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Article

Based on biomechanics analysis of table tennis players' forehand forward loop drive

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Abstract: In the Olympic Games and other high-level events, the forehand forward loop technique has always played an important role. Therefore, the forward loop ball technology should be promoted and mastered. Based on biomechanics, this paper analyzes the change of the movement characteristics of the forehand forward loop shot in table tennis players. Specifically, the experimental method and statistical method were used to make an empirical study on the changes of the joint angular velocity of the upper and lower limbs of the study object. The results showed that the peak angular velocity of the shoulder joint was 14.75 ± 3.881 when hitting a backspin ball, which was higher than that of 4.2 ± 3.58 when hitting a topspin ball, $p = 0.253 > 0.05$. The peak angular velocity of the elbow joint was −10.97 ± 1.74, which was higher than that of the wrist joint, 5.10 ± 1.2, $p = 0.537 > 0.05$. The peak angular velocity of the hip joint was 6.52 ± 1.73, which was higher than that of the hip joint when hitting a topspin ball (4.84 ± 1.57, $P = 0.011 < 0.05$). The peak angular velocity of the knee joint was 2.20 ± 0.8, which was larger than that of the knee joint when hitting the topspin ball 2.03 ± 0.66, $P = 0.231 > 0.05$. The peak angular velocity of the naked joint was 1.75 ± 0.65, which was higher than that of 1.43 ± 0.54, $P = 0.078 > 0.05$. It can be seen that when hitting the backspin ball, the peak angular velocity and speed of the joint of the upper and lower limbs of the body are greater than that when playing the top spin ball; the peak angular velocity difference between elbow and hip joints is the largest. Therefore, when hitting the backspin ball, pay attention to the lower arm to achieve the purpose of accelerating elbow flexion. At the same time, the rotation speed of the body should be properly reduced, and the speed of the body translation should be increased so as to maximize the peak angular speed of the joint.

Keywords: biomechanics; table tennis; forehand forward loop drive technique

1. Introduction

In recent years, the competition among table tennis players has gradually become more intense. In the competition of high-level athletes, it is difficult to score a round directly, and there are many situations of stalemate. This has led to an increased emphasis on strategic play, where players must not only focus on their own techniques but also anticipate and counteract the strategies employed by their opponents. As matches become more competitive, the ability to adapt and respond effectively becomes crucial for success. Therefore, the players must improve the quality of the single ball, cause a greater threat to the opponent, and create favorable conditions for their own score. With the help of a biomechanical analysis model to analyze the technical movements of table tennis, we can master its technical characteristics [1,2]. Biomechanics provides insights into the physical principles underlying athletic performance, allowing coaches and players to optimize their techniques for better results. By examining body movements, force application, and the mechanics of striking the ball, players can enhance their skills significantly. In previous studies, biomechanical analysis was mostly carried out on hitting a single rotating ball with a certain technical action, while there were few studies on hitting different rotations with the same technique [3–5]. This lack of research on the versatility of techniques in response to various spins is a critical gap that needs to be addressed. Understanding how to apply the same fundamental technique across different types of spins can greatly enhance a player's adaptability during matches. By analyzing the characteristics of table tennis players using the same technique to hit balls with different rotations, this technique can be deeply understood, and its help to domestic players can be improved [6,7]. The capacity to execute a consistent technique while facing a variety of spins not only showcases a player's skill but also their strategic flexibility. This adaptability is essential in high-stakes matches, where opponents may employ an array of spinning techniques to gain an advantage. The loop technique is an offensive technique, which can combine the three elements of power, speed, and rotation [8–10]. The loop technique stands out in its ability to create dynamic and aggressive plays, making it a crucial component of any competitive player's arsenal. By mastering this technique, players can exert significant pressure on their opponents, thereby forcing them into defensive positions and limiting their options for counterplay. It has a wide range of applications, not only has a powerful lethality, can quickly pull a punch, but also can use rotation to effectively control the drop point and arc, and hold the opponent [11]. The effectiveness of the loop technique lies in its multifaceted nature. Players can vary the angle, speed, and spin of the ball, making it challenging for opponents to predict and respond effectively. This unpredictability is vital in maintaining an offensive edge during matches. Furthermore, understanding the biomechanics behind the loop technique can lead to enhancements in training regimens, focusing on optimizing body mechanics and improving overall performance.

