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Article

Biomechanical model of forehand stroke of tennis players

Shubin Wen[1], **Qiwen Wang**[2,*]

[1] Teaching Department of Public Courses, School of Marxism, Hubei Science and Technology College, Wuhan 430000, Hubei, China
[2] Physical Education, Huanggang Normal University, Huanggang 438000, Hubei, China
*** Corresponding author:** Qiwen Wang, 15377131868@163.com

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Abstract: In recent years, tennis has become more and more popular. There is more and more research on tennis. The forehand stroke is the most important technique in many tennis techniques, and it is the main scoring means that all kinds of playing methods must have. With the continuous development of artificial intelligence technology, intelligent technical means are analyzed to improve tennis skills. In this paper, the tennis player's forehand attack hitting image is analyzed in three dimensions. Through the three-dimensional video analysis method, the specific data information of each part of the body when hitting the ball is obtained, and a biomechanical model is constructed. The experimental results show that the shoulder-hip angle of high-level tennis players is 20.44°, while that of ordinary tennis players is 15.79°. From the statistical point of view, the significance test of the shoulder-hip angle between the two groups of players is $P = 0.029$, less than 0.05, with a statistical difference, indicating that high-level tennis players have a large shoulder-hip angle at the end of the backswing. A large shoulder-hip angle means that the body muscle tissues are more fully flexed and extended, and the stored elastic potential energy is greater. The results of the experiment can help people train tennis forehand skills more intelligently and pertinently.

Keywords: forehand stroke; biomechanical model; tennis player; human hand link

1. Introduction

Tennis, as a new project requiring high technology, requires not only excellent physical fitness and high responsiveness, but also perfect integration of strength and technology. The forehand stroke is the most basic technique of tennis players, and also one of the commonly used techniques in tennis competitions. It requires the player to hit the tennis ball from the opponent on the same side of the clapping hand. Its movement structure is divided into several parts: preparation, lead racket, forward swing, hitting and free swing. When hitting the ball, the above actions must be played coherently. Many studies have found that the biomechanical transformation of players in forehand attack has a great impact on the effectiveness and accuracy of forehand attack, and is also very important to the injury probability of players. Therefore, this paper carried out scientific research on the biomechanics of tennis forehand touch.

It has been a research field for many scholars to improve the competition level of athletes by analyzing their movements. At present, research on the forehand stroke of athletes mainly includes the following: Yevtyfiieva used the best Ukrainian tennis players as an example to study the relationship between biomechanical indicators of hitting technique and personal tennis playing style, and used the chi-square criterion to evaluate the correspondence between the empirical distribution of the data and the theoretical normal distribution. Descriptive statistics were performed for each biomechanical parameter measured, and univariate analysis of variance (ANOVA) was used to compare the mean values of biomechanical parameters between groups of tennis players with different playing styles [1]. Chalakov used the Sigma method to optimize the forehand stroke technique of 12-year-old tennis players. In order to achieve the research goal, three test results were analyzed through video recording to obtain information about the technical mastery level and training process efficiency of 12-year-old tennis players. The results showed that the forehand performance evaluation model can provide reliable quantitative feedback for the management and optimization of the training process of young tennis players [2]. Rigozzi Chantelle measured and analyzed the peak normalized muscle activity of the extensor carpi radialis and flexor carpi radialis corresponding to each forehand stroke and delivery speed. The results showed that coaches can consider recommending players to use topspin forehand strokes to potentially reduce the risk of lateral elbow tendinitis [3]. Oliveira et al. explored the effect of introducing variable conditions (such as different courts and balls) into tennis training on the accuracy of forehand straight shots at the net and found that variable training could maintain shot accuracy better than stable training after a period of no practice [4].

For the above research, other scholars have different ideas. Rusdiana analyzed the forehand hitting ability of tennis with three-dimensional kinematics analysis method. The results showed that the maximum external and internal rotations of the shoulder in a series of motions starting from the rotation of the hip joint contribute greatly to the greater ball momentum generated by the racket speed. At the same time, the speed inside the shoulder is the key to producing the maximum speed of the racket. It is suggested to further study and compare the performance of forehand and backhand strokes of elite groups with a three-dimensional analysis method [5]. The Brito study used an inertial measurement system to conduct a detailed analysis of the serving action of 18 male competitive tennis players, evaluating the key biomechanical events and kinematic indicators of each stage of serving, and comparing the differences in joint angles (hip adduction, knee flexion, and thoracic spine tilt) and angular velocity (maximum angular velocity of the wrist, thoracic spine, and hip joints) between the high-serving speed group and the low-serving speed group, revealing the biomechanical factors that affect serving speed [6]. Wibowo studied the influence of partial and overall learning methods on the performance of male forehand tennis in the fifth semester of the University of Surakarta. Through the partial learning method and the whole learning method, this paper conducted an experimental study on the performance of forehand tennis. The results showed that sports have a good effect on improving the forehand hitting ability of students at the University of Surakarta [7].

Tennis is a highly technical sports event. Correct scientific and technical guidance can help people learn tennis efficiently and with high quality. Forehand stroke is a basic technique commonly used in tennis. More than 70% of strokes on the court are completed by forehand stroke. A forehand stroke is generally divided into four parts: preparation, backswing, swing and follow-up. From the perspective of biomechanics, this paper uses the basic laws of biomechanics and the basic principles of following up the human coordination chain to analyze the forehand attack and touch in the hitting link, in order to effectively understand the main causes of tennis players' wrong operation and scientific and specific guidance is clearly put forward.

