Kinematic analysis of badminton smash techniques of badminton players

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ABSTRACT

Objective: To analyse the kinematic characteristics of smash in badminton and to explore the key factors affecting the effectiveness. Method: Forty badminton athletes at national level were selected from a university, and each of them performed 10 smashes in situ. They all wore sensors equipped with motion capture system, which are designed to collect their three-dimensional coordinate movement trajectories. The data then could be used to calculate the joint angular velocities, respectively of the knee, hip, shoulder, elbow and wrist. The calculation of peak angular velocities and the time lag naturally render the descriptive statistics of mean and standard deviation. Results: The transmission sequence of the badminton smash action is knee→hip→shoulder→elbow→wrist, and the joint torsion speed gradually increases during this process with the joint torsion speed increasing gradually with the transmission of the dynamic chain. The shoulder joint forward flexion contributes the most, the elbow joint speed should not be too fast, otherwise it will lead to the blockage of speed transmission, and the wrist joint rotation and deviation contribute more. The acceleration of the racket hand and the position of the centre of gravity are strongly correlated. Conclusion: The power source of the badminton smash action comes from the ankle, upper limb joints contributed significantly more than lower limb joints. A good position of gravity is beneficial for the player to start and move quickly and thus get more active opportunities to hit the ball.
Keywords: Performance analysis, Badminton, Smash, Kinematic analysis, Motion capture.

INTRODUCTION

Badminton is the fastest racket-holding sport in the world. As of 2021, the global badminton lovers have exceeded 300 million (data collected in 2021). Badminton is popular because it involves confrontation and is fun to watch. It is a combination of fashion, fitness and social intercourse. In particular, the smash action in badminton is known for its high speed and aggressive nature. In fact, the world's fastest smash has reached 426 km/h. Smash is now the main approach of scoring in the game and has become the focus of much researches (Zhang et al., 2016). The previous reports (Song et al., 2015; Liu et al., 2002) shows that the acceleration of the upper limb action is positively correlated with the ball speed, and the acceleration of the upper limb action comes from the transmission of the limb power chain, in which the proximal link to the distal link of the limb is accelerated and braked in turn, so that the end link produces the maximum speed, which is also called the whipping (Liu, 2004). However, previous studies lean heavily on the transmission of dynamic chain only of the upper limbs, losing sight of the whole body movement.

Motion capture technology is widely used in all kinds of sports as a means of capturing movements (Wang et al., 2018; Manin et al., 2014; Peploe et al., 2019; An et al., 2017). As far as badminton is concerned, it was initially video capture, where pictures were obtained through high speed cameras and video recorders; then, motion simulation was performed using those pictures, and later inertial measurement units were introduced by placing sensors on the racket for motion capture. Thanks to technology advancement, the sensors are getting smaller and the impact on the players are remarkably reduced. With the help of a whole-body motion capture system (Perception Neuron PRO), we first test the smash movements of professional high-level athletes (national level). Then, we collect data to analyse the kinematic parameters of knee, hip, shoulder, elbow and wrist as well as the dynamic chain conduction sequence, and the motion of shoulder joint in sagittal, frontal and horizontal planes. A model of the smash movements is therefore established and then used to analyse the kinetic chain conduction sequence of high-level athletes and the motion characteristics of the shoulder joint in the three-dimensional direction. In order to examine the practical significance of the research, the kinematical analysis of those high-level athletes is compared with that of players who are less good at smash. The factors affecting the quality of smash are explored using the data, and a corrected coaching plan is proposed to provide guidance for badminton training and teaching.

METHODS

Subjects
Forty professional badminton players, half male and half female, are selected for this study. The subjects are all first-rate national athletes. They join in this study of their own accord and are free of physical diseases or injuries within a month prior to testing. They have also signed the informed consent (Table 1).

Table 1. Basic information of the subjects.

Gender	N	Height/cm	Age/Years	Training year/year	Professional level
Male	20	175.45 ± 3.37	19.4 ± 1.16	10.75 ± 1.65	Level 1
Female	20	170.85 ± 5.44	19.2 ± 2.13	9.25 ± 1.29	Level 1

Data acquisition
In the gymnasium of Beijing Jiaotong University (BJTU), the motion capture system was used to collect 40 players' smash data under the guidance of professionals and coaches. The motion capture equipment (Perception Neuron PRO) is an IMU sensor-based full-body motion capture system with excellent accuracy and reliability. The Perception Neuron PRO motion capture system has a shooting frequency of 300 frames

per second and a static accuracy of <1deg roll angle, <1deg pitch angle and <1deg yaw angle. The equipment consists of one all-weather master node and 17 wireless sensors (see Figure 1), which are lightweight and small in size and do not affect the players' movements. The sports equipment is provided by Unix, our sponsor. The rackets are Extreme 700 with a string poundage of 28 ± 2b, and the shuttlecocks are Unix 5.

