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Article

Application of AI in table tennis technique optimization based on biomechanics

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Abstract: The application of AI in table tennis technology is an innovative way for table tennis players to train in daily life, aiming to improve the players' technical level and competition results. Athletes only need to upload their training videos, and the AI system can conduct in-depth analysis of the videos, control strength, and evaluate various technical performances.AI technology can accurately identify and analyze key mechanical control actions such as the athlete's serve power control, receiving and kicking skills, and movement strategies from a biomechanical perspective. Through precise data analysis, AI technical analysis will generate detailed reports to help athletes understand their strengths and areas for improvement, and provide specific optimization suggestions so that players can continue to improve their skills, especially in power control and center of gravity adjustment. In addition, AI applied to table tennis technology will also provide more targeted training plans based on the athlete's personal strength and training goals. This targeted strength and ball skills training can help athletes focus on improving their special skills and achieve their goals more effectively. In the journey of AI table tennis technology, we will continue to challenge ourselves and achieve higher achievements.

Keywords: biomechanics; AI technology; table tennis training; strength optimization; smart sports

1. Introduction

Artificial intelligence is quietly changing the traditional sport of table tennis. From table tennis robots to big data analysis systems, new technologies are bringing unprecedented opportunities to athletes and enthusiasts [1]. The rapid development of new technologies with digital, information and networking features has promoted the widespread application of artificial intelligence technology in the field of sports, promoted sports into a new era of artificial intelligence, and spawned "smart sports". The birth of intelligent sports has injected a strong impetus into the rapid development of sports and the sports industry. This is a mobile robot equipped with a mechanical arm function. AI integrates technologies in multiple fields such as real-time visual systems and robot control, which reduces manpower, improves the accuracy of competition data, and ensures the fairness of the competition [2].

2. Control of serve power

There are two ways to play table tennis: horizontal and vertical. The difference between these two ways directly affects players' different paths and skills in the game. The ball path produced by the horizontal racket is more stable and the force is more

even. The ball path produced by the pen-hold racket has greater rotation and is more aggressive but is relatively less stable [3].

Table tennis players mainly use their forearms and wrists to exert force, but they should pay attention to the coordination of the waist to improve the quality of their serve [4]. For example, when serving with the right hand, the body's center of gravity usually moves from the right foot to the left foot, and the opposite is true when serving with the backhand.

After each contact with the ball, the arm should swing smoothly and return to the original position quickly. The traditional preparation posture for serving (taking the right-handed racket as an example) is: for a forehand serve, the left foot is slightly forward, the body is slightly tilted to the right, and the left palm holds the ball in front of the body and on the right side. For a backhand serve, the right foot is slightly forward, the body is slightly tilted to the left, and the left palm holds the ball in front of the body and on the left side. However, with the development of table tennis technology, more and more players use the sideways serve method: this makes it easier to serve diagonally at a large angle, and then use the straight line to contain the opponent, which is beneficial for locking the opponent in the middle and making it easier for them to use forehand attacks. Some players also do the opposite, standing in the middle of the table and using backhand serves, so that they can combine backhand attacks without moving over a large range [5].

When serving, if the force is applied diagonally upwards at the moment of contact with the ball, it is topspin; if the force is applied diagonally downwards at the moment of contact with the ball, it is backspin. Some athletes often perform fake moves, and the movements are very similar and difficult to judge [6].

The function of the forearm is to accelerate. If the serve speed is not fast, it is mostly because the forearm strength is not used well or the forearm is not used at all. When a table tennis player serves, the forearm swing speed from the swing to the ball must be fast. The forearm swing speed is used to speed up the serve speed, especially when serving a long ball, the effect of using the forearm to accelerate the force will be better [7].

