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A Technical Study of Tennis Forehand Topspin Based on Sports Mechanics

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Abstract

INTRODUCTION: Forehand topspin is an important technique in tennis.
OBJECTIVES: This paper studied the forehand topspin through sports mechanics to understand the technical feature differences of tennis players with different levels and to provide a reference for guiding the movement of forehand topspin of tennis players.
METHODS: They were divided into groups A and B. Group A included the first-grade players, and group B included the second-grade players. The forehand topspin movement of the players was filmed by two high-speed cameras. The videos were processed using APAS software. The results showed that the ball speed of group A was 47.89 ± 5.64 m/s, which was significantly higher than that of group B ($p < 0.05$, i.e., significant level). After the back swing, group A had significantly smaller lower limb joint angles than group B ($p < 0.05$) and larger upper limb joint angles and velocities than group B. At the moment of swinging to hit the ball, the right elbow joint angle was smaller and the upper limb joint velocity was faster in group A. At the end of the follow-through, group A had smaller right shoulder and elbow joint angles than group B ($p < 0.05$).
RESULTS: The experimental results show the difference between players with different levels.
CONCLUSION: Higher level players have more adequate lower limb pedaling and stretching and upper limb stretching and higher limb swing speed so that they can hit better topspin shots.

Keywords: tennis, sports mechanics, topspin, shoulder joint, lower limb, ball speed.

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1. Introduction

With the development of technology, the research methods in the field of sports have become more and more diversified. The advanced technical methods can help coaches and athletes to better master the movement techniques [1] and improve the level of competition, and also have a prominent role in the prevention of sports injuries, etc. The commonly used methods include wearable technology [2], intelligent robot [3], computer simulation [4], surface myoelectricity [5], sensors [6], etc., which have been widely used in basketball and football [7]. Wang et al. [8] investigated ligament injuries in 50 javelin throwers and found through biomechanical analysis that the stretching of the athlete's left leg in the final stage of javelin throwing might be an important factor in the injury. Okubo et al. [9] found that the forearm and hand were almost vertical at the time of the shot during basketball shooting, shoulder rotation was conducive to generating optimal velocity, and elbow and wrist movements were conducive to generating ball backspin. Katis et al. [10] studied 30 soccer players and found through kicking experiments that male athletes had higher ball velocity, higher knee and hip linear velocities and higher knee and

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ankle angular velocities, and presented more plantar flexion before kicking. Nirendan et al. [11] studied the effect of resistance training on badminton players. They divided 40 players into two groups, one group for resistance training and the other for control, and found that wrist flexion and extension improved significantly after 12 weeks of resistance training. Yeh et al. [12] studied a tennis racket with a new vibration damping technology (VDT). They used a triaxial accelerometer to record vibration behavior and found that VDT was effective in reducing racket vibration and delaying muscle fatigue in a study of 19 young tennis players. Tennis is a widely popular sport that is is explosive and intense [13]; however, it has a late start in China, and China's competitive level of tennis has a gap with the international level [14]. Topspin is an important serving technique in tennis, which has been widely used in various tactical playing methods. It is not only aggressive, but also has good stability, making it an important scoring tool in the game [15]. Therefore, studying its technical characteristics is of great value to help players master the technical movement of topspin better and faster. At present, the sports mechanics analysis method has been applied in many sports, but the research in tennis is still less. The research on how to improve tennis skills from the perspective of sports mechanics is also insufficient, and most of the studies remain at the theoretical level, i.e., teaching methods [16], lacking the analysis of specific technical movements in practical experiments. Therefore, this study investigated the forehand topspin movements of 12 tennis players and analyzed the technical characteristics of players with different skill levels in order to understand the difference of forehand topspin movements of players with different skill levels. Taking the technical characteristics of high-level players as a reference can help to correct the deficiencies of low-level players in the movement of forehand topspin, and provide support for improving the topspin level of tennis players and achieving better training effects.

2. Research subjects and methods

2.1. Research subjects

Twelve tennis players were used as the study subjects. They were proficient in the forehand topspin action. They used the right hand as the racket holding hand, held the racket in a semi-western manner, had an open stance, had no limb injury in the past six months, understood the procedure of the experiment, and signed the informed consent. They were divided into two groups according to their sport level, and the general information is shown in Table 1.

Table 1. Basic information of athletes

	Group A (n=6)	Group B (n=6)
Height/cm	180.79±4.32	181.34±3.21
Body weight/kg	76.18±3.21	75.89±2.57
Training time/year	12.34±2.04	6.89±1.28
Sports level*	Level 1	Level 2

Note: *: referring to *Athlete Technical Level Standards released* by the China General Administration of Sport.