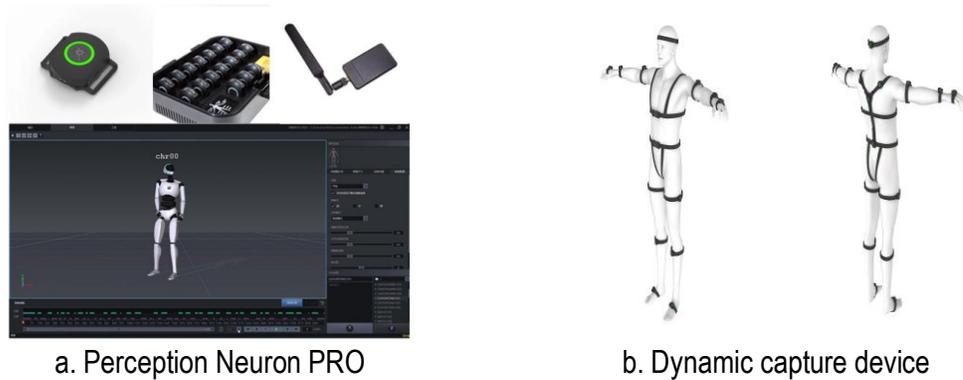a. Perception Neuron PRO   b. Dynamic capture device

Figure 1. Motion capture equipment and wearing diagram.

Before starting, 40 subjects were instructed in the test procedure and precautions (Figure 2). After that, they had 20 minutes to prepare. 3 testers and 1 coach participated in the test; 1 tester debugged the field, the main node of the equipment, as well as the computer; the other 2 testers helped the subjects to put on the dynamic capture equipment in order not to affect the movement and in the correct anatomical position as the best standard. To ensure the quality of the smash, the system was calibrated according to the standard A-Pose, with the body being upright, eyes level, arms down, palms forward, feet together and toes forward, at which time the data of all joints were 0. This test includes two contents.

Component 1: Smash technique data collection
After the "*start*" command is issued, the test subject starts to smash the straight ball , and the ball falls within the smashing zone and the hitting point is on the front side of the body for effective smashing. After the smash is finished, the coach will shout "*stop*", and each player will complete 10 effective smashes, totalling 400 times. (Figure 2).
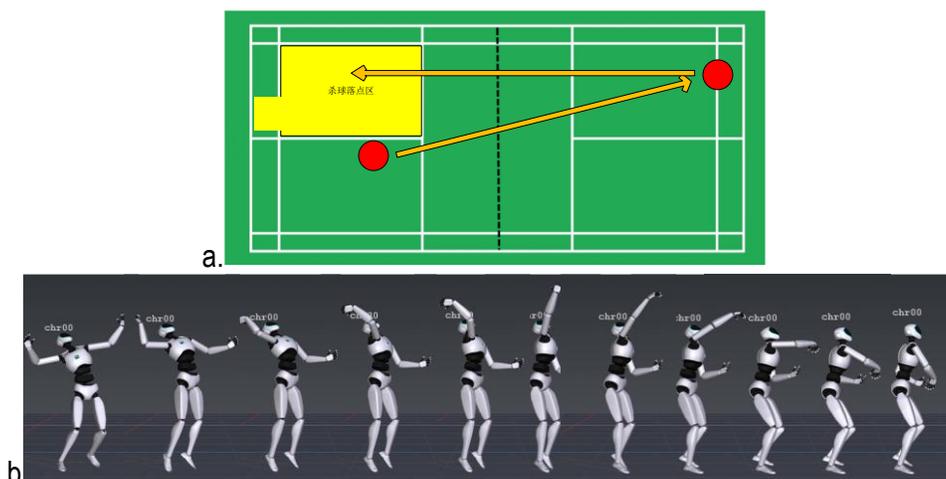

Figure 2. a Diagram of the route after hitting a shuttlecock, b Trajectory for smash.

Content 2: Athletes' starting, moving and hitting data collection
This part tests the relationship between the position of the centre of gravity at the moment of a player's start and the effect of hitting the ball. 40 players are grouped by the coaches, with two players in the same group and close to the same level, for a total of 20 groups. Each pair of players in turn played an 11-run game in which both players wore motion capture equipment. After the "*start*" command, the athletes began to play, and began to collect data, 11 points after the game, the next pair of athletes in turn.

Data processing
When the subject performs the movement, the master node collects the signal from the sensor by radio, and the computer records the raw data such as displacement coordination, acceleration, and angular velocity in three-dimensional space in real time at 300 frames per second. The technical movements are made by the combination of the movements of different joints of the human body, so the data are further converted, and according to the human anatomy method, the human body movements are divided into three mutually perpendicular tangential planes and three mutually vertical basic axes, namely sagittal plane, frontal plane, horizontal plane and sagittal axis, frontal axis and vertical axis (Figure 3).
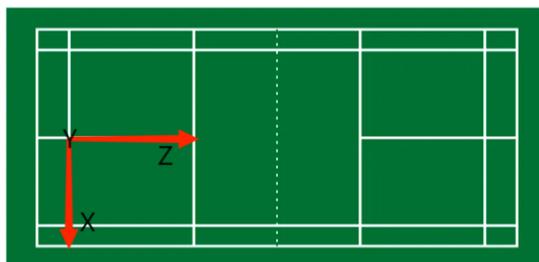

Figure 3. Illustration of 3D coordinate axes in badminton court.