The outstanding characteristics of professional table tennis players' power generation are: that large muscle groups mainly generate power, and small muscle groups mainly adjust. That is, they use their legs, waist, back, and shoulders to generate power, and then use their forearms and wrists to adjust the racket shape and the angle of the ball. The coordination relationship between large muscle groups and small muscle groups and the order of power generation. The energy when hitting the ball is taken from the ground and finally transmitted to the ball in the order of: foot→calf→knee→thigh→waist→hip→back→shoulder→upper arm→elbow→forearm→wrist→hand→paddle. The farther away from the ball, the more power should be generated first, and even more power should be generated.

3. Analysis of table tennis players' wrist strength and movements when serving

The highest state of wrist force for table tennis players is "loose but not shaking, tight but not stiff". Fingers must exert force at the moment of contact with the ball,

and the final contact with the ball depends on the fingers to transmit force. At the moment the racket touches the ball, the fingers should have the feeling of holding the racket tightly, to transfer all the force to the racket. When serving with a horizontal racket, the middle finger, ring finger, and little finger that were originally held on the racket handle should be placed behind the racket to improve the flexibility of the wrist and the instantaneous force of the fingers, to increase the rotation change of the serve.

In terms of skills, the key to serving lies in the perfect combination of "spin" and "speed". Spin can make it more difficult for the opponent to receive the ball, while speed can shorten the opponent's reaction time. To achieve this, it is necessary to accurately control the force and angle at the moment of throwing and hitting the ball. When throwing the ball, the ball should be vertically upward at a moderate height, about the distance from your eyes to the top of your head, which helps to judge the timing and strength of the hit. When hitting the ball, table tennis players use the coordinated rotation of their legs, waist, even the whole body to concentrate the force on the wrist, generate strong rotation by quickly rubbing the surface of the ball, and control the strength of the hit at the same time, so that the ball flies to the predetermined area at an ideal speed [8].

Before hitting the ball, table tennis players must pull the racket back to stretch the muscles in their arms and waist so that they can quickly contract when hitting the ball. It is like compressing a spring, stretching the muscle is like compressing the spring, and then contracting the muscle, the spring pops open, and the power explodes.

When hitting the ball, it is also very important to choose the correct hitting time and hitting point. The correct hitting time and hitting point are conducive to the full force of the arm, making the swing speed faster. When hitting the ball, the correct hitting point should be in front of the side of the body. Mastering the hitting point mainly requires that the racket reaches the maximum speed at the moment of contact with the ball, to hit the ball with the highest efficiency [9].

Loop balls are sometimes called pull balls. The friction between the ball and the rubber surface of the racket causes the ball to spin forward at high speed, which is called topspin [10].

Its characteristic is that the racket swings with a large amplitude, and the ball needs to be hit hard to make it spin faster. Therefore, a large displacement range and a stable center of gravity are required to swing each ball hard.

Its characteristics are that the stance is slightly raised, the swing of the racket is large, and the ball needs to be hit with force to produce a faster rotation (**Figure 1**, **Figure 2**). Therefore, it requires a large range of displacement and a stable center of gravity to swing each ball with force, so its footwork movement is mainly cross-step movement, and then combined with other footwork.

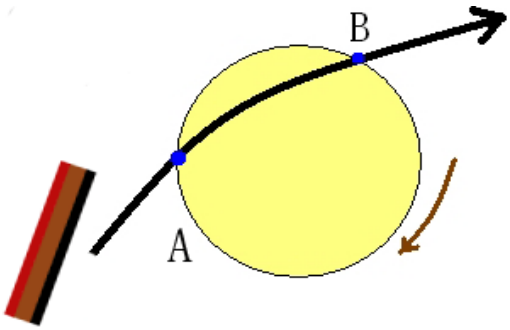

Figure 1. Loop A.

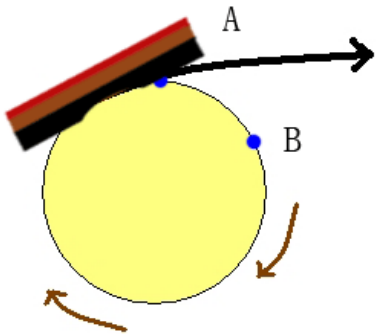

Figure 2. Loop B.