Additionally, incorporating biomechanical analysis into training programs can help coaches identify specific areas for improvement. By utilizing motion capture technology and other biomechanical tools, coaches can provide immediate feedback on players' techniques, allowing for real-time adjustments that can lead to significant performance gains [12]. By summarizing previous studies, it can be found that few scholars analyze the movement characteristics of players hitting table tennis with the loop-ball technique from the perspective of biomechanics. In order to promote this technique, this paper studies the forward loop-ball technique. From the perspective of biomechanics, undergraduate students in the College of Table Tennis are taken as the research topics. With the help of experimental methods and statistics, this paper studies and analyzes the changes of the angular velocity characteristics of the forehand circular ball in order to draw the necessary conclusions and give reasonable suggestions to promote the development of table tennis.

2. Case analysis

2.1. research topic

In order to study the effect of biomechanics on the forehand forward curling movement of table tennis players, 10 undergraduates of Table Tennis College were selected as the research topics. The 10 undergraduate students were all male. They use their right hand to hold the racket laterally, and both the front and back of the racket were pasted with reverse rubber. The playing method was loop and fast attack, and the upper and lower limb joints of the subjects were not damaged. The details are shown in **Table 1**.

Table 1. Disclosure of relevant information.

Label	Height (cm)	Age (years)	Weight (kg)	Class of motion	Holding hand	Play
A	182	19	76	first-order	The right hand	Circle and fast break
B	170	20	63	first-order	The right hand	Circle and fast break
C	189	21	77	first-order	The right hand	Circle and fast break
D	172	20	62	first-order	The right hand	Circle and fast break
E	181	20	72	first-order	The right hand	Circle and fast break
F	174	19	65	first-order	The right hand	Circle and fast break
G	171	20	60	first-order	The right hand	Circle and fast break
H	174	20	66	first-order	The right hand	Circle and fast break
I	185	19	73	first-order	The right hand	Circle and fast break
J	188	19	75	first-order	The right hand	Circle and fast break

In order to capture the movements of these moving objects, the following experimental equipment is used: First, the infrared high-speed motion capture system camera is used, and the infrared reflective ball is equipped with 14mm, and the experimental sampling frequency is set to 100Hz. Secondly, a KISTLER three-dimensional force measuring platform with model number 9260AA and a size of 600×500mm was installed to collect the support reaction force on the ground during the movement of the research topic. The device has a built-in signal amplifier, and the sampling frequency is set to 1000Hz during the test. thirdly, the Phantom Miro R111 model was installed with a high-speed camera and Kimbe fill light with a set resolution of 768×480. The sampling frequency is 4500fps; Thirdly, we choose the Red Double happiness three-star brand ping-pong ball as the experimental ball. The whole body of the ball is marked with the “L” font with black big head pen; Fifth, the table tennis racket bottom plate is the King Butterfly horizontal beat, shooting film is the red double happiness three province set.

2.2. Esting methods

The Testing method was experimental, and the test time was from 1 November 2023 to 30 December 2023, and the test place was the laboratory on the third floor of the training hall of the school district. Testers hit the ball with the same table tennis racket using the forehand forward loop drive technique. During the experiment, the server needs to stand on the side of the table tennis table and serve the forehand long ball and the backspin long ball to the test subject in the form of multiple serves. The subjects were standing on the forehand to hit the diagonal ball, and the hitting power required was above medium. During the test, the service personnel cannot be replaced, and the fixed point of service should be served in place, and the speed, landing point, and rotation of multiple services should be basically consistent as far as possible. The schematic diagram of the experimental setup is shown in **Figure 1**.

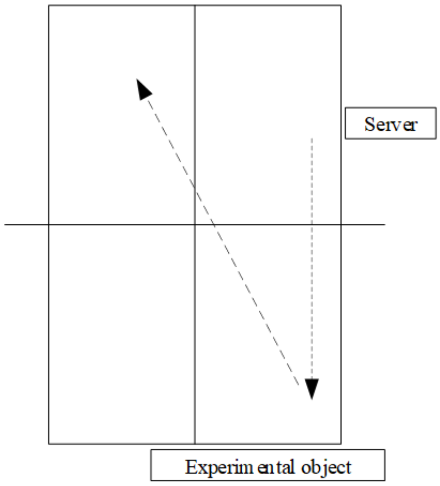

Figure 1. Schematic diagram of experimental setup.

