

Kinematic Analysis on the Serve Technique of Elite Tennis Player Grigor•Dimitrov Based on 3D Virtual Reality Technology

Chuan Jia Du^{1*}, Ji He Zhou² and Shuai Wang³

Chengdu sport university

Chengdu, Sichuan, China

E-mail:549828421@qq.com*

Abstract: By using three-dimensional video analysis, we made a kinematic analysis on Grigor Dimitrov's Serve technique, aiming at finding the kinematic characteristics of his serve technique during various stages. The results showed that: (1) During the stage of tossing the ball and lifting the racket, the tossing height of the ball was at minimum appropriately, while the elbow extension of the tossing arm was stright, and the angle of his left knee was 95.4°, which is beneficial to making greater kicking power; (2) At the back-swing stage, Dimitrov's both feet made a great range of pedal and stretch quickly, and the "scratch-back" posture is obvious, and momentum caused by the kicking and coxae-turning was rather large; (3) When hitting the ball, the contact point was accurate and the speed of the racket head was high, which passed a relatively large initial momentum to the ball; (4) Dimitrov's entire service action was integral and coordinate, smooth and powerful, which was in accordance relatedly with kinematic characteristics.

In recent 30 years, the tennis competition has made an earth-shaking change, especially in the tennis serve, ground stoke and the strategic arrangement. As the start of every score of tennis, serve technique plays a vital role. A strong, consistent, well-placed serve is the first step toward taking the offensive. It can set up to win points, games, and matches with your other stokes ^[1].With fiercer tennis competition today, many elite athletes will use serve techniques as their stunts.

This paper use three-dimensional video analysis method to make corresponding exploration and analysis on

the serve technique of the 2014 China Open men's tennis player Grigor•Dimitrov, so as to reveal the serve technique mode of the world's excellent potential tennis players, which can provide reference for coaches and athletes, strengthen serve training and improve serve techniques as well as enrich theoretical knowledge of the serve techniques.

Keywords: Tennis serves, kinematics analysis, 3D video analysis

1 Subject and methods

1.1 Subject

Bulgarian tennis player, Grigor•Dimitrov,the 2014 China Open men's single's player.

Table 1.Basic information of Grigor•Dimitrov

Name	Height (cm)	Weight (kg)	Birth date	Dominate hand	Highest Ranking
Grigor Dimitrov	188	77	1991.5	Right	22

1.2 Methods

1.2.1 Three-dimensional video analysis: At the game site of the 2014 China open,we used two JVC9800 cameras (made in Japan) shooting frequency:50*fps*, to shoot the entire serve techniques of Grigor•Dimitrov.Camera 1 was right behind the side line of the tennis court, camera 2 right in front of the base line, showing an included angle about 45° between main optical axes of the two cameras(as is shown in Figure 1).Then the exertion videos were analyzed by the 3D Signal TEC V3.2HDC software, frame by frame. Europe Dempster(16 links, 21 joints parameter) was chosen as the mannequin. In the need of study, two test points (the racket's head and the ball) were added when we did the analysis. The available original data was processed smoothly by low-pass digital filtering method and the cutting frequency is 8*Hz*.

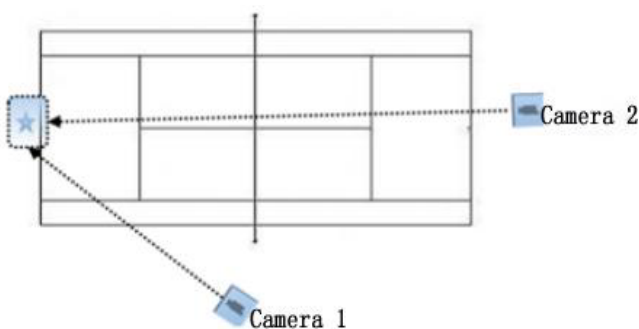


Figure 1: Diagram of camera position

1.2.2 Three-dimensional virtual reality technology method: based on the kinematics data gained by Three-dimensional

video analysis, we made a more accurate diagnosis and analysis on the technical movements of the athlete. The parameters of Dimitrov's serving technology were reproducibly observed 360° virtual rotation in the three-dimensional virtual reality system.