2.2. Movement for study

Topspin means that the racket swings forward and rubs against the tennis ball from the bottom to the up and then causes the tennis ball to rotate from the back down to the front up. From the mechanical point of view, the process of the racket colliding with the ball when hitting topspin can be divided into two parts: the first is that the ball hits in the opposite direction of the racket, the speed decreases due to the resistance of the racket, the deformation of the racket deepens, and the elastic potential energy increases, and the second is that the racket releases elastic potential energy after reaching some degree of deformation and the tennis ball leaves the racket surface. At the moment of hitting the ball, the tennis ball is subjected to an oblique upward force and a frictional force due to the bottom-up swing, and the combined effect causes the tennis ball to spin upward. The forehand topspin can be divided into three parts, which are:

(1) the backswing: The player is ready to face the incoming ball, keeps eyes on the ball, and leads the racket backward with the racket face down;

(2) swing to hit the ball: The player drives the racket to the hitting point (the upper middle of the ball) and swings and brushes the ball to make it spin forward;

(3) follow-through: After the shot, the player controls the grip with the index finger and swings the racket from the right side to the left side.

2.3. Experimental method

Two high-speed cameras were used to record the athletes, as shown in Figure 1. Camera A was placed on the left side of the athlete, and camera B was placed in front of the left side of the athlete, 11 m away from the test center. The two cameras were synchronized using a synchronization device. The main optical axis angle of cameras A and B was 60°~90°. The recording frequency was 120 frames per second. The PEAK frame was used for calibration. The axis parallel to the bottom line was considered as the Y axis, the front-to-back direction was considered as the X-axis, and the plumb line was regarded as the Z axis. A uniform racket and ball were used in the experiment. After the athletes had fully warmed up and practiced their movements, one athlete was tested first to check whether the experimental equipment was synchronized. The ball was delivered by the same coach with uniform speed and force. Each athlete performed three forehand topspin strokes. The action of a player hitting a topspin ball with her forehand is shown in Figure 2.

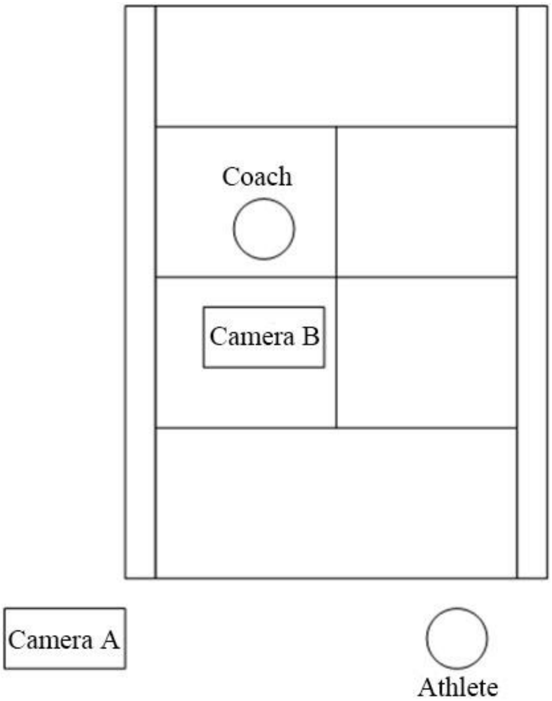

Figure 1. Experimental site layout

Figure 2. A player is hitting a topspin ball with her forehand

At the same time, a researcher, standing about two meters to the rear of the player, used an American Bushnell hand-held speedometer (model 10-1911) to test the player's ball speed. The measured speed was the instant speed when the racket touched the ball.

2.4. Statistical analysis

The large video taken was digitized using APAS software developed by Ariel company [17]. The collected data were processed in Excel software, and the data were recorded in the form of $\bar{x} \pm s$. Then, the data were statistically analyzed by SPSS 17.0 software. The significance level was 0.05.

3. Results

A comparison of the ball speed between the two groups of players is shown in Figure 3.

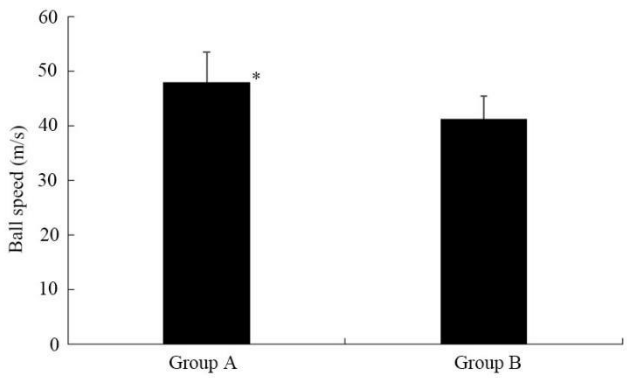

Figure 3. Comparison of ball speed between different levels of players

It was seen from Figure 3 that there was a significant difference in the tennis ball speed between the two groups ($p < 0.05$), the ball speed of group A was 47.89 ± 5.64 m/s, and the ball speed of group B was 41.26 ± 4.21 m/s. The results showed that players with higher sport levels had significantly higher ball speed, which meant that their forehand topspin had a higher level and better effect in competition.