2. Construction of biomechanical model of forehand stroke of tennis players

Tennis is beautiful and vigorous, and it is very popular all over the world. The precondition of tennis hitting is proper and scientific body posture and hitting technique. According to the principle of biomechanics, correct technical posture can prevent knee joint sports injury and improve the actual effect of tennis hitting [8].

The principle of biological structure mechanics in tennis mainly includes balance, inertia force, interaction force and reaction force, momentum theorem, elasticity, harmonious chain, etc. In a tennis forehand stroke, the five key parts of the leg, hip, upper body, head and shoulder and racket surface cooperate with each other to form an important factor when touching the ball. If people can master these skills well, they can hit a better ball.

Legs: The legs are the starting point of the force, providing a stable support and power source for hitting the ball. By pushing the ground with the legs, the player can transfer the ground reaction force to the upper body, thereby generating the power required for hitting the ball. Good leg movements can also help players maintain balance, especially when hitting the ball while moving. The stability and explosiveness of the legs directly affect the accuracy and power of the hit.

Hip: The hips are the key hub connecting the lower limbs and upper limbs. Their rotation transfers the power of the legs to the upper body. The rapid rotation of the hips increases the torque and speed of the shot, while helping to adjust the body posture to adapt to different shot positions and angles. The flexibility of the hips directly affects the fluency and power efficiency of the shot.

Upper Body: The upper body transfers the power of the hips to the shoulders and arms through the rotation and stability of the torso. The coordinated movement of the torso not only increases the power of the shot, but also helps control the direction and stability of the shot. The tilt angle and rotation speed of the upper body will also affect the arc and depth of the shot.

Head and shoulder: The stability of the head and shoulders is the key to ensuring the accuracy of the shot. Keeping the head stable can help players focus on the ball better and improve the accuracy of the shot. The rotation and relaxation of the shoulders directly affect the swing of the arm. The rapid rotation of the shoulders can increase the speed of the racket head, thereby increasing the power of the shot. At the same time, the coordinated movement of the shoulders can also reduce unnecessary muscle tension and reduce the risk of injury.

Racket surface: The racket face is the part that directly contacts the ball. Its angle, position and speed determine the direction, rotation and power of the ball. Controlling the racket face requires the fine coordination of the arms, wrists and fingers, especially at the moment of hitting the ball. The stability of the racket face directly affects the flight trajectory of the ball. By adjusting the angle of the racket face, players can hit the ball with different effects such as topspin, flat hit or slice.

Both players with a high technical level and beginners in tennis should learn various basic skills. Forehand stroke plays the most important role in all basic tennis skills. As a basic means of attack and defense, the forehand stroke is also the key to winning the attack and scoring in the game. With the vigorous development of contemporary competitive tennis, the technical demand for forehand strokes is also increasing [9]. However, there are two types of forehand strokes: topspin and flat. From the technical characteristics of topspin ball, the technology has high forward force and good jumping ability. Competition dominance can be effectively mastered through this technology. The square ball has the advantages of great strength, fast speed and a high landing point. It is an effective means of scoring in the game. To some extent, the understanding and use of forehand strokes can reflect the players' tennis technical strength level, which plays an important role in the game. In order to make forehand reach a better level, in addition to long-term training, people can also obtain the data information of human body links in tennis through a 3D high-speed camera. Compared with excellent players, the forehand stroke of the players can be improved in a targeted way [10].

Figure 1 shows the placement position of the 3D high-speed camera. When the high-speed camera is used for long-distance shooting on the tennis court, the main optical axis of the two surveillance cameras is about a right angle. The 3-DSignal Tec analysis system is selected for the whole process of analysis. According to scientific research, when processing the racket, the intelligent digital filtering method is used to smooth the original records obtained at a distance to get the dynamic data information related to the players [11].

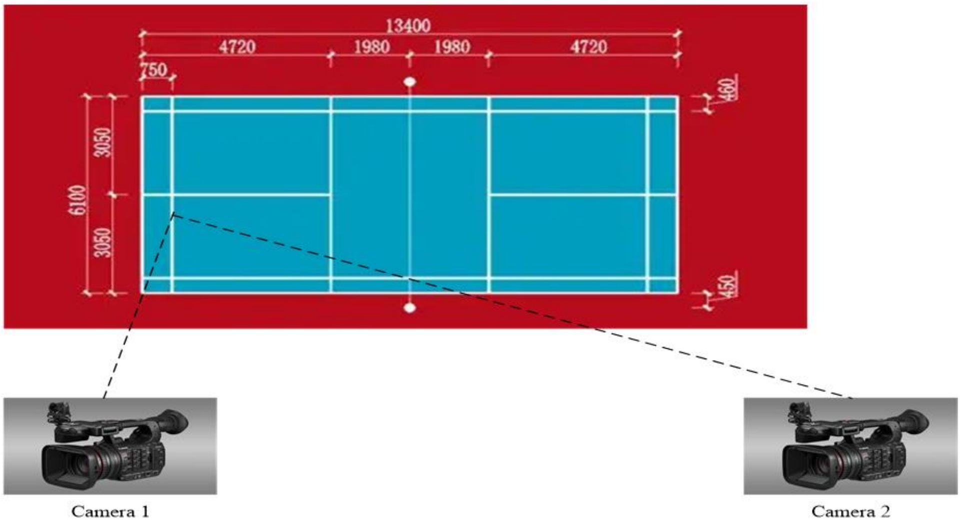

Figure 1. Placement position of 3D high-speed camera.