When collecting data, the infrared high-speed motion capture system is used, which can accurately capture the movement of the experimental object and collect the kinematic data. After an action collection is completed, it needs to be exported in C3D format and renamed. In the equipment, the Simi system signal collector is also used to collect data from the 3D force measuring table. It is mainly the reaction force in the *x*, *y*, and *z* directions of the ground. Each collection is recorded, named, and saved. In order to achieve synchronization of motion data and force table data, the following software and equipment are used: First, a synchronization box, which is a homemade product with two ends connected to the Simi system signal collector and diode. When the power supply is started, an electrical signal can be sent to the Simi system signal collector. By turning off the power switch of the synchronous box, the electrical signal can disappear and the infrared diode can be extinguished at the same time. Secondly, the Simi system signal collector: the device can collect the data of the force measuring table and the signal data of the synchronization box at the same time, and the collector collects the frequency of both of them at 1000 Hz, so the data of the force measuring table and the data of the signal of the synchronization box are consistent in time. Thirdly, infrared diodes, through two infrared diodes plus two infrared markers to form four markers, the four markers are placed in the infrared high-speed motion capture system camera field of view. A marker is built into the data acquisition software of the infrared high-speed motion capture system, and the infrared diode is extinguished by turning off the power switch of the synchronization box, and the marker disappears in the data acquisition software. The synchronization process between devices is shown in **Figure 2**.

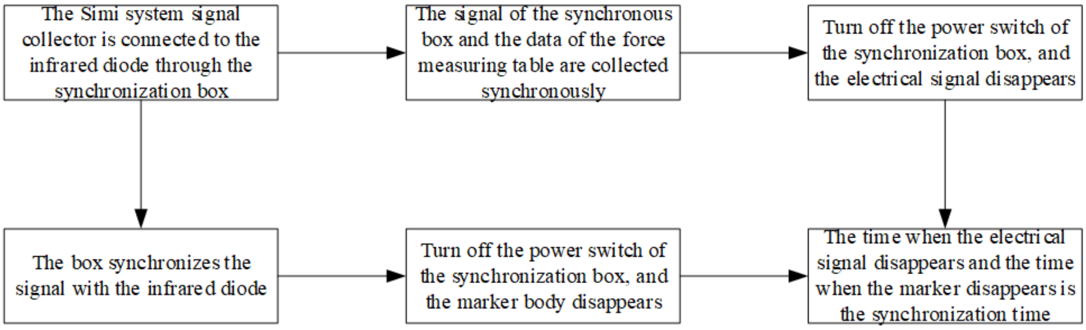

Figure 2. Synchronization process.

To sum up, the specific operation method when collecting data is as follows: First, before the test, one end of the synchronization box is connected to the Simi system signal collector through the BNC line, and the other end is connected to the infrared diode. Secondly, two infrared diodes and two marker points are placed in the field of view of the camera of the dynamic capture system, and a new marker body is created in the data acquisition software of the dynamic capture system. Finally, during the test, the Simi system signal collector and dynamic capture data acquisition software are used first, and then the power switch of the synchronization box is turned off. When the marker in the dynamic capture data acquisition software is seen, the action start command is issued. In the experiment, the surface of the ping-pong ball was marked with an "L" symbol. The high-speed camera is placed on the side of the net, and the position, height, and lens of the high-speed camera are adjusted to make it clear that the ball flies over the net. In order to make the picture captured by the high-speed camera clearer, a fill light is added above the high-speed camera.

2.3. Statistical analysis

In the statistical analysis of the data, the mean value of the kinematics and dynamics data is calculated, and the calculated results are all expressed as the mean ± standard deviation. Then the experimental data is statistically analyzed with the help of SPSS24.0 statistical software, and the statistical method is applied to the paired sample *T*-test. $p< 0.05$, significant difference; $p< 0.01$, the difference is very significant.

3. Result analysis

The test action in this paper is a single hitting action, not a continuous hitting action, so this paper focuses on the difference analysis of the joint angle at the beginning of the swing and the end of the swing, as well as the ground reaction force at the beginning of the swing, the phase definition of joint motion is shown in **Figure 3**.