The comparison of the angles of the left and right knee joints and the hip joints of the two groups of athletes after the backswing is shown in Table 2.

Table 2. Comparison of angles of the left and right knee joints and hip joints after backward swing (unit: °)

	Group A (n=6)	Group B (n=6)
Left knee	128.68±2.21*	140.37±1.29
Right knee	114.32±1.37	112.68±3.15
Left hip	145.27±3.12*	152.73±2.28
Right hip	134.59±3.41*	152.64±1.29

*: p<0.05 compared to group B

It was seen from Table 2 that there was a difference in the lower limb joint angles between the two groups of athletes after the backswing. First, the right knee angle of both groups was smaller than the left knee angle, and the left knee angle of group A was 128.68 ± 2.21°, significantly smaller than that of group B ($p < 0.05$). Second, the right knee angle of group B was 112.68 ± 3.15°, slightly smaller than that of group A (114.32 ± 1.37°), but there was no significant difference. Third, the hip joint angles of group A were significantly smaller than group B ($p < 0.05$), and the left and right hip angles of group A were 145.27 ± 3.12° and 134.59 ± 3.41°, respectively.

After the backswing, the angles and speeds of the upper limb joints of the two groups are shown in Table 3.

Table 3. Comparison of upper limb joint angles and velocities after backward swing

		Group A (n=6)	Group B (n=6)
Angle (°)	Right shoulder	42.39±4.32*	38.64±3.13
	Right elbow	117.64±3.64	118.46±3.36
Speed (m/s)	Right shoulder	0.87±0.01*	0.54±0.02
	Right elbow	1.42±0.03*	1.02±0.03
	Right wrist	2.67±0.02*	1.57±0.01

*: p < 0.05 compared to group B

It was seen from Table 3 that the shoulder joint angle of group B was 38.64 ± 3.13°, significantly smaller than group A, but there was no significant difference in the elbow joint angle; the joint velocity of the shoulder was the largest, followed by the elbow and wrist; the upper limb joint velocities of group A were significantly greater than that of group B ($p < 0.05$). For example, the right wrist joint velocity of group A was 2.67 ± 0.02 m/s, while that of group B was only 1.57 ± 0.01 m/s.

The comparison of the angles and speeds of the upper limb joints between the two groups when the racket touched the ball after the back swing is shown in Table 4.

Table 4. Comparison of the angles and speeds of the upper limbs when the racket touches the ball

		Group A (n=6)	Group B (n=6)
Angle (°)	Right shoulder	60.36±4.56	61.38±3.77
	Right elbow	124.56±5.46*	141.26±4.92
Speed (m/s)	Right shoulder	1.45±0.05*	1.21±0.02
	Right elbow	4.54±0.04*	3.34±0.03
	Right wrist	8.78±0.06*	6.15±0.01

*: p < 0.05 compared to group B

It was seen from Table 4 that the right elbow joint of group A was 124.56 ± 5.46° at the moment of ball contact, which was significantly smaller than group B ($p < 0.05$): the right shoulder joint velocity of group A was 1.45 ± 0.05 m/s, the smallest, followed by the right elbow joint (4.54 ± 0.04 m/s) and the right wrist joint (8.78 ± 0.06 m/s). The joint velocities of group A were all higher than those of group B ($p < 0.05$).

The right shoulder and elbow joint angles of the two groups at the end of the follow-through are shown in Figure 4.

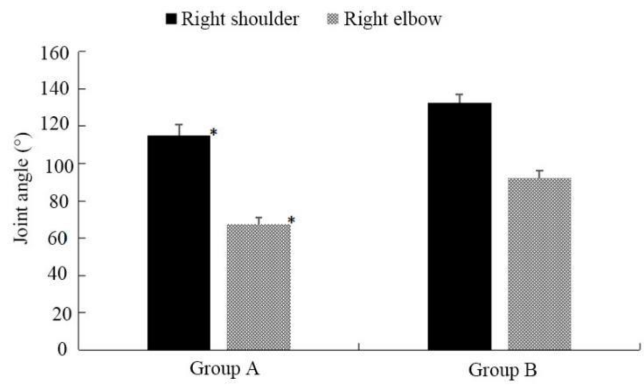

Figure 4. Comparison of right shoulder and elbow joint angles between the two groups at the end of the follow-through

*: p < 0.05 compared to group B

It was seen from Figure 3 that the right shoulder joint angle of group A was 115.26 ± 5.64°, while that of group B was 132.69 ± 4.26° at the end of follow-through, i.e., group A was significantly smaller than group B ($p < 0.05$), and the right elbow joint angle of group A and group B was 67.69 ± 3.21° and 92.36 ± 3.78°, i.e., group A was smaller ($p < 0.05$). The results demonstrated that high level athletes had smaller joint angles at this stage.