Before video analysis, it is necessary to carry out format conversion and forward cutting of video to analyze the forehand stroke motion dynamics of the system by the data. When selecting the most ideal video content, the starting point and ending point of the action shot of the object are expanded to 8 frames respectively. The video file format must also be processed before the use of software tools is described in the video analysis audit. The analysis of points and points is applied. When the distance between the points is 1 point and the angular frequency is 8 Hz, the required information can be obtained.

The EMG signal includes two methods: collecting positive electrode and surface electrodes. The positive electrode must be inserted into the muscle tissues of the subjects, which may cause certain damage to the players, and it is not suitable for sports [12]. The surface electrode only needs to be pasted on the skin surface of the subject, which may not cause harm to the subject and affect the movement of the subject. Therefore, surface electromyography is usually used to collect data signals.

There is a certain degree of correlation between muscle movement and surface electromyography, which can reflect the muscle activity of the nervous system to a certain extent. It has key practical significance in the diagnosis of nervous system muscle diseases in clinical medicine, muscle activity in the ergonomics industry, ergonomic analysis, muscle function evaluation in the rehabilitation treatment technology industry, scientific and reasonable identification of fatigue, rational analysis of competitive ability, types of muscle tissue, anaerobic exercise and non-invasive prediction analysis [13].

Surface EMG (electromyography) signals mainly include time domain, frequency domain and wavelet statistical analysis methods. Time domain analysis index value includes integral EMG and amplitude root mean square value. The index value of frequency domain analysis includes the number of centers and average power. Wavelet analysis combines the characteristics of time domain analysis and frequency domain analysis. The main parameters are also of great use value in studying the degree of regulation of the body, the type of retraction and the characteristics of the compressive strength of muscles and distinguishing the value of muscle fatigue and damage. **Figure 2** is the electromechanical test flow chart.

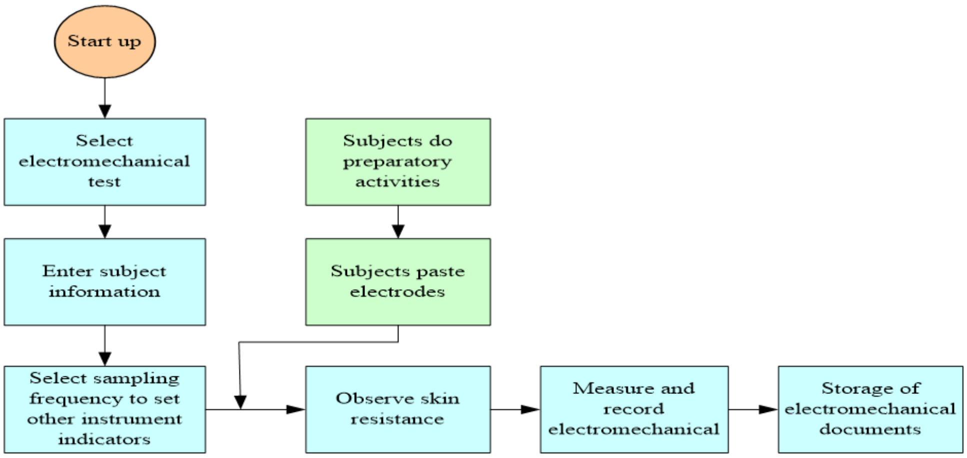

Figure 2. Electromechanical test process.

The difference between contemporary tennis and traditional tennis is that athletes are required to be more technically advanced. Most excellent tennis players like to break through the bottom line. In daily practice, there are more combinations of training speed and strength. In contemporary international tennis competitions, if the forehand stroke of the players is not well mastered, it is difficult to achieve an ideal ranking. From the collected video courseware, the position used by excellent tennis players for forehand attack and hitting technology is the most popular semi-open position at present, which is not special. The semi-open posture is easier to run than the closed posture. The stroke is hidden and can be hit from every direction. The application of the forehand stroke method of sideways can also affect the prediction analysis of the opponent [14]. In addition, the semi-open position can quickly return to the normal position after hitting. Therefore, many world-famous tennis players adopt the semi-open posture. However, the competition is not static. In response to different types of shots, the position should be changed accordingly.

The forehand attack volley is mainly divided into four stages, namely, confrontation posture, pull in, swing and follow swing. This paper divides it into four stages: starting, leading the racket, hitting and swinging. In the starting stage, the distance between the feet is 1.5 times the width of the shoulder, and the knee joint bends significantly; the upper body is slightly extended forward, and the racket is held in front of the body; the racket is lifted, and the wrist is bent forward; the center of gravity of the body falls to the palm of the forefoot. In the lead racket stage, the center of gravity is transferred to the right leg; the upper body is turned to the right so that the ball coming from the other side is facing the body; the left racket swings to the right rear; the left-hand movement becomes smaller, and it is better not to exceed the body. After pulling the racket, the racket is left from the right hand, and then the face of the racket is opened. During this time, the eyes should always be on the ball. In the hitting phase, when the left leg moves forward significantly, the arm bends forward and swings forward from behind to welcome the ball until the racket touches the ball. At this time, the hand should be placed under the arm, and the wrist should be fixed. Follow swing stage is the swing action after the racket hits the ball, which is actually the follow swing after the racket contacts the ball [15]. **Figure 3** shows the phase diagram of the forehand stroke of players.

