Biomechanical Analysis of Forehand Shot in Tennis

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Abstract. To explore the forehand stroke technique characteristics and kinematics rules. Use two sets of GC-PX10AC JVC high speed camera (50 frames/sec) field shooting, and use Signal TEC V2.0C 3-D software on the field shooting video analysis. Results show: (1) At backswing stage, the left shoulder angle is 46.3° and the left elbow angle is 143.8°. Arms are fully extended which is in line with the principle of modern tennis backswing; (2) At the moment of touching the ball, the angle of rotation of the shoulder-hip angle is 57.4° and the speed of racket head is 17.02m / s, reaching a maximum; (3) In the follow-up stage, the initial momentum of Kvitova passing to the ball is larger with the range and the distance. Most of the existing research for the right hand holding players, the study object for the left hand holding athletes, can provide a more comprehensive technical reference for tennis players.

Introduction

Tennis is a technically complex sport which involves various muscle groups. Forehand topspin technology is one of the most commonly used technique in tennis athletes, especially in the bottom line of attack, the level of forehand technical level plays a vital role for the game, also reflects their attack. From the perspective of biomechanics terms, perfect technique is not only an effective combination of power and control but also can reduce the possibility of injury to a minimum. In this paper, the important kinematic parameters of the forehand technique of Kvitova, the world's best female tennis player, are obtained by means of 3D camera analysis. From the backswing, swing and follow through three stages to analyze the causal relationship between them and the technical details.

Research Objects and Methods

Research Objects

<table>
<thead>
<tr>
<th>Name</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Birthday</th>
<th>Professional Features</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kvitova</td>
<td>183</td>
<td>70</td>
<td>1990.03</td>
<td>Left-handed</td>
<td>3</td>
</tr>
</tbody>
</table>

Methods

Three-dimensional Imaging Analysis Method. In 2014 China Open tennis tournament site, 2 JVC GC-PX10AC (50 frames/s) shot Kvitova’s forehand video. Main axis angle between two machines is about 65 degrees, 1.25 meters high. The 1st machine was placed behind the sideline of tennis court, the 2nd one was placed in front of the bottom line of tennis court, two cameras main axis angle of approximately 65°. The angle of the main optical axis of the two cameras is about 65 degrees. Europe Dempster was chosen as mannequin mannequins (16 links, 21 joints parameter). In order to study the need, the study needs to add parsing a test point (racket). Using Beijing SenMiaoXin company that developed high peptide star 3-D Signal TEC V2.0C software to parse the video field shooting by frame analysis, smoothing the raw data obtained using the optimized low-pass digital filter, cutoff frequency of 8 Hz. The kinematic parameters such as joint angle and linear velocity of the motion technique are obtained.
Research Results and Analysis

The Definition and the Division of the Time of the Forehand Stroke

In this paper, according to the characteristics of the tennis forehand technique, Kvitova's forehand is divided by three stages and defined by four times:

T1 Prepare ending moment: when athlete approaching the ball and doing small amplitude jump, the moment right foot touches the ground.
T2 Backswing ending moment: the moment racket getting farthest from the trunk.
T3 Hitting moment: the moment racket makes contacts with the ball.
T4 Complete with play moment: the moment racket swing to the right shoulder and shoulder rotation angle is reduced.

Three stages:
Backswing stage: T1-T2
Swing and hitting stage: T2-T3
Follow-up stage: T3-T4

Kinematic Analysis of Backswing Stage

Table 2. Kinematic parameters of athlete in backswing stage (unit:°).

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Left shoulder angle</th>
<th>Left elbow angle</th>
<th>Left wrist angle</th>
<th>Left knee angle</th>
<th>Right knee angle</th>
<th>Left hip angle</th>
<th>Right hip angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kvitova</td>
<td>46.3</td>
<td>143.8</td>
<td>152.0</td>
<td>119.0</td>
<td>121.2</td>
<td>124.3</td>
<td>140.5</td>
</tr>
</tbody>
</table>

Table 3. Kinematic parameters of athlete body joints speed in swing and hitting stage (unit:m/s).

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Left shoulder</th>
<th>Right elbow</th>
<th>Left wrist</th>
<th>Weight speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kvitova</td>
<td>0.89</td>
<td>1.55</td>
<td>4.79</td>
<td>2.90</td>
</tr>
</tbody>
</table>

From Table 2 and Table 3, in the backswing ending moment Kvitova’s left shoulder angle is 46.3°, left elbow angle is 143.8°, left wrist angle is 152.0°. Left shoulder and left elbow angle showed at the end of backswing the player’s arm relative to the torso in the extended state. Both the left and
right elbow angles show an increasing trend, which means that the athlete's racket is farther away from the body. Significant changes in the left shoulder angle refers elbow lift obviously; The elbow leads the body backwards; High lift elbow makes the racket in a relatively high initial position, with good potential energy. At the end of the swing stage arm stretches more fully, the action is more stretch. The left and right hip angles are 124.3° and 140.5° respectively. The left and right knee angles are 119.0° and 121.2° respectively. Left knee angle is less than the angle of the right knee angle, the center of gravity of the athletes turns to the left side of the body, left leg play a major supporting role. The left shoulder joint velocity was 0.89 m/s, the left elbow joint velocity was 1.55 m/s, the left wrist joint velocity was 4.79 m/s, and the center of gravity velocity was 2.90 m/s. At the end of backswing moment, the body center of gravity in the dynamic squatting process combined with the video. Before the racket touching the ball, the trunk is in a certain state of tension playing an important role for the subsequent stroke. From the Prepare ending moment to hit the ball is 0.74s, of which T1-T2 time is 0.62s, T2-T3 time is 0.12s. This shows that backswing time is reasonable; the speed is relatively average; T2-T3 time is relatively short, faster, increasing the inertia and speed of the racket.