2. Results

2.1 Division of the technique

Grigor Dimitrov used Foot-Back serve technique. According to the need of the research, we divided his serve techniques into the following four stages:

- 1) The tossing ball and lifting racket stage (S_{tl}): the moment when ball and racket were separated (BR_{sep}) to the moment when knee flexion reaches the maximum (KF_{max});
- 2) The backward-swing stage (S_{bs}): the moment when knee flexion reaches the maximum to the moment when racket reaches the lowest position behind (R_{lowest});
- 3) The swing upward at the ball stage (S_{su}): the moment when racket reaches the lowest position behind ("scratching-back" position) to the moment when hitting the ball (H_{ball});
- 4) The following-through stage (S_{ft}): the moment when hitting the ball to the moment when his left foot touch the ground.

2.2 The tossing ball and lifting the racket stage

Tossing ball and lifting the racket stage refers to the moment when ball and racket were separated to the moment when knee flexion reaches the maximum (the height of gravity reaches lowest). During this stage, Dimitrov's holding-hand put the ball near to the throat area of the racket, then the ball and racket moved back while the center of gravity moved to the right foot, and when holding-hand moved near to the left hip, the racket was separated from the ball. His knee bend forward gradually, and the holding-arm straightened and put upward gradually, and his holding hand remain low position. Then making shoulder as the axis, he lifted the racket from low to high and stretched to the right side, eventually.

Table 2.Kinematic parameters of the S_{dl} (°)

moment	Left knee angle	Right knee angle	Shoulder-hip angle	Right elbow angle
BR _{sepd}	171.0	165.3	9.6	167.7
KF _{max}	95.4	123.7	31.5	78.0

The moment when ball and racket were separated, the knee angles of Dimitrov’s left and right were 171.0° and 165.3° respectively, shoulder hip angle was 9.6° , the right elbow angle was 167.7° . The moment when the ball and racket separated, the right shoulder angle gradually increased from 12.5° to 83.8° . When the ball and the racket were separated, the right elbow angle decreased to 125.9° , the height of the ball was 1.91m. Related studies suggest that: the position of the ball when separating from hand should be at the head level^[5]. If the position is too low or too high, the tossing hand would not be fully extended and the ball would be very unstable. Thus the ball could not to the batting position accurately.

The ball to the highest point moment, his knees bent to the maximum, hold the racket get-back. In this process, Dimitrov tossed the ball to the height 3.24m,the left and right knee angle were 95.4° and 123.7° , his right elbow angle decrease to 78.0° . Studies show that: when the center of gravity decreases to the lowest point, the knee angle of excellent tennis player was about 100° ^[6]. Observing through a virtual reproduction of the rotation, combined with the curve of the height of his center of gravity, we can see his knee bent fully, which lower the height of center of gravity. At the maximum knee flexion moment, his shoulder-hip angle is 31.5° , which showed that he pulled shoulder fully, which can prepare well for the next stage.

2.3 The backward-swing stage

Backward-swing stage refers to the moment when knee flexion reaches the maximum to the moment when racket reaches the lowest position behind. During this stage, Dimitrov of lower extremity joint force kicking, front hip rotation axis, chest and shoulder portion to form a larger bow back because of lower limb inertia force kicking, holding clapping effective force form a" scratching-back" posture ,racket head down.

Table 3.Kinematic parameters of the S_{bs} (°)

moment	Knee angle		Squatting knee extension amplitude		Right elbow angle
	Left	right	left	right	
KF _{max}	95.4	123.7	81.9	44.5	78.0
R _{lowest}	177.3	168.2			69.5

As is shown above,Dimitrov’s at the moment when racket reaches the lowest position,his left, right knee angle were 177.3° and 168.2° .The range of his left and right knee angle were respectively 81.9° and 44.5° .The total time of the stage was 0.28 seconds,maximum kicking angular velocity was 230.7° /s, which showed he had a fast speed, and generated large momentum. The minimum angle of right elbow was 69.5° , which means a larger the magnitude of his elbow.

2.4 The swing-upward at the ball stage

Swing-upward at the ball stage refers to the moment when racket reaches the lowest position behind to the moment when hitting the ball. His right wrist forearm form an inward rotation of "whipping" action, which is the key action of serve technique,his shoulder trunk rotation axis on the basis of accelerated forward rotation, elbow flexion should be maintained stance against the trunk, to reduce the moment of inertia of the body, while the balance of the body play a regulatory role.