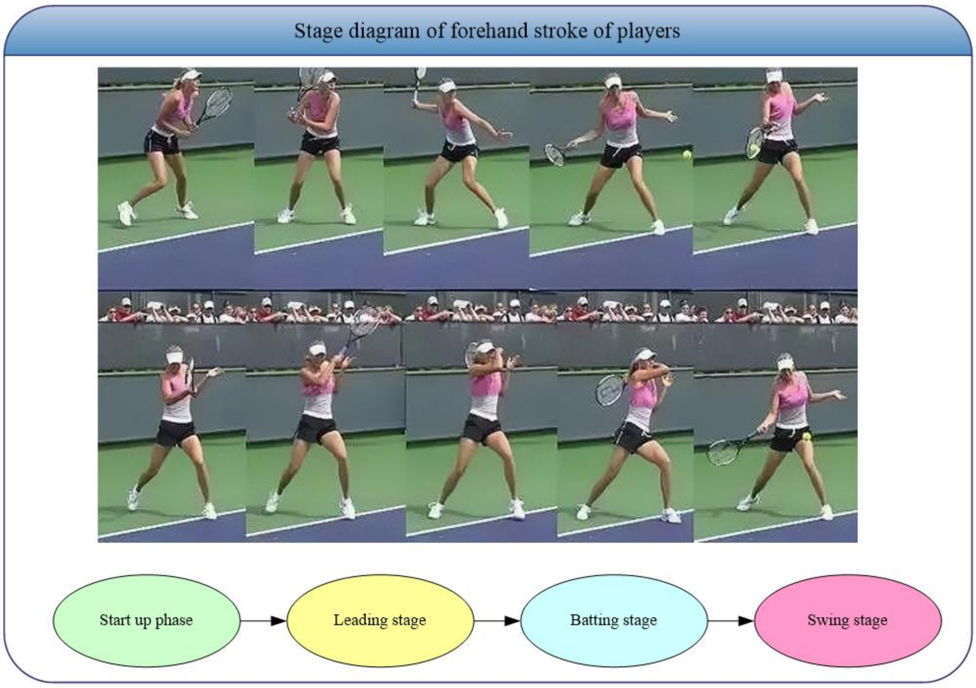

Figure 3. Stage diagram of forehand stroke of players.

The purpose of the backswing is to reserve potential energy for the ball to obtain power and to establish favorable positions and conditions for the next stroke. In this process, the tennis player rotates the shoulder to the left after the opponent returns the ball to the backhand position and aligns the position with the position of the opponent's return. At the same time, the rotation of the shoulder can push the knee joint and arm joint to pull the racket to the back of the body. In double backhand, the shoulders should rotate backward, which is different from the general single-hand big rotation movement. The focus of the force is to rotate the shoulders. The racket returns to a simple and relatively small place, and the shoulders should keep rotating, while also keeping the body twisting. If the ball can be seen from behind the right shoulder, the arm should automatically rotate backward with the rotation system, and both arms should be as close to the body as possible. When the shooting action is completed, the head height of the racket should be slightly lower than the hand, and the right bottom of the handle should be kept facing the ball.

The stage from the beginning to the end of the swing is called the swing-hitting stage. During the transition from the backswing to the front swing, the ball should be hit forward. The body is violently swung by centrifugal force, while the hips and waist are rapidly rotated to swing the racket. In fact, there should be three elements in the swing hitting stage: the part from the front swing of the racket to the contact with the ball, the hitting part and the subsequent swing part. In this paper, the three parts are considered as a whole, rather than separate. Tennis players change their posture and use the kinetic energy accumulated earlier to complete the swing. Tennis players must use the racket to convert the kinetic energy accumulated in the previous cycle into tennis when hitting. In order to minimize energy loss, this action must be rapid. Sports biomechanics shows that this process is to convert elastic potential energy into kinetic energy pulse. Athletes must coordinate their body joints and pay close attention to how they are applied. It is also necessary to control the angle between the racket surface and the ground. High-level tennis players also use this method to improve the speed of the racket during this period, so as to hit the ball with greater strength.

The completion of the swing is not equal to the completion of the hitting process. Because of the inertial force of the human body, the racket cannot stop moving immediately after touching the tennis ball. The latter action is also crucial to the completion of the forehand stroke, which is called the stage of swing back. The high-level tennis player guides the racket by combining the inertia when hitting the ball. The racket continues to move forward for a certain distance along the tennis track, and then suddenly leaves the tennis for retraction. This action may seem simple, but it may be difficult to perform it naturally and correctly. In order to complete this process, tennis players' body joints must be active, and their hip joints and shoulder rotation must be coordinated. The energy consumption of racket braking can be reduced through natural and full swing.

This paper presented a biomechanical model of the forehand stroke of tennis players. The formulas involved mainly include:

$$\mathrm{d}(\mathrm{m},\mathrm{n}) = \sum\nolimits_{\mathrm{w}} [\mathrm{I}(\mathrm{m_i},\mathrm{n_i}) - \mathrm{I}(\mathrm{m}+\nabla\mathrm{m},\mathrm{n_i}+\nabla\mathrm{n})]^2 \tag{1}$$

$(\nabla m, \nabla n)$ is the probability density function of tennis forehand stroke trajectory distribution, and (m_i, n_i) is the coordinate point of tennis forehand stroke trajectory linear capture.

$$\dot{\mathrm{x}} = \mathrm{V}\cos\theta\cos\varphi, \dot{\mathrm{y}} = \mathrm{V}\sin\theta \tag{2}$$

$$\dot{\mathrm{z}} = -\mathrm{V}\cos\theta\sin\varphi\mathrm{v}, \dot{\vartheta} = \omega_{\mathrm{y}}\sin\gamma + \omega_{\mathrm{z}}\cos\gamma \tag{3}$$