During the competition of table tennis players, the high-speed rotation of the table tennis ball, combined with the forward movement of the table tennis ball, causes the oncoming airflow relative to the table tennis ball to produce different pressures on the upper and lower sides of the table tennis ball, with the pressure on the lower side being smaller. Therefore, the table tennis ball will fall in a shape different from a parabola, similar to a banana ball in football. This allows the table tennis ball to quickly sink to the opponent's table after crossing the net at a high speed. In addition, due to the high-speed rotation of the loop ball itself, the opponent is likely to catch the ball too high when catching it, thus giving the loop player an offensive opportunity [11].

4. Table tennis movement trajectory

The AI system can change the way athletes train. It can identify eight major types of actions, such as serving, pulling, and swinging, with an accuracy rate of over 97% for start and end rounds, and over 80% for action recognition [12]. AI big data analysis systems are also playing an increasingly important role in the field of table tennis. They capture game data through video streams, including key information such as the ball's speed, rotation, and hitting position. The core of this system is a deep neural network model built using the PyTorch framework, which can model the trajectory of a table tennis ball and accurately predict the various properties of the ball [12]. These data not only provide accurate game analysis, helping coaches evaluate the technical level of table tennis players and develop targeted training plans; it also provides athletes with real-time game strategy analysis, helping them make adjustments based on their opponents' playing habits and strategies [13].

Equation of Motion:

$$\vec{r}(t) = \overrightarrow{r_0} + \overrightarrow{v_0}t + \frac{1}{2}\vec{a}t^2.$$

Angular Velocity:

$$\omega = \frac{d\theta}{dt}.$$

Magnus Force:

$$F_M = \frac{4}{3}\pi^2\rho r^3\omega^2.$$

For example, the core of the looping technique lies in its unique rotation characteristics. Unlike ordinary flat shots, the looping ball forms a beautiful arc in the air with strong rotation through the quick shaking of the wrist and the appropriate tilt of the racket face (**Figure 3**). This rotation not only increases the uncertainty of the ball's flight trajectory, but makes it difficult for the opponent to predict the ball's landing point and bounce direction. It also makes the ball generate greater rebound force when it touches the opponent's racket, increasing the difficulty of returning the ball.

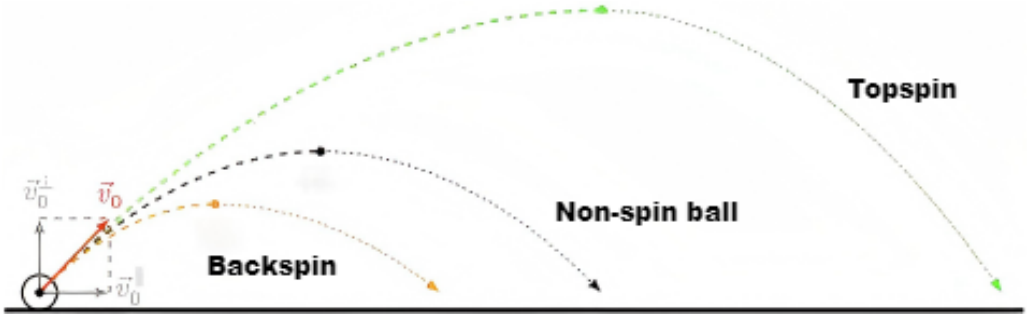

Figure 3. The trajectory of the ball with different rotations.

