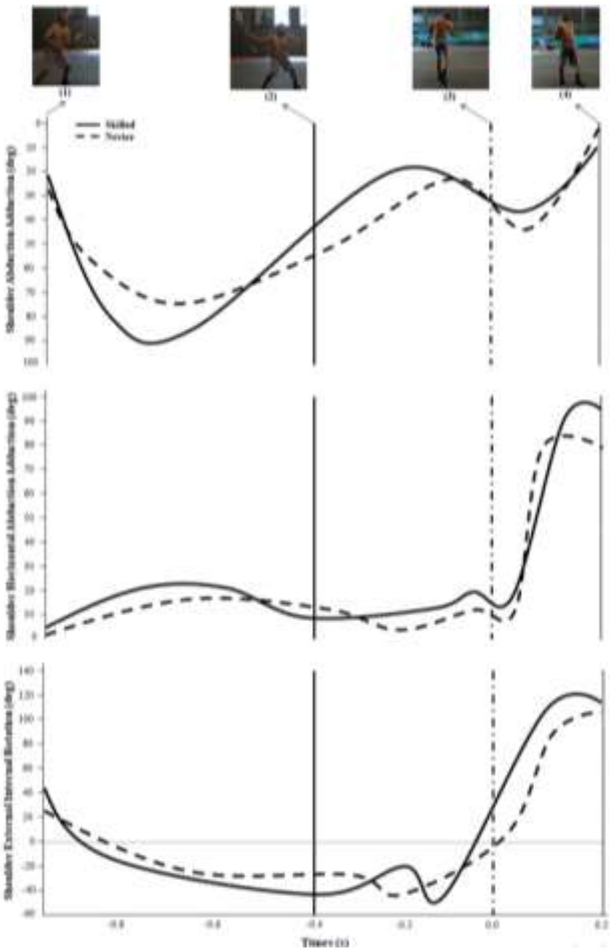

Figure 4. Explanation of the mean shoulder joint motion patterns and movement time (s) between of skilled player group (black line) and novice player group (dotted black line). As for the series of flat forehand drive movement chains: (1) preparation, (2) maximum backswing, (3) impact and (4) follow-through phases.

Table 2 shows that the movement of the shoulder joint when swinging backwards there is a significant difference (p = 3.785) when the movement of the shoulder angle is lifted up (shoulder abducted) is 42º for the skilled player group, whereas in the novice group the motion of the shoulder joint was 60º with a difference of 18º. The next movement is to make a backward shoulder rotation (shoulder external rotation) to quickly reach the angles of -38º (skilled player group) and -20° (novice player group) as shown in Figure 4. While the forward swing towards in the

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impact ball phase, the motion of the shoulder joint is lowered toward the hip (shoulder adducted) by about 32º by carrying out a shoulder internal rotation as soon as possible with fast acceleration with a shoulder rotation angle of 43º (skilled player group) and -4º (novice player group), so there was a difference in the angle of 47º which was greater for the skilled player group (Figure 4).

During the shoulder internal rotation, this showed a significant difference (p = 5.642) between the group of skilled players and the novice player group (table 2). furthermore, in the follow-through phase for forward horizontal movement of the shoulder (shoulder horizontal abduction) there was a significant difference (p = 3.465) with the angle of the shoulder joint reaching 99º (skilled player group) and 76º (novice player group) with a difference of 23º. Meanwhile, in the backswing and impact phases there is no significant difference (Figure 4).

Figure 5 shows that there is no significant difference in movement of the elbow joint (elbow joint) when the backswing with the arm is pulled straight back with the elbow extension almost straight approaching 83º, while the angle of forearm supination reaches 57º (skilled player group) and 49º (novice player group). However, at the speed of the forward racket swing just before impact, the elbow flexion motion was more open (28º) for the skilled player group, while the group of beginners bent the elbow joint more narrowly by 52º. This makes the range of motion in the shoulder joint wider, so the acceleration of the racket swing is faster.