4. Discussion

With the development of society, tennis has entered people's lives and become a daily sport, and at the same time, it has also occupied an important position in competitive sports. Serving is an important and difficult issue in tennis [18]. For tennis players, they not only need good physical quality, but also need to play at a high technical level. The study of topspin, an important scoring technique, is of great realistic importance.

In the back swing phase, the human body was in the dynamic squatting process, and the bending of the knee and hip joints had a great influence on the effect of pedaling and stretching. The results showed that the athletes of higher level, i.e., group A, had larger left knee and hip angles than right knee and hip angles, indicating that the center of gravity of the body was to the right, which was conducive to better pedaling and stretching of the lower limbs and provided greater ground reaction force. The difference between the left and right hip angles in group B was not large, which meant that the athletes did not tilt their bodies to the right, the knee flexion amplitude was small, and the pedaling and stretching force of the legs was also small. In the perspective of lower limb angles, group A had larger shoulder joint angles, a wider range of motion, and better trunk extension, and full extension of shoulder and elbow muscles, which was more conducive to providing higher ball speed. In terms of lower limb velocities, the lower limbs exhibited a mechanical characteristic of large joints driving small joints, but the joint angles of group A were higher, indicating that the movement of group A was smoother.

In the stage of swing to hit the ball, the player stomped the ground, turned the body and quickly transferred the ground reaction force from the racket to the tennis ball, i.e., converting the elastic potential energy into kinetic energy, and the power generation sequence was shoulder-elbow-wrist-head of the racket. The results showed that the shoulder and elbow joint angles of group A were smaller, and $p < 0.05$ in comparing the elbow joint angle between two groups. At this stage, too large shoulder and elbow joint angles are not conducive to improving the limb acceleration, and a smaller radius of rotation is more conducive to increasing the speed of human joints. It was seen from Table 4 that the joint velocity of group A was higher, i.e., high-level athletes will accelerate the swing of their limbs while stomping and turning, thus achieving higher ball speeds. In the back swing phase, the players in group A used the right shoulder joint to accelerate the movement and then drove the right elbow and right wrist, and the momentum was superimposed sequentially according to the whip law, so the ball had a high speed. The players in group B did not have enough pedaling and stretching in the previous stage and had a smaller body rotation amplitude, so the momentum was not transferred well, which led to a lower ball speed.

In the phase of follow-through action, the player used the inertia of the racket to continue to push forward through of the stroke and finishes the follow-through on the opposite side of the body with a quick rotation of the body. In this phase the player must focus on body balance and stability to make the whole movement more coordinated. In addition, shoulder and elbow injuries are common in tennis [19]. The results showed that the shoulder and elbow joint angles were smaller in elite players during the follow-through, and compared with group B, $p < 0.05$. In the follow-through phase, the high-level players prolonged the action time of the racket on the ball through the rapid forward thrust and internal rotation of the arm, thus achieving better ball control and less rotational pressure on the shoulder and elbow, which was conducive to the prevention of sports injuries. The shoulder and elbow joints of group B could be subjected to excessive rotation and stretching, and the body's center of gravity was also destroyed, so the effect of follow-through was poor, which was not conducive to completing a smooth topspin action.

Based on the differences in the technical characteristics of the two groups of players at different stages, the following aspects can be taken into account when correcting the forehand topspin movements and improving the technical level of the low-level players.

In the back swing phase, players should lower the body's center of gravity, maintain stability and balance, and make sure the lower limbs are fully stretched and the trunk is fully extended. In daily training, the coordination and flexibility of the athletes can be strengthened to improve the consistency of the stroke.

In the phase of swinging to hit the ball, players should be active and proactive in hitting the ball forward, following the laws of whip action. In their daily training, they can increase their power training to achieve higher ball speeds.

In the follow-through phase, players should pay attention to keeping the center of gravity stable and try to avoid excessive rotation of the upper limb joints to reduce sports injuries. In daily training, it is also necessary to strengthen the training of limb stability and coordination.

5. Conclusion

This study analyzed the forehand topspin of athletes of different levels using high-speed cameras. The experiment found that the higher level athletes, i.e., group A, had significantly greater ball speed than group B ($p < 0.05$). During the back swing, the center of gravity was more to the right, the right shoulder joint angle was greater, and the joint velocities of the shoulder, elbow and wrist were significantly greater. When the racket touched the ball, the elbow joint angle was smaller and the upper limb joint velocity was greater in group A. At the end of the follow-through, the shoulder and elbow joint angles of group A were significantly smaller than those of group B. The experimental results showed the difference in the action of players at different levels, which provides some contributions on how to better improve the technical level of topspin and reduce sports injuries.

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