The figure above shows the trajectory of balls with different spins shot at the same initial velocity. The black, orange and green lines correspond to no spin, backspin and topspin respectively, where the dotted line is the arc of the rising phase and the dotted line is the arc of the falling phase. To achieve a perfect loop, table tennis players should stand firmly, with their feet shoulder-width apart, knees slightly bent, and the center of gravity of the body stable. Before hitting the ball, the player should fully lead the racket and pull the racket to the side of the body to accumulate power for hitting the ball. When hitting the ball, the player's wrist should shake quickly and the racket face should be tilted appropriately to generate enough rotation. At the same time, the player's body should rotate naturally with the hitting action, concentrating the whole body's strength on the racket to make the ball gain greater initial velocity and rotation [14].

The loop technique is not only applicable to offense but also to defense. When the opponent launches a strong attack, the athlete can use the loop technique to send the ball back to the opponent's half-court with a high arc and strong rotation, forcing the opponent to make mistakes in a passive situation or unable to make an effective counterattack.

AI data can help table tennis players continuously improve the quality of their serves and create new serves. This is a need for the development of table tennis and a

manifestation of the vitality of table tennis. When facing a new high-quality serve, the opponent is unfamiliar with it and has not yet established a conditioned reflex in his mind. Therefore, when hitting the ball, he feels uncoordinated, uncomfortable, or even helpless, which leads to direct or indirect scoring from the serve, which fully demonstrates the great power of the new serve [15].

5. Table tennis player movements and completion

During table tennis training, the AI terminal automatically recognizes five referee postures to realize the automatic timing and scoring system, namely, game pause, serve, score, exchange of venues, and foul [16].

The type of dataset for training table tennis is in the VOC dataset format. Use the ppyolo model for training on the AI platform to obtain a model for detecting table tennis. AI uses various modules in Pyqt5 to design the display interface and connects each module with signals and functional modules through slots so that the data in the interface can change according to the recognized information [17].

To pull a looping ball, you hit it first and then rub it, hit it, and rub it again, with rubbing as the main thing. Therefore, table tennis players should not stretch their arms too straight (**Figure 4**), draw the racket too low, tilt the racket too far forward, and also exert force forward when exerting force upward, to avoid missing the ball, hitting the ball late, and exerting force poorly.

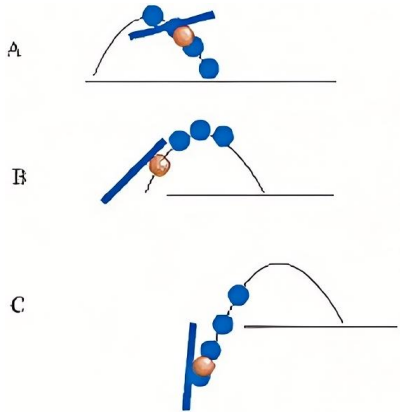

Figure 4. Loop ball at different times and different hitting positions.

Center of gravity movement: When the ball approaches the net, start to move the center of gravity along with the movement of the arms. When the center of gravity moves, the waist turns slightly, but not too much. The body has a certain inclination. It is enough as long as the center of gravity of the body is on the right foot. After the center of gravity moves to the right foot, the right shoulder sinks slightly. The supporting leg is slightly bent, but not too much, so as not to cause the center of gravity to be too low and unable to exert force. During training, players tend to rotate their hips too much, causing the body's center of gravity to move too much on the vertical axis, resulting in the dispersion of force when pulling the ball and inability to effectively exert forward force. After AI data correction, the better approach is: while the center of gravity moves slightly on the vertical axis, there should be a certain amount of movement on the sagittal axis, so that the center of gravity has enough

distance to move backward, which is conducive to moving forward when exerting force. During the movement of the center of gravity, the player's waist and abdomen should be tightened and kept in a certain state of tension. The position of the center of gravity on the foot is slightly forward and outside the entire sole, so that the effect of pushing off the ground to the left front and upper side can be fully exerted.