**Kinematical Analysis of Swing and Hitting Stage**

After the backswing stage, it comes to the swing and hitting stage. Be sure to hit the ball forward with hip and waist of the fast, short twist which using strong centrifugal force to swing the body and racket.

![Figure 4. T2 Backswing ending moment.](image1)

![Figure 5. T3 Hitting moment.](image2)

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Left shoulder</th>
<th>Right elbow</th>
<th>Left wrist</th>
<th>Left hand speed</th>
<th>Racket speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kvitova</td>
<td>1.41</td>
<td>3.66</td>
<td>6.93</td>
<td>7.95</td>
<td>17.02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Left shoulder angle</th>
<th>Left elbow angle</th>
<th>Left wrist angle</th>
<th>Left knee angle</th>
<th>Right knee angle</th>
<th>Left hip angle</th>
<th>Right hip angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kvitova</td>
<td>35.7</td>
<td>125.8</td>
<td>117.0</td>
<td>128.6</td>
<td>141.2</td>
<td>137.0</td>
<td>163.5</td>
</tr>
</tbody>
</table>

As can be seen from Table 4.5, left and right hip, left and right knee, the two joint angles are gradually increased. Indicating Kovicova’s center of gravity is high when hitting the ball. With the decrease angle of the left shoulder and the left elbow, the radius of the rotation of the body decreases. With the trunk as the axis of the rotation of the ball movement due to the decrease of the radius of the rotation is helpful to increase the angular speed, so that the racket can touch the ball faster.

When hitting the ball, the velocity of the left shoulder is 1.41m/s, the velocity of the left elbow is 3.66m/s, the velocity of the left wrist is 6.93m/s, and the left hand is 7.95m/s. It can be known that the speed of the hand and the wrist is the largest, and the speed of the elbow is the second. That is to say when hitting a forehand topspin the wrist is dynamic, which is the internal rotation of the elbow to the wrist on the arm, wrist turn quickly to drive. At the end of backswing, the shoulder and hip
angle is -40.1 degrees. At T3 moment, the shoulder and hip angle is 17.3 degrees. The rotation range of the shoulder and hip angle is 57.4 degrees. Combined with the video, Kvitova used her left foot to push the ground and rotate the whole body so that the momentum of backswing stage accumulation can be transferred to the ball through the racket. At T3 moment, Trunk muscles have a certain stretch, which will have a favorable effect for the subsequent hit.

**Kinematic Analysis of Follow-up Stage**

![Figure 6. T3 Hitting moment.](image1) ![Figure 7. T4 Complete with play moment.](image2)

<table>
<thead>
<tr>
<th>Moment</th>
<th>Left shoulder angle</th>
<th>Left elbow angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>T3</td>
<td>35.7</td>
<td>125.8</td>
</tr>
<tr>
<td>T4</td>
<td>120.9</td>
<td>106.3</td>
</tr>
</tbody>
</table>

As can be seen from Table 6, Kvitova’s left shoulder angle is 35.7° and 120.9°, respectively, the left elbow angle of 125.8° and 106.3° at T3 moment and T4 moment. In the follow-up stage, the right shoulder angle gradually increased and reached 120.9° with the end of the T4 moment, indicating that Kvitova’s elbow lifts significantly. The elbow is away from the trunk in accordance with the large range, long distance follow-up principle.

**Conclusions**

Forehand stroke is a continuous process. When stopping at the hitting moment, you need to bend the legs adequately in order to fully turn. At this point the foot can be off the ground but the body still continues to be in the coordination chain of strength and speed. In the whole process of hitting the ball, hip, shoulder and upper body constitute the basic elements of balance. Kvitova's technical characteristics are summarized as follows:

1. At the ending moment of backswing, Kvitova's left hip angle is 124.3 degrees, the right hip angle is 140.5 degrees, the left shoulder angle is 46.3 degrees, the left elbow angle is 143.8 degrees, the left wrist joint velocity is 4.79m/s. Kvitova pulls the racket away from the body, the force of the holding arm is passed in turn.

2. At the moment of touching the ball, the angle of rotation of the shoulder-hip angle is 57.4°. When hitting the ball, the left shoulder joint velocity is 1.41m/s, the left elbow joint velocity is 3.66m/s, the left wrist joint velocity is 6.93m/s, the left hand speed is 7.95m/s, the speed of the racket head is 17.02m/s. Kvitova is relying on the internal rotation of the elbow wrist, playing a strong spin on the ball. At the same time of swing forward, it is the arm doing a quick upward movement onto the wrist.

3. In the follow-up stage, the left shoulder angle increased gradually and reached 120.9 degrees at the T4 moment. Left elbow angle is 106.3°. It indicates that Kvitova’s elbow lifts significantly. The direction of the swing arm is forward and upward in accordance with the large range, long distance follow-up principle. Its kinematic technical parameters are worthy of the majority of tennis coaches, athletes to learn from.
References