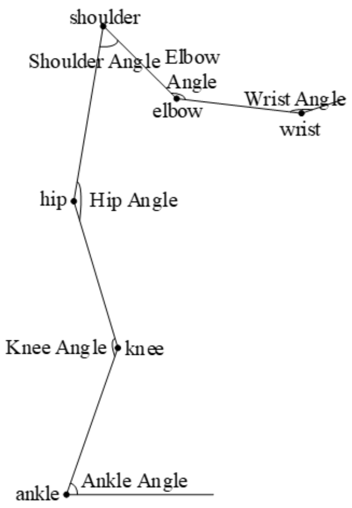

Figure 3. Phase definition of joint motion.

The Swing stage is the only stage of contact with the ball, so the focus is on the difference analysis of the peak joint angular velocity at this stage. Among them, angular velocity is a kinematic index to evaluate rotation, and angular velocity can reflect the speed of joint Angle change, the integrity of angular velocity means the joint Angle change is large, and the negative value means the joint Angle change is small. The specific experimental results are shown below.

3.1. Characteristics of angular velocity changes of upper limb joints

The upper limb joint consists of three parts: right shoulder, right elbow, and right wrist. The changes of the right shoulder are shown in **Figure 4**.

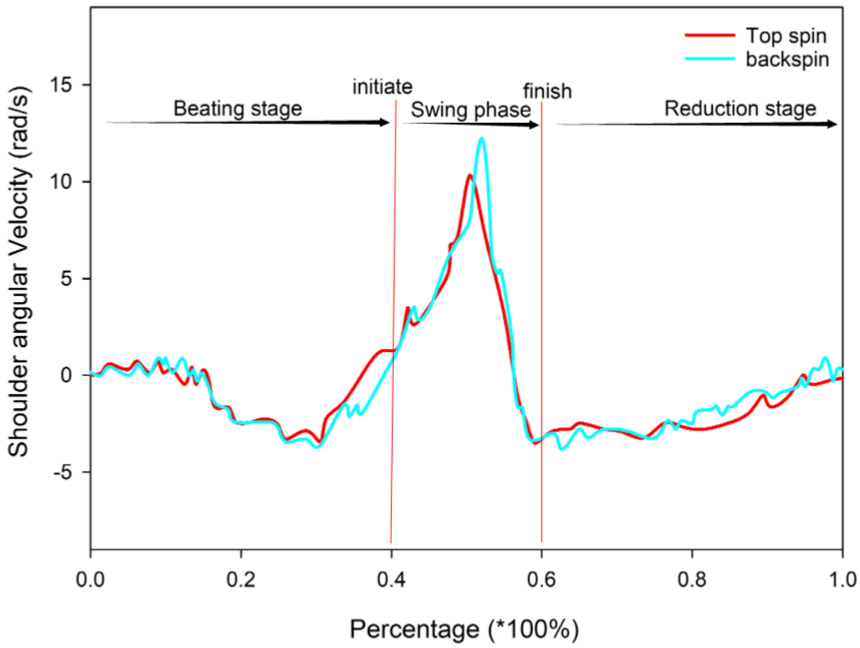

Figure 4. Changes in the angular velocity of the right shoulder joint.

It can be seen that when table tennis players use the forward loop technique to hit the top spin ball and the top spin ball, the change trend of the right shoulder joint angular velocity is similar in the three stages. In the lead-up stage, the angular velocity curve of the right shoulder joint changed little in the first half and began to decline in the secondly half. During the swing phase, the angular velocity curve of the right shoulder joint shows a rapid rise and then a rapid decline. In the reduction stage, the angular velocity curve of the right shoulder joint gradually increased. The change characteristics of the right elbow are shown in **Figure 5**.