Racket draw: While the center of gravity is moving, the racket moves from the front of the abdomen to the right and back. The player should put the racket in the right position in the shortest time and through the most economical route. And it should be natural. The general position of the racket draw for forehand pull is below the waist on the right side of the body, a little behind the middle of the thigh. The shoulders should maintain appropriate tension. If the player cannot fully open the shoulder, it will affect the momentum transfer when pulling the ball. The arm is relaxed, and the forearm and upper arm are not in a line, that is, the arm cannot be fully straightened, which is easy to cause stiffness. At this time, the angle of the elbow joint is generally between 150° and 170°. During the backswing process, a fatal problem for players who want to hit a looping ball is pulling the elbow backward or lifting the elbow upwards. It is not easy to control the strength, which greatly affects the power of hitting the ball. During the entire backswing process, the elbow joint is almost always in a straight line with the hand. The order is that the forearm drives the elbow joint to move, and the elbow joint cannot pull the forearm to move forward and backward. During the backswing process, the distance between the upper arm and the body should be naturally opened, and the arm should not be clamped. It should be about a fist's distance.

Joint Torque:

$$\tau = I\,\alpha.$$

Kinetic Energy:

$$\mathrm{KE} = \frac{1}{2}mv^2.$$

Potential Energy:

$$PE = mgh.$$

Strength: Generally speaking, the force of pulling the ball is a process of momentum transfer. It is transferred from large muscle groups to small muscle groups, from the lower part of the body to the upper part, and from the proximal end of the body to the distal end. In the specific operation process, the player starts by pushing the ground forward and upward with the outer front side of the right foot, and gradually lifts the center of gravity upward, from the calf, thigh, hip joint, waist, shoulder, elbow, wrist, fingers, and finally acts on the racket at the moment of hitting the ball. During this process, the player's hip joints should be properly pushed forward, the waist and abdomen should be tightened, and the strength should be controlled and concentrated. The forearm and wrist should be retracted at the moment of hitting the ball, and the fingers should hold the racket tightly at the moment of hitting the ball. When pulling the ball with a straight racket, while holding the racket tightly, pay attention to the action of the middle finger pushing the racket to concentrate the strength on the racket.

6. The gap between AI power simulation and reality

The AI platform swiftly captures the position of the table tennis ball in high-speed motion and forms a trajectory through a high-speed binocular stereo vision system. By analyzing the ball's trajectory, it determines the rotation direction and speed within milliseconds, translating table tennis techniques into quantifiable real data. This process enables real-time adjustments for more accurate training. To close the gap between simulation and reality, advanced machine learning models incorporating larger and more diverse datasets, including real-world gameplay scenarios, should be developed. This will ensure the AI simulation reflects the complexities of real-world movements and force applications.

During trajectory analysis, the AI collects and analyzes movements through a digital system, combining trajectory and movement factors to evaluate the athlete's level. To enhance accuracy, it's essential to use multiple input sources like motion sensors, high-speed cameras, and biomechanical trackers for cross-validation. The AI then recommends suitable movement characteristics based on this comprehensive data analysis (**Figure 5**).

Loss Function:

$$\mathrm{L}(\theta) = \frac{1}{n}\sum_{i=1}^{n}\left(y_i - f(x_i;\theta)\right)^2.$$

Gradient Descent:

$$\theta_{new} = \theta_{old} - \eta\nabla_{\theta}L(\theta).$$

Cross-Validation:

$$\mathrm{CV} = \frac{1}{k}\sum_{i=1}^{k} L_{train}^{i}.$$

Error Checking:

$$\mathrm{E} = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|.$$

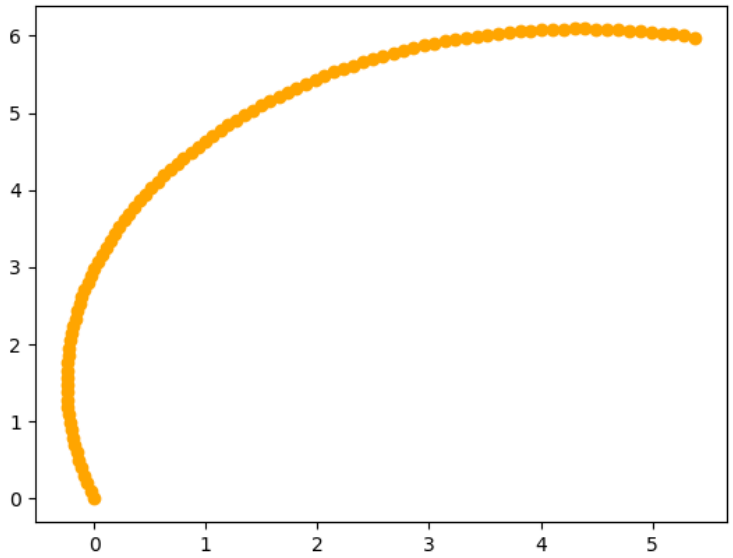

Figure 5. Loop effect prediction.

Source: www.cnblogs.com/dechinphy.

In this simulation, the initial velocity is set to the left front instead of directly forward. Under the influence of Magnus force, the arc effect of the table tennis ball is notably pronounced. To improve the robustness of the system, error-checking mechanisms and redundancy in data collection should be employed (**Figure 6**). We simulated two variables: increasing the speed by 1.5 times (blue) and reducing it to 0.5 times the original speed (black), without altering the angular velocity. The results are as follows:

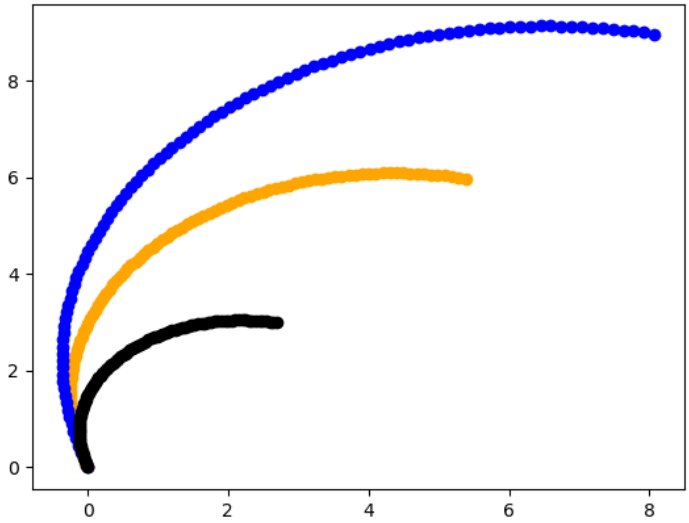

Figure 6. Simulate speed change trajectory.

Source: www.cnblogs.com/dechinphy.

From these results, we observe that the loop's arc size is primarily determined by angular velocity, with forward speed having minimal impact. However, focusing on specific local areas reveals that higher speeds result in less apparent deviation. The AI algorithms should periodically be updated based on feedback and advances in biomechanics research. We adopted two comparison schemes: one directly adjusting the ping-pong ball parameters without altering speed and angular velocity (blue track), and the other modifying the ball size while increasing angular velocity (black track). The comparison results are as follows (see **Figure 7**):

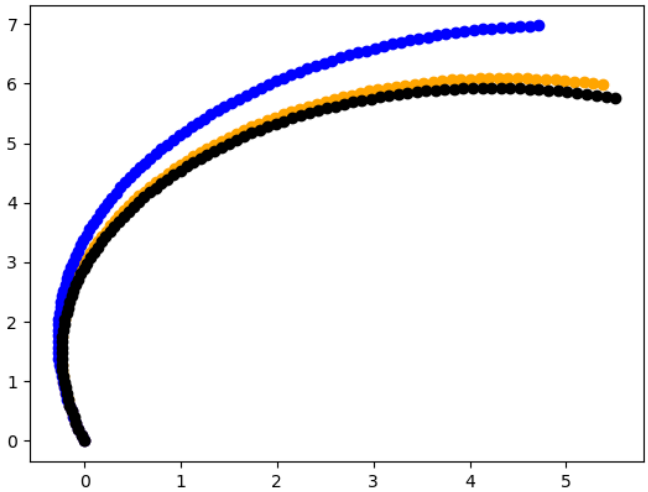

Figure 7. Comparison of ball trajectories.