Through the relative position changes of the two sensors, mathematical operations are performed to calculate the angular velocity changes of different joints in the three vertical planes and axes. For example, if the motion of the elbow joint through the relative motion of the large and small arm sensors are to be calculated, the following formula could be applied:

Angular velocity
The measured part of the athlete is assumed to be in uniform circular motion during the short period, i.e., the angular velocity ω is assumed to be a constant quantity. The angular velocity ω is expressed as the ratio of the angular displacement $\triangle\theta$ of the measured joint part of the badminton player to the line of gravity of the body and the corresponding time interval Δt , as shown in Equation (1).

$$\omega = \Delta\theta / \Delta t \qquad\qquad (1)$$

Where, the angular displacement $\triangle\theta$ is the difference of angles in the time interval Δt . Define the coordinate point of an athletic joint at the moment t as $(x_t,\ y_t,\ z_t)$, then the joint is in the frontal plane, i.e. z_t = 0. The angular displacement $\triangle\theta$ at the moment t is calculated as shown in Equation (2).

$$\Delta\theta = \arctan(\frac{y_t - y_{t-1}}{x_t - x_{t-1}}) \qquad\qquad (2)$$

The joint definitions, angles and directions of motion for different joint movements are explained in Table 2.

Table 2. Calculation of joint activities.

Joint	Definition of the joint	Movement parameters
Hip	Connection of the pelvis to the right thigh	Internal rotation (+)/External rotation (-)
Knee	Connection of the right thigh to right calf	Internal rotation (+)/External rotation (-)
Shoulder	Connection of the right shoulder to the right upper arm	Internal rotation (+)/External rotation (-) Flexion (+)/Extension (-) Inward (+)/Outward (-)
Elbow	Connection of the right upper arm to the right lower arm	Flexion (+)/Extension (-) Inward (+)/Outward (-)
Wrist	Connection of the right upper arm and hand	Internal rotation (+)/External rotation (-) Flexion (+)/Extension (-)

Acceleration
The ratio of the change in angular velocity Δω of the rotating rigid body from instantaneous time t to the corresponding time interval Δt is called the average angular acceleration. The angular displacement $\triangle\theta$ at time t is calculated as shown in Equation (3).

$$\alpha = \Delta\omega / \Delta t \qquad (3)$$

Centre of gravity
In the space where the athlete is located take the spatial right angle coordinate system O-xyz shown in Figure 3, the athlete's weight is M. The athlete can be divided into N masses according to the test joint parts. Biomechanics theory considers the human body as a non-homogeneous object and the divided body parts are considered to be homogeneous, then each mass, corresponding to the respective coordinates(X_i, Y_i, Z_i) and mass mi. known, let the athlete's centre of gravity be G (X, Y, Z), then the equation for the centre of gravity is shown in equations (4)-(6).

$$X = (x_1 m_1 + x_2 m_2 + ... + x_i m_i + ... + x_N m_N)/M \qquad (4)$$

$$Y = (y_1 m_1 + y_2 m_2 + ... + y_i m_i + ... + y_N m_N)/M \qquad (5)$$

$$Z = (z_1 m_1 + z_2 m_2 + ... + z_i m_i + ... + z_N m_N)/M \qquad (6)$$

The centre of gravity coordinates are further subjected to a maximum difference calculation, i.e., the difference between the maximum and minimum values on each of the three axes is calculated in a complete killing action, indicating the distance travelled in different directions.

Gravity lines and support lines
As shown in Figure 4, the gravity line refers to the vertical line of the body's centre of gravity on the ground at the moment of initiation, and the support line refers to the edge line connecting the two feet on the ground part (Lin, 1983). It is known that, let the coordinates of the point mapped on the ground by the gravity line be M（X, Z）, then the calculation formula is equation (7) and (8).

Figure 4. Diagram of athlete's centre of gravity at the moment of start (Quoted from Lin Chuanchao 1983).

The coordinate points of the two feet are known to be $N1(x1, y1, z1)$ and $N2(x2, y2, z2)$, Then the formula of the support line is shown in equations (7) and (8).

$$k = (y_2 - y_1)/(x_2 - x_1) \tag{7}$$
$$y = kx - kx_1 + y_1 \tag{8}$$

Then, it is known that the ground mapping point M of the gravity line and the formula of the support line, let the distance from M to L be S, then the formula of S is shown in equation (9).

$$S = \frac{|(kx_0 - y_0 - kx1 + y1|}{\sqrt{1 + k^2}} \tag{9}$$

Data processing
Firstly, the original data are converted, filtered and smoothed, etc. The Perception Neuron PRO analysis system is used to convert the original data and obtain the angular velocity of different joints in three-dimensional space from anatomical point of view, and a hitting cycle is selected from the end of the previous action to the end of the next action. The technical movements were divided into four stages: preparation, introduction, hitting and follow-