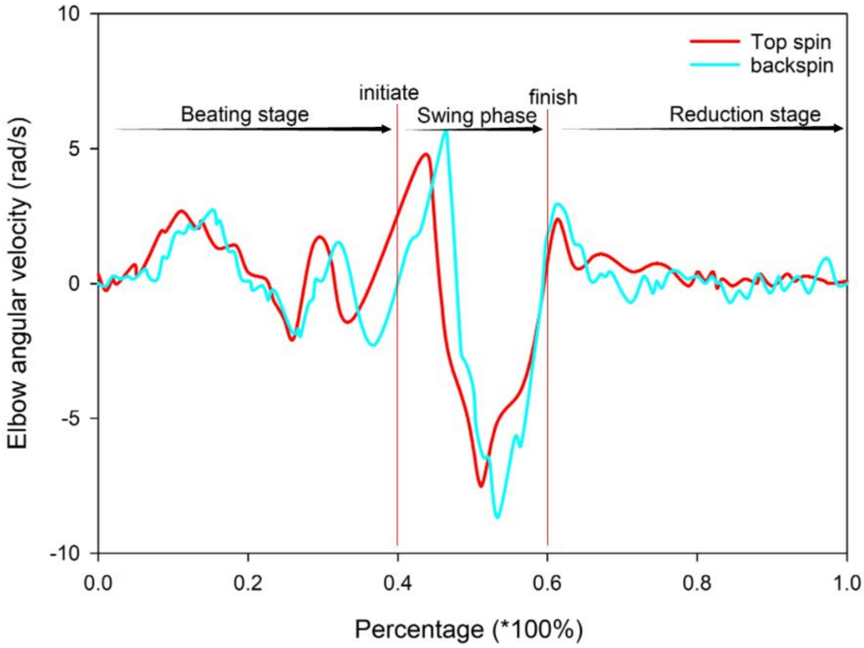

Figure 5. Changes in angular velocity of elbow joint.

It can be seen that when table tennis players use the forward loop technique to hit the topspin and backspin, the change trend of the right elbow joint angular velocity is similar in the three stages, but the curve inflection point is quite different. In the lead-up stage, the angular velocity curve of the right elbow joint rose twice and fell twice. During the swing phase, the angular velocity curve of the right elbow joint first rises, then rapidly drops, and finally rises again. In the reduction stage, the angular velocity curve of the right elbow joint first increases and then gradually decreases. The characteristics of the changes in the angular velocity of the right wrist joint are shown in **Figure 6**.

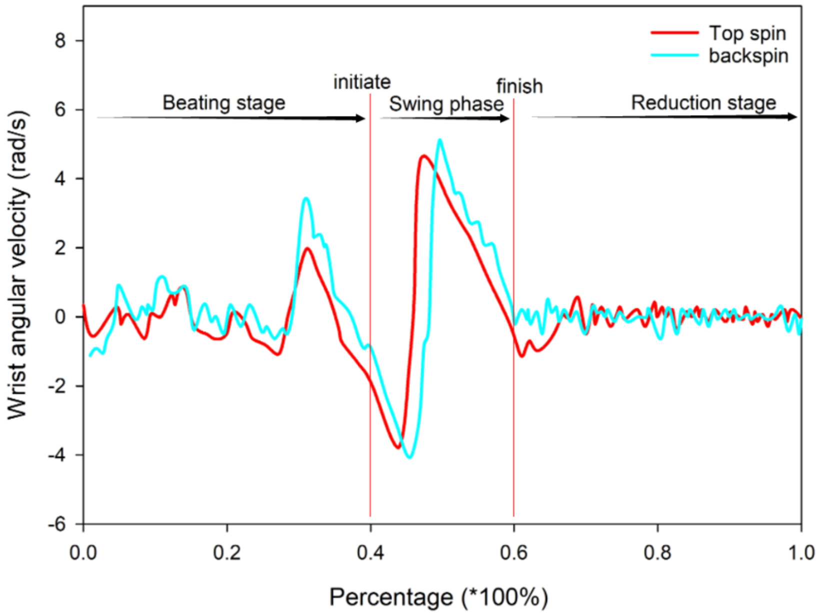

Figure 6. Changes in angular velocity of wrist joint.

It can be seen that when table tennis players use forehand forward loop technology to hit the topspin and backspin balls, the change curve of the right wrist joint angular speed in the last stage is similar. In the lead-up stage, the angular velocity curve of the right wrist changes little at the beginning. Near the beginning of the swing, the angular velocity curve of the right wrist increases and decreases. During the swing phase, the angular velocity curve of the right wrist joint first drops, then rises rapidly, and then drops rapidly. In the reduction stage, the angular velocity curve of the right wrist joint changed little. The statistical results of changes in the peak angular velocity characteristics of the upper limb joints are shown in **Table 2**.

Table 2. Peak angular velocity results of forehand forward loop drive technique.