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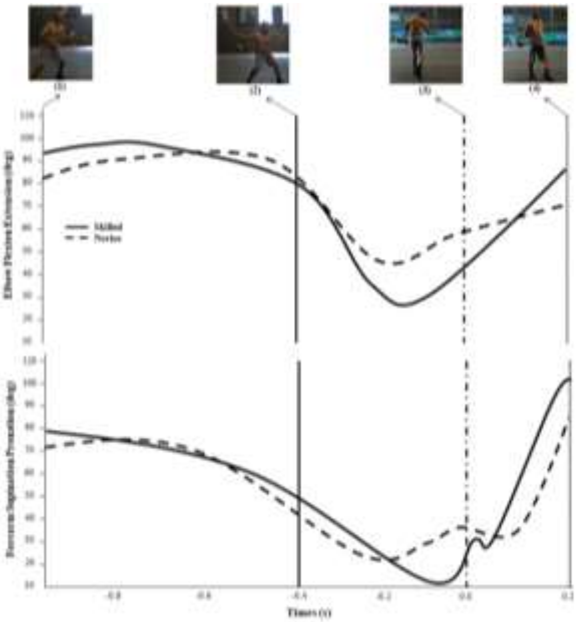

Figure 5. Explanation of the mean elbow and forearm joint motion patterns and movement time (s) between of skilled player group (black line) and novice player group (dotted black line). As for the series of flat forehand drive movement chains: (1) preparation, (2) maximum backswing, (3) impact and (4) follow-through phases.

Furthermore, the group of players who had skilled forearm pronation arm movement just before the impact angle was formed (11º) was greater than the novice player group (39º), with a significant difference (p = 3.652).

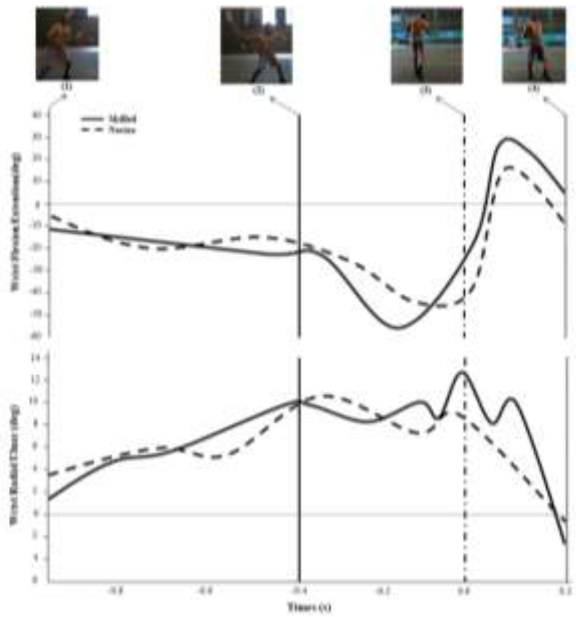

Figure 6. Explanation of the mean wrist joint motion patterns and movement time (s) between of skilled player group (black line) and novice player group (dotted black line). As for the series of flat forehand drive movement chains: (1) preparation, (2) maximum backswing, (3) impact and (4) follow-through phases.

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Figure 6 shows that the movement speed of the wrist flexion-extension and wrist radial ulnar joints has no significant difference in both the backswing, impact and follow-through phases. However, players who have skills during the elbow extension movement just before impact (55º) are greater than beginners (44º). Furthermore, the maximum elbow flexion angle in the follow-through phase showed results of 28º (skilled group) and 16º (novice group), respectively.

DISCUSSION

Racket Speed

The transfer momentum from the racket to the ball is the main influence of the speed of the racket at impact. Therefore, the ability to produce high racket speed is the key to successful play because it will affect ball speed (Rota et al., 2014). The result of a ball stroke that comes faster to the opponent's field area will be more difficult to anticipate and the opponent will change the wrong move which results in a stroke error by returning the ball out of the field or hitting the net. These results are in accordance with the research of Rota et al., (2014), which states that there is a strong relationship between skill level and racket swing speed. This study also shows that there is a significant difference in racket and ball speed between skilled players (25.1 $m.s^{-1}$) and novice players (14.8 $m.s^{-1}$).

In addition, another study conducted by Creveaux et al., (2013) reported that the elite group produced a greater racket speed (31.1 $m.s^{-1}$) when compared to the group in the high performance youth group (27.6 $m.s^{-1}$).