Source: www.cnblogs.com/dechinphy.

The message conveyed by this result is that if we only change the big ball, but can maintain the same initial speed and angular velocity as the original small ball through training, the trajectory curvature of the big ball will be higher, or the trajectory will be more bizarre. Even if we change from a big ball to a small ball now, we need to increase the angular velocity of the big ball by 20% to achieve a more curved rotation on the small ball than on the big ball. Of course, these comparisons may be relatively one-sided and can only be used as a reference for the effect.

However, there will be a certain contrast in the training process of players. Backhand loop is one of the main techniques of horizontal racket loop players. Its speed is slightly faster than forehand loop, but its power and rotation are slightly inferior to forehand. Backhand loop can be used for serving, receiving, rubbing and turning, general attack and middle-table counter-attack, etc. It can pull the spin loop and the forward loop (from the perspective of development and innovation, the backhand fast pull technology should be improved in particular); it can be pulled near the table, and it can be pulled when retreating to the middle table, and it can create conditions for turning from passive or stalemate to active.

(1) Racket-leading stage: The player's feet are basically parallel, with the distance between them slightly larger than shoulder width. The knees are naturally bent, the waist and hips are slightly turned to the left, the abdomen is slightly contracted, the forearms are naturally bent, and the racket-leading action draws a small arc to the left and rear.

(2) Hitting stage: As the ball approaches the player, the player pushes the ground with both feet, stretches the knees, expands the abdomen, and slightly turns the waist and hips to the right. The forearm drives the wrist to exert force to the upper right front at the same time, hitting the middle of the ball, and immediately turns to friction after hitting the ball, and uses the thumb to adjust the arc of the shot. When the player pulls quickly, the hitting time is the early rising stage; when the player actively exerts force to rush forward near the table, the hitting time is the late rising stage or the peak stage; When pulling with strong backspin or pulling forward and upward from the middle table, the hitting time is the early stage of the descent; the hitting time of the middle and long table is the middle stage of the descent.

(3) Ending action: After the ball is hit, the racket gradually stops in front of the right shoulder due to inertia. You should quickly restore the racket to its original position and prepare for the next shot.

7. Conclusion

Although the application of artificial intelligence technology in table tennis training has made significant progress, and can simulate and analyze the movement path of table tennis, providing accurate data support to improve the technical level of athletes, there is still a gap between AI simulation and actual conditions. In addition, as a sport that relies heavily on skills and flexibility, the movement details and force application of table tennis are extremely complex. When simulating and analyzing these movements, the AI system may have deviations due to algorithm limitations and data collection restrictions, resulting in discrepancies between the simulation results and the actual situation. Therefore, in the actual training process, athletes still need to

adjust and optimize the analysis results of the AI system based on their own experience and perception.

In short, the application prospects of artificial intelligence technology in the field of table tennis training are broad and have great potential, but it still needs to be continuously improved and perfected. In the future, with the continuous development of technology and the gradual optimization of algorithms, the gap between AI simulation and reality will be further narrowed, thus providing table tennis players with more accurate and effective training support.

Author contributions: Conceptualization, YP and YH; methodology, YP and YH; software, YP and YH; validation, YP and YH; formal analysis, YP and YH; investigation, YP and YH; resources, YP and YH; data curation, YP and YH; writing—original draft preparation, YP and YH; writing—review and editing, YP and YH; visualization, YP and YH; supervision, YP and YH; project administration, YP and YH; funding acquisition, YP and YH. All authors have read and agreed to the published version of the manuscript.

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