Peak angular velocity	Right shoulder joint	Right elbow joint	Right wrist joint
Top spin stroke	14.2±3.58	−9.08 ± 1.52	4.82 ± 0.63
Backspin stroke	14.75±3.88	−10.97 ± 1.74	5.10 ± 1.2
P	0.254	0.003**	0.538

Note: $^{**}p < 0.01$.

It can be seen that when table tennis players use the forehand forward loop technique to hit the topspin and backspin balls, the comparison result of the peak angular speed of the three joints of the upper limb is the largest shoulder joint, then the elbow joint, and finally the wrist joint. When hitting the backspin ball, the peak angular velocity of the shoulder joint was greater than that of the backspin ball, $p = 0.253 > 0.05$, indicating that there was no significant difference in the peak angular velocity of the shoulder joint when hitting the topspin ball and the backspin ball. When hitting the backspin ball, the peak angular velocity of the elbow joint is greater than that of the wrist joint ($p = 0.537 > 0.05$), indicating that there is no significant difference in the peak angular velocity of the wrist when hitting the top spin ball and the top spin ball. Among the three joints of the upper limb, only the peak angular velocity of the elbow has a very significant difference, indicating that the bending velocity of the elbow is the most different when hitting the ball with two different rotations. It is suggested that when hitting the backspin ball, we should pay attention to the forearm in order to accelerate the purpose of elbow flexion.

3.2. Characteristics of lower limb joint angular velocity change

The lower limb joints include three parts: right hip, right knee, and right ankle. The changes of right hip are shown in **Figure 7**.

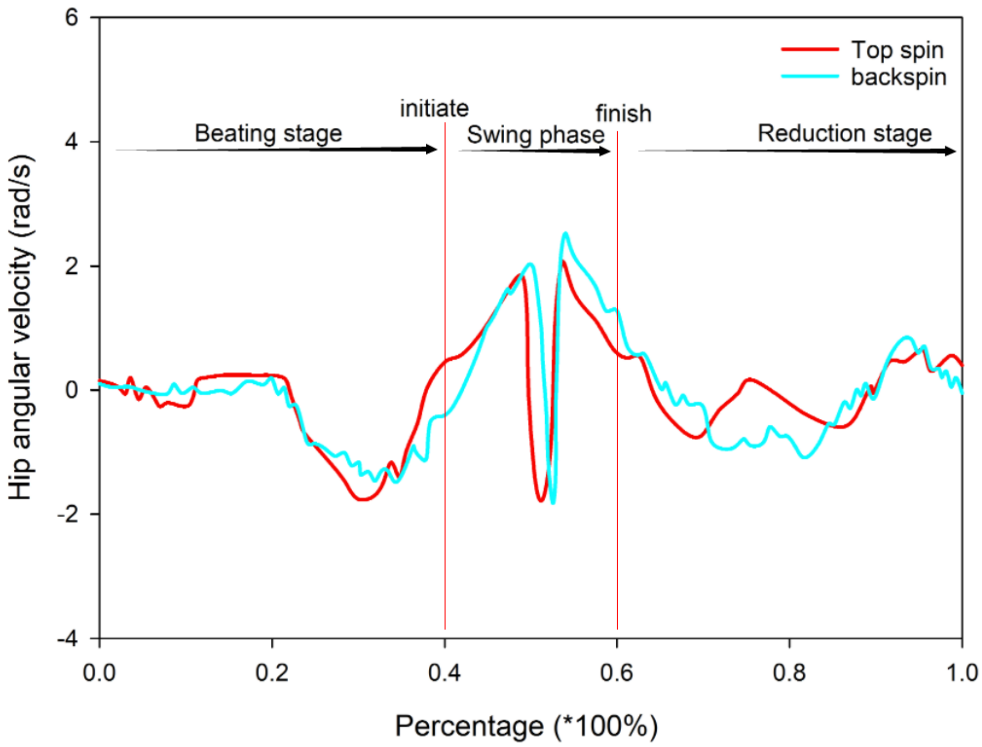

Figure 7. Changes in hip joint angular velocity.

It can be seen that when table tennis players use the forward loop technique to hit the top spin ball and the top spin ball, the change trend of the right hip Angle velocity curve in the three stages is similar. In the lead-up stage, the first half of the right hip Angle velocity curve changed little, and the second half of the curve fell first and then rose. During the swing phase, the right hip angular velocity changes gradually up and then rapidly down, then rapidly up and then gradually down. During the reduction phase, the right hip angular velocity curve gradually decreased. The changes in the angular velocity characteristics of the right knee joint are shown in **Figure 8**.