Table 4.Kinematic parameters of the S_{su}

Toss height (m)	Starting point height (m)	The distance of the highest point to the starting point (m)	Starting point height / body height
3.24	2.82	0.42	1.50

During this stage, the height of centre of gravity increased,when hitting the ball, the ball's height was 2.82m, the velocity of the ball was 2.84m/s.Related research shows that: the gap between the highest point of the ball and the starting point should be around 0.5m, if the peak point of the ball is too low, it will lead an insufficient "scratch back" action; if too high, will enlarge the velocity when hitting the ball^{[5][6]}, which both have a bad influence on the quality of serve technique. The appropriate ratio of spot height and body height is 1.50^[6].The gap between height if peak point

and the starting height is 0.42m, the ratio is nearly 1.50, which showed his contact height was suitable.

Table 5. Maximum velocity of joints in the H_{ball} (m/s)

Right shoulder speed	Right elbow speed	Right wrist speed	Racket head speed
3.45	3.82	6.48	25.83

Changes of shoulder, elbow and knee hip are also an important factor affecting on the serve. When hit the ball, his right shoulder and elbow angle were 161.4°, 178.0°. His legs straight, feet off the ground, the left hip joint angle was 189.5°. The speed of right shoulder, elbow, wrist, racket head was 3.45 m/s, 3.82 m/s, 6.48 m/s, 25.83 m/s, respecting the speed increase gradually, which explained his action in line with the principle of whipping action.

2.5 The follow-through stage

Following-through stage means the moment when hitting the ball to the moment when left foot touch the ground. Follow-through stage is an indispensable part of the action. The equation $Ft = m * v$ shows that the initial speed of the ball is closely related to the total contact time and strength. The longer the contact time, the faster of the ball. After touching the ball, Dimitrov quickly rotated his forearm, at the same time of the pressure, his step forward, left foot steps onto the floor, stretching right foot to maintain balance. Racket is still in the direction of movement of the ball after ball, which is to increase the contact time. When his left foot touches the ground, his left knee angle was 162.4°, the right knee was 165.5°, leaning forward center of gravity in the left hip joint. Racket head forward across the circular path described the batting wrapped solid, and showed an aggressive serve gap.

3 Conclusions

Through 3D virtual reality technology analysis Dimitrov's serve technique, we can make conclusions as follows:

1) For the tossing ball and lifting racket stage, Dimitrov ball from hand height is 1.91m, and peak height is 3.24m, starting point height appropriate for the fast kicking

knee is fully prepared and capable of subsequent processes cohesion appropriate. The maximum time shoulder hip knee flexion angle is 31.5°, the left and right knee angles were 95.4°, 123.7°, appropriate bent knees, lower center of gravity.

2) The backward-swing stage: Dimitrov's left and right knees kicking rate were 81.9° and 44.5°, kicking maximum angular velocity is 230.7° /s, had huge and rapid kicking amplitude, making the virtual reality technology we can see the longer distances of the head movement trajectory.

3) The swing upward at the ball stage: starting point height was 2.82m, speed of the ball was 2.84m/s, his right shoulder, elbow, wrist and racket head speed were increasing in turn, which passed a large initial momentum to the ball.

4) With the following-through stage: Dimitrov had a good control of the center of his gravity, and wrapped the ball well, which made his serve technique more aggressive.

References

1. David Whiteside, Bruce Clifford Elliott. *Coordination and variability in the elite female tennis serve*[J]. Journal of Sports Sciences; 2015, **33** (7): 675-686.
2. Zhilei Wang, Shanfei Zhang. *Kinematic Analysis on the Serve Technique of lower limbs*[J]. Journal of ningbo university of technology. 2009, **21**(3):77-80.
3. Xiping Ren. *Mechanical factor analysis of tennis serve*[J]. Journal of Zhejiang Normal University, 2012, **35**(2):226-230.
4. Qiang Chen. *Affect the level of tennis serve technology for a number of factors*[J]. Journal of competitive sport, 2011, 28:15-16.
5. Botao Yan, Yanxi Wu. *Biomechanical analysis of the tennis serve*[J]. Journal of Sports science. 2000, **20** (4): 80-84.
6. Kai Hu, Yun Wang. *Serve action analysis of the Elite male tennis players*[J]. Journal of Sports research and education: 104-106.