Backswing Phase

The displacement of the hip joint, shoulder joint and racket which is associated with a speed indicator results in different variations of the player's backswing motion, this is a controversial topic among coaches (Genevois et al., 2020). The rotation speed of the shoulder and hip joints in the backswing phase in this study showed smaller results than the study conducted by (Herbaut et al., 2017) Meanwhile, Rogowski et al., (2011)

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showed that the maximum torso-pelvic acceleration results increased simultaneously. With the ball speed for golfers, Nesbit et al., (2008) further revealed that the trunk rotation speed produced by the pro golf group is greater when compared to the high handicap group.

Extension of the shoulder joint (shoulder abduction), the angle of external rotation of the shoulder joint (angle of shoulder external rotation), elbow extension and forearm supination during the backward swing are the main keys to producing maximum acceleration of the racket swing with a range of motion (King et al., 2012). In addition, trunk rotation followed by hip joint acceleration is the main support for producing racket speed (Herbaut et al., 2017).

Impact Phase

There is a significant difference between the maximum racket speed in the forward swing phase and the impact in the two groups (skilled vs novice player gorups). For the group of players who have skill, the maximum speed of the racket occurs when it hits the ball (impact), while in the case of the novice player group, the maximum speed of the racket occurs before impact. This result is similar to the findings of Rota et al., (2012) related to a research study on the analysis of tennis backhand drive. Then, the maximal hip rotation is the main supporting part which results in the trunk rotation speed and shoulder internal angular velocity which results in a faster racket swing.

Furthermore, the rotational velocity of the elbow during elbow flexsion angular velocity should have a positive effect on linear velocity of the wrist as it does for smash movements in badminton, but in general it contributes little in the effort to generate racket speed (Smeeton et al., 2013). Furthermore, the combination of wrist movement (wrist palmar and dorsi flexion) can contribute about 25% of the racket speed at impact to the tennis serve (Johnson & McHugh, 2006). In addition, Landlinger et al., (2010) found that range of motion hip rotation has a strong relationship with trunk rotation at the close stance of the forehand swing. Then

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Knudson & Bahamonde, (2001) reported that trunk rotation has a strong correlation with racket speed.

Follow-Through Phase

In general, the follow trough when the flat forehand drive stroke is constantly changing, this is due to the racket grip, the type of shot played and the need for strategic stroke tactics when competing (tactical intention of the stroke on the game) (Christensen et al., 2016). The results of this study indicate that the position of the two hip and shoulder joints is further parallel to the ball in the follow-through phase. In the group of players who have faster trunk rotation with smaller hip and shoulder angles compared to the group of novice players at the end of the racket swing movement.

The follow-through movements performed by the two groups of players are almost the same, namely placing both arms and the racket above shoulder level with the body weight shifting from the right leg to the left and the racket moving with respect to the ball. This is very important because this continued movement determines the speed and direction of the ball to the opponent's field. In addition, the balance of the body should always be maintained with the right foot, left arm and with the heel slightly off the surface. Then the direction of motion of the racket forward and downward approaches the hips, while the velocity of various body segments decreases gradually (Bańkosz & Winiarski, 2018).

CONCLUSIONS AND SUGGESTIONS

Conclusions

From the results and discussion previously described, the flat forehand drive stroke in tennis is a very dynamic and complex movement technique. Identifying kinematic parameters of the chain of motion, especially in the upper body between groups of skilled players and novice player group, is a comprehensive study of the purpose in this study. The skilled player group showed stroke performance by obtaining a higher racket speed at impact than the novice player group. Furthermore, the skilled players showed that the rotation speed of the hips and torso was

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greater at the impact. Meanwhile, shoulder internal rotation is the key to producing maximum racket speed in various strokes. The results of this study will help instructors, coaches and practitioners, especially in improving the performance of the flat forehand drive in tennis. The weakness of this research is that the instruments that still use video recordings using markings on the joints of the body manually have not used a motion capture system due to limited equipment.

Suggestions

After conducting a comprehensive analysis study of the characteristics of the flat forehand drive stroke technique, it is recommended that special weight training be given to players, especially in the shoulder joints specifically on the shoulder internal-external external rotation, elbow flexion extension, trunk rotation and hip rotation. The purpose of this weight training is to increase strength and power in the hip, shoulder, arm and wrist joints in an effort to improve the performance of the forehand drive stroke. The next suggestion from the results of this study is that for further research, it is to compare the performance of forehand and backhand tennis strokes in the elite group of athletes using a three-dimensional analysis approach.

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