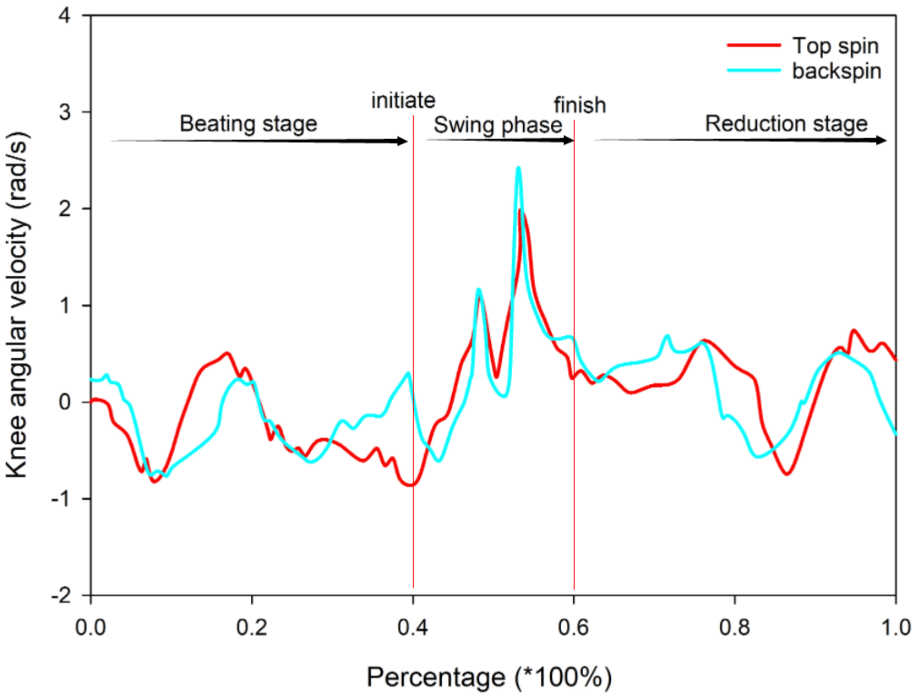

Figure 8. Changes of knee joint angular velocity.

It can be seen that when table tennis players use the forehand forward loop technique to hit the top spin ball and the top spin ball, the overall change of the knee joint angular velocity curve in the three stages is small. Among the three stages, the knee joint angular velocity curve changes the most in the swing stage; there are two rises and two falls. The changes in the angular velocity characteristics of the right ankle joint are shown in **Figure 9**.

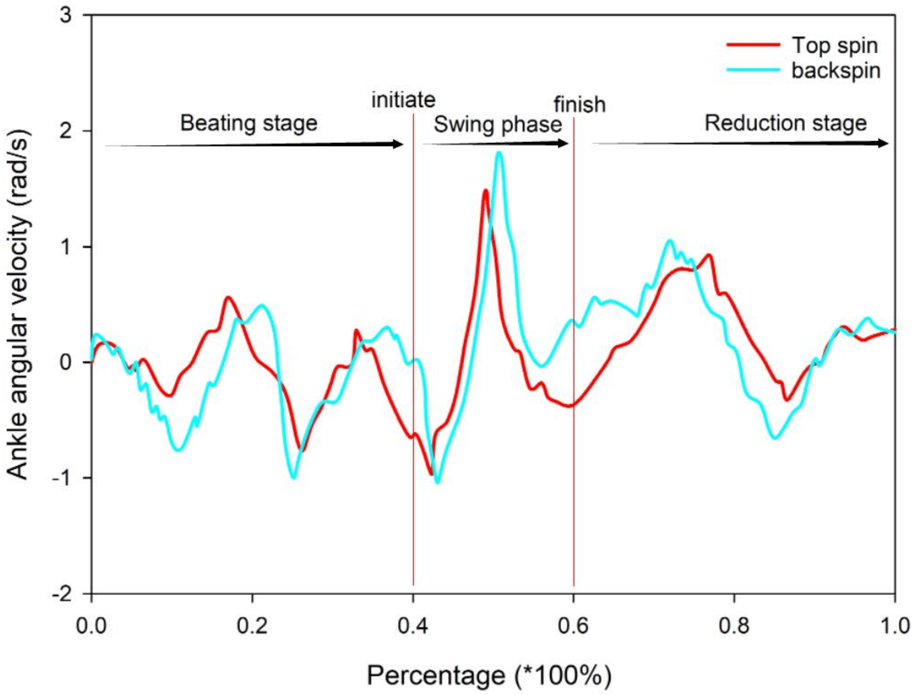

Figure 9. Changes in angular velocity of bare joint.