$\dot{x}, \dot{y}, \dot{z}, \dot{\vartheta}$ are the information fusion capture equation of the image, and x, y, z are the distribution characteristics of the linear local information feature points of the tennis forehand hitting error trajectory.

$$\sigma(U; D_X) = \sum_{a>b} |d_{ab}(U) - d_X(m_a - m_b)|^2 \tag{4}$$

$\sigma(U; D_X)$ is the gray pixel set of the linear work path of the tennis forehand stroke.

$$L(a, b_m) = \frac{\log\left(\frac{|V||V_m \cap V_n|}{|V_m||V_n|}\right)}{f(g_i)} \tag{5}$$

$L(a, b_m)$ is the gray information component of the local image of the tennis forehand hitting error.

$$F = \tilde{p}(x, y) = p(x, y)\left(\frac{v(x)}{v(y)}\right)^{1/2} \tag{6}$$

F is the key action feature point positioning output of tennis forehand stroke trajectory.

Among them:

$$q(m, n) = \frac{k(m, n)}{v(m)}, v(m) = \sum_n k(m, n) \tag{7}$$

3. Biomechanical model experiment of forehand stroke of tennis players

Next, through the use of a biomechanical model, the forehand stroke of tennis players is compared and analyzed. Before the experiment, the technical actions and experimental steps of the test are shown. In order to ensure the smooth implementation of the experiment, the place where the experiment is conducted is separated from other areas by a baffle, and irrelevant staff cannot appear in the experiment site. After the completion of the normal warm-up exercise, the experimenter shall be marked and played for 10 min until the contestants become stable. When the test is announced, the downward hit of the spinning ball is tested first, and the upward hit of the spinning ball is tested again. During the two action tests, the contestants have a certain time to rest. On the premise of the detailed structure of the forehand stroke, the experimental staff needs to check whether the experimental data information is detailed when each stroke is successful. If the player hits the ball successfully, but the experimental data collection is incomplete, each technical action should be tested again until detailed data information is obtained. **Figure 4** shows the forehand stroke test process of tennis players.

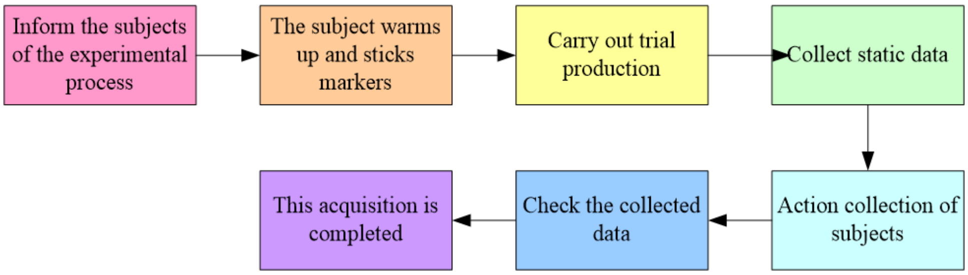

Figure 4. Forehand stroke action test process.

Figure 5 shows the average peak speed of each link in the high-level group and the ordinary group. It can be seen that the horizontal velocities of the right hip, right shoulder, right elbow, right wrist and swing of the subjects in the high-level group are 1.62 m/s, 2.58 m/s, 6.19 m/s, 10.23 m/s and 21.34 m/s respectively. Compared with the ordinary group, the velocity of each joint is significantly faster, and the difference is very significant, indicating that the horizontal velocity of the tennis players' shoulder joint, elbow joint and wrist joint in the high-level group is faster than that in the ordinary group. Then tennis training at ordinary times can also be targeted to tennis players for special speed training.

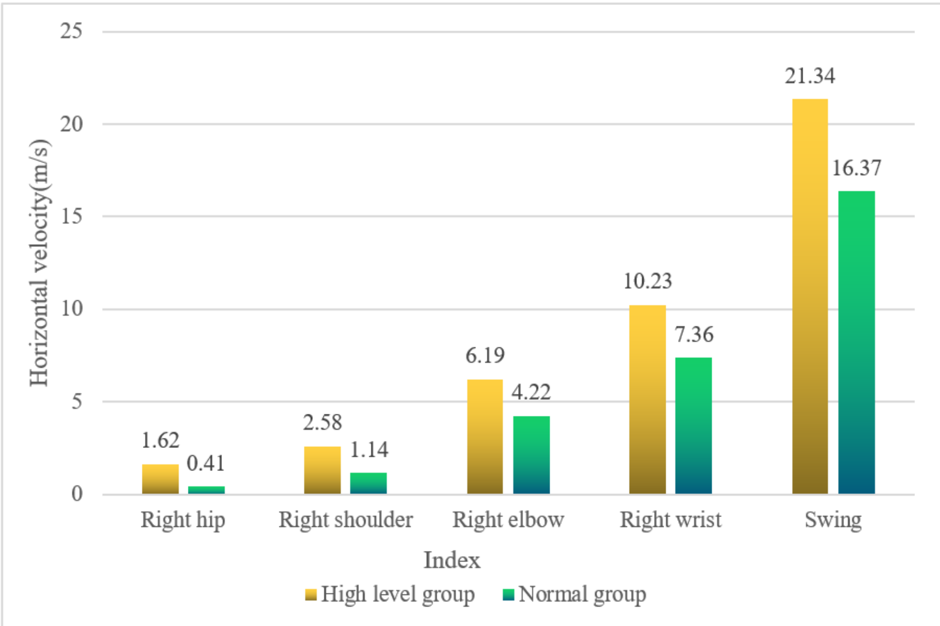

Figure 5. Peak speed of each link in the high-level group and ordinary group.

A tennis forehand stroke needs to catch and store energy by bending the knees and lowering the center of gravity. Tennis players' lower limb joint activities are too small to stretch the muscles properly, which may also affect the stability of the shot. **Table 1** shows the significance test results of the kinematic change amplitude of each link in the preparation stage, and **Figure 6** shows the kinematic change amplitude of each link in the preparation stage. The unit of center of gravity displacement is cm. It can be seen that the right hip joint of the normal group and the high-level group is stretching during this process. The stretching range of the ordinary group is 10.24, and that of the high-level group is 4.55, with a significance test of P = 0.003, indicating that there is a significant difference between the two groups in the stretching range of the right hip joint. There is no significant difference between the high-level group and the ordinary group in the change amplitude of the right knee angle (P = 0.794), but there is a significant difference in the right ankle angle flexion amplitude (P = 0.001). The dorsiflexion amplitude of the right ankle angle in the high-level group is significantly greater than that in the normal group. In addition, in terms of the displacement changes of the body center of gravity in the front and back directions, left and right directions and vertical directions, the significance test P values in the left and right directions and vertical directions are 0.698 and 0.425, respectively, which are greater than 0.05, so there is no significant difference between the high-level group and the ordinary group in the left and right displacement and vertical displacement. However, in the front and back direction of the high-level group, the displacement moving towards the hitting direction was 3.23 cm, which was less than 10.36 cm in the ordinary group. The significance test is p = 0.038, less than 0.05, indicating that there is a significant difference between the high-level group and the general group in the front and back direction displacement. The significant test of the change range of the shoulder and hip angle between the high-level group and the general group is P = 0.253, and there is no significant difference in the change range.

Table 1. Significance test of kinematic change amplitude of each link in the preparation stage.

Variable	***P***
Right hip angle	0.003
Right knee angle	0.794
Right ankle angle	0.001
Shoulder hip angle	0.253
Fore and aft displacement	0.038
Left and right displacement	0.698
Vertical displacement	0.425

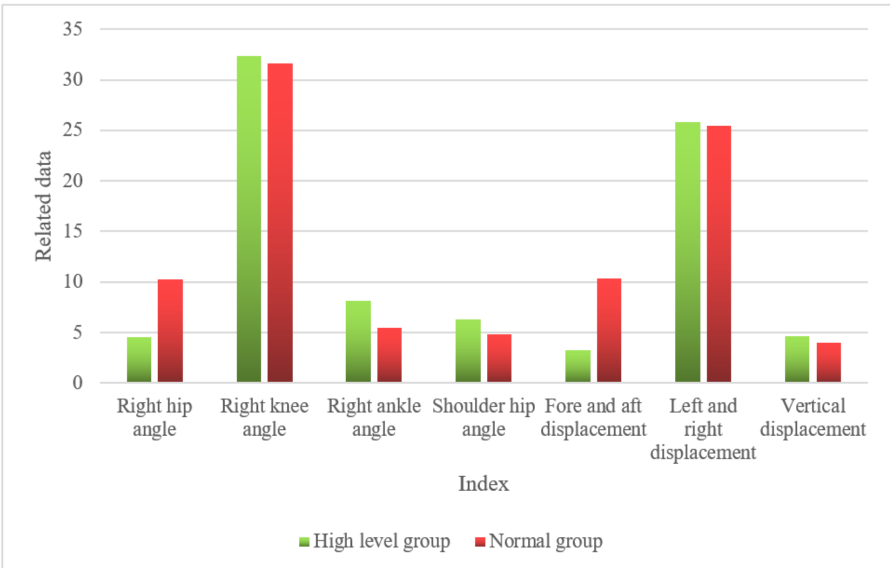

Figure 6. Kinematic change range of each link in the preparation stage.

Tennis players need to stretch the abdominal cavity, back, shoulder and forearm muscles before forehand hitting, so as to improve the path of hitting and receiving. **Table 2** shows the results of the significance test of the joint angles at the end of the rear swing racket, and **Figure 7** shows the joint angles at the end of the rear swing racket. It can be seen that at the end of the lead time, the significance test values *P* of the knee angle, ankle angle, right shoulder angle and right elbow angle of the high-level group and the ordinary group are 0.796, 0.375, 0.683 and 0.784 respectively, which are greater than 0.05, and there is no significant difference in statistics. The shoulder-hip angle of tennis players in the high-level group is 20.44°, while that of the ordinary group is 15.79°. From a statistical point of view, the significance test of the shoulder-hip angle between the two groups of players is $P = 0.029$, less than 0.05, with a statistical difference.

Table 2. Significance test of each joint angle at the end of the backswing racket.

Variable	*P*
Knee angle	0.796
Ankle angle	0.375
Shoulder hip angle	0.029
Right shoulder	0.683
Right elbow angle	0.784

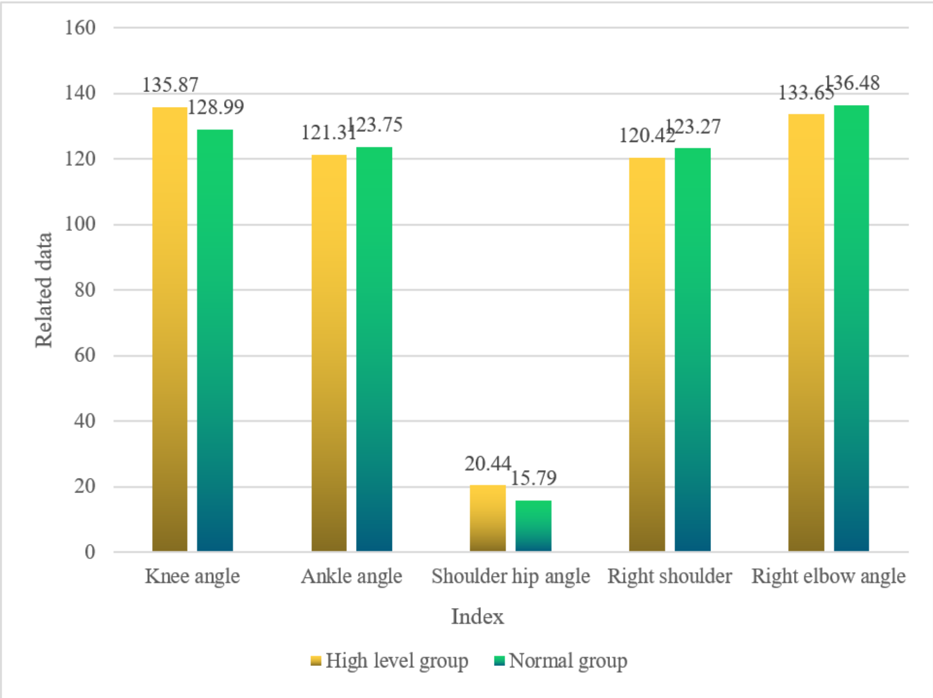

Figure 7. Joint angles at the end of the backswing lead.

The main dynamic parameters of human joints can reflect the characteristics of tennis players' ball control technology. As shown in **Table 3**, the results of the significance test of each joint angle at the time of hitting. **Figure 8** shows the joint angles at the time of hitting. It can be seen that in terms of knee angle, hip angle and ankle angle, the significance test values *P* of the high-level group and the general group are 0.014, 0.001 and 0.007 respectively, which are less than 0.05. There are significant differences in statistics, and the high-level group is significantly higher than the general group. However, the significance test value *P* of the shoulder abduction angle is equal to 0.038, less than 0.05. There is a significant difference between the two groups of athletes. The shoulder abduction angle of the high-level group is significantly lower than that of the ordinary group, indicating that tennis players in the high-level group are closer to the trunk with their tennis rackets. The significance test values *P* of the right elbow joint angle and wrist joint are 0.769 and 0.278 respectively, greater than 0.05, and there is no significant difference between the two

Table 3. Test results of significance of joint angles at hit time.

Variable	*P*
Hip angle	0.014
Knee angle	0.001
Ankle angle	0.007
Right shoulder	0.038
Right elbow angle	0.769
Right wrist	0.278

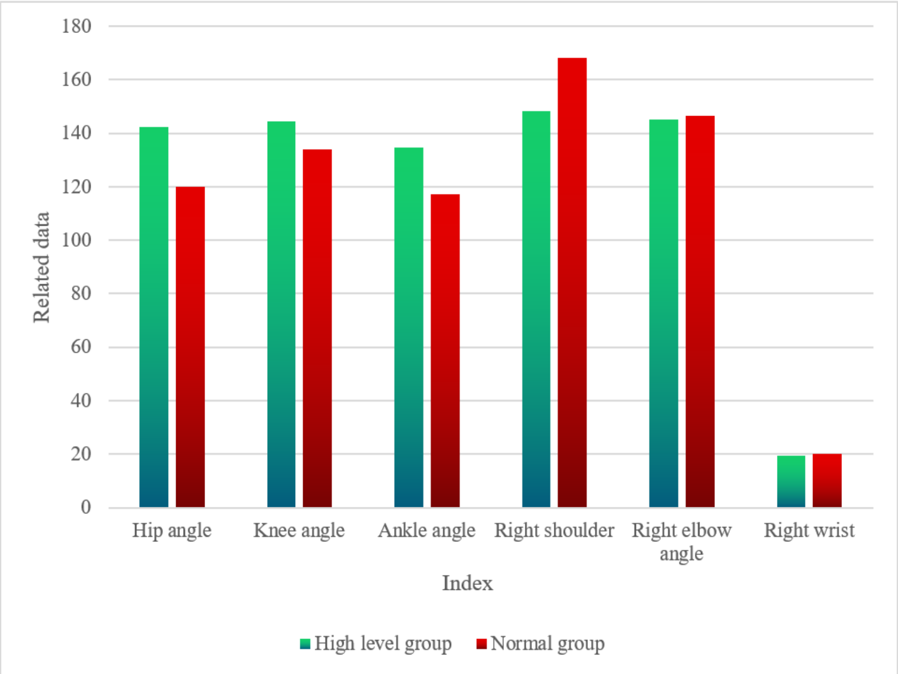

Figure 8. Joint angles at hitting time.

As shown in **Table 4**, the significance test results of the change range of the main indicators in the accelerated swing stage are shown, and **Figure 9** shows the change range of the main indicators in the accelerated swing stage. It can be seen that the significance test values of the right knee extension angle and the right hip joint angle change are 0.028 and 0.035 respectively, less than 0.05, which is statistically significant. The right knee extension angle and right hip joint angle of the high-level group were 35.78 and 55.34, respectively. From the numerical point of view, the extension amplitude of the high-level group was significantly higher than that of the normal group. The significant test values of pelvic rotation angle, trunk rotation angle and right shoulder internal rotation angle *P* are 0.598, 0.356 and 0.479 respectively, greater than 0.05, and there is no significant difference. In the accelerated swing phase, the ankle joint of the athlete completes the ground pedal force through a prone position. The ankle also receives the ground reaction force from the ground, thus encouraging the hip and knee joints to complete the positive stretching movement. In order to obtain the best hitting effect, players should stretch their hips, knees and ankles before hitting, and their center of gravity should also move forward and upward. From the displacement distance of the athletes' center of gravity in the forward, right and upward directions, the significance test *P* values in the left and right directions and vertical directions are 0.118 and 0.073 respectively, which are greater than 0.05, so there is no significant difference between the high-level group and the ordinary group in the left and right displacement and vertical displacement. However, in the front and back direction, the displacement of the high-level group moving toward the hitting direction is 8.33 cm, while the average forward movement of the ordinary group is 5.19 cm. The significance test is $P = 0.046$, less than 0.05. It shows that there is a significant difference between the high-level group and the normal group in the front and back direction displacement during the accelerated swing phase.

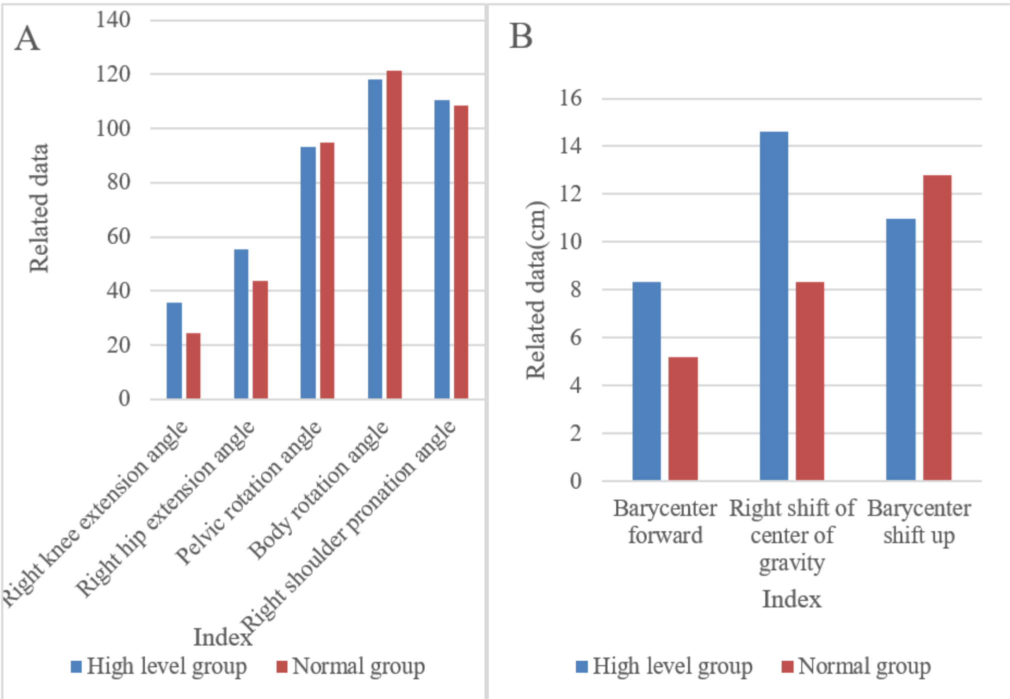

Figure 9. Change range of main indicators in accelerated swing stage. **(A)** shows the change of joint angle; **(B)** shows the change of directional displacement.

Table 4. Test on the significance of the change range of the main indicators in the accelerated swing stage.

Variable	*P*
Right knee extension angle	0.028
Right hip extension angle	0.035
Pelvic rotation angle	0.598
Body rotation angle	0.356
Right shoulder pronation angle	0.479
Barycenter forward	0.046
Right shift of center of gravity	0.118
Barycenter shift up	0.073

4. Conclusions

The main purpose of the current study is to compare the biomechanical characteristics of the forehand stroke of high-level tennis players. According to the research results, the tendency of the top group to have a higher horizontal shoulder and racquet speed is caused by a significantly different time pattern of the maximum angle rotation of the pelvis and torso. When the transverse field and the lower line are compared, the different times and results of the maximum hip, racquet and separation angle, horizontal racquet speed and elbow speed peak value show that both groups adjust the swing according to the corresponding conditions. Based on the research results, the coach should pay close attention to the proper rotation of the pelvis and trunk to help the players master forehand hitting skills. When it comes to strength and physical training, coaches should keep in mind the kinematic similarities between strength training exercises and tennis hitting methods. Therefore, activities involving different parts of the body should be carried out to coordinate and imitate tennis.

In order to better apply the results of this study to actual training, guidance and injury prevention, coaches and sports science experts can make some strategies: First, in technical guidance, the rotation pattern of the pelvis and trunk should be focused on, emphasizing its coordination with the shoulder and racket speed to help players optimize the force mechanism of forehand shots. Second, in training design, the kinematic similarities between strength training and tennis-specific movements should be combined to design targeted strength and coordination exercises, such as strengthening core strength and body coordination through rotation training that imitates the hitting action. In addition, for different hitting scenarios (such as horizontal court and downline), coaches should help players adjust the timing of swinging the racket and body posture to adapt to the diverse needs in the game. In terms of injury prevention, special attention should be paid to the load management of the shoulders, elbows and hips to avoid sports injuries caused by overuse or incorrect technical movements. By combining biomechanical analysis with actual training, the technical level, sports performance and long-term health of players can be more effectively improved.

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