It can be seen that when table tennis players use the forehand forward loop technique to hit the topspin ball and backspin ball, the change trend of the right ankle angular speed curve is similar, and the right ankle angular speed curve has two ups and two downs in the lead-up stage. During the swing phase, the angular velocity curve of the right ankle joint drops first and then rises rapidly. During the reduction phase, the right ankle angular velocity curve shows a rise, then a decline, and finally a sharp rise. The peak angular velocity characteristics of the three joints of the lower extremities were statistically obtained, as shown in **Table 3**.

Table 3. Characteristics of peak velocity of lower extremity joint.

Peak angular velocity	Right hip	Right knee joint	Right ankle joint
Top spin stroke	4.84 ± 1.57	2.03 ± 0.66	1.43 ± 0.54
Backspin stroke	6.52 ± 1.73	2.20 ± 0.8	1.75 ± 0.65
P	0.011*	0.232**	0.078

Note: *$p < 0.05$,**$p < 0.01$.

It can be seen that when table tennis players use forehand forward loop technology to hit the top spin ball and backspin ball, the peak angular velocity of the three joints of lower limbs is hip joint, knee joint and ankle joint in order. Among them, the peak angular velocity of the hip joint when hitting the backspin ball is greater than that when hitting the topspin ball, $P = 0.011 < 0.05$, which means that the peak angular velocity of the hip joint when hitting the topspin ball and the backspin ball is significantly different. The peak angular velocity of the knee joint when hitting the top spin ball was greater than that when hitting the top spin ball ($P = 0.231 > 0.05$), which meant that there was no significant difference between the top spin ball and the top spin ball. When hitting the backspin ball, the peak angular velocity of the naked joint is greater than that of the topspin ball, $P = 0.078 > 0.05$, which means that there is no significant difference between the peak angular velocity of the naked joint when hitting the topspin ball and the backspin ball. Finally, the conclusion is that among the three joints of lower limbs, only the hip joint has a significant difference in angular velocity, indicating that the hip joint has the largest difference in extension velocity when hitting the two different balls with more rotation, suggesting that we should pay attention to the use of the hip joint when hitting the backspin ball.

4. Discussion

Through the above research, it is not difficult to find that mastering the forehand front loop technology can improve the competitive level of table tennis players and allow them to play more "beautiful balls". Thus, the widespread promotion and mastery of the forehand forward loop are of utmost importance for the development of table tennis players at all levels [13–15]. Based on the above analysis, the following suggestions are given: First, we should pay attention to the forearm when hitting the backspin ball, in order to accelerate the purpose of elbow flexion; secondly, when we hit the backspin ball, we should pay attention to closing the forearm to achieve the purpose of accelerating elbow flexion. Thirdly, when using the forward arc technology to hit the ball, the rotation speed of the body should be properly reduced, and the speed of the body translation should be increased so as to maximize the correlation between the peak joint angular speed and the ball speed, and so on.

5. Conclusions

In summary, the conclusion can be drawn as follows: First, when hitting the backspin ball, the peak angular velocity and speed of the joint of the upper and lower limbs of the body are greater than that of the top spin ball; secondly, the peak angular velocity difference between elbow and hip joints is the largest. Therefore, two suggestions are given: First, when we hit the backspin ball, we should pay attention to the forearm, in order to accelerate the purpose of elbow flexion; secondly, when we hit the backspin ball, we should pay attention to closing the forearm to achieve the purpose of accelerating elbow flexion. Thirdly, when using the forward arc technology to hit the ball, the rotation speed of the body should be properly reduced and the speed of the body translation should be increased, so as to maximize the correlation between the peak joint angular speed and the ball speed, and so on.

Ethical approval: Not applicable.

Conflict of interest: The author declares no conflict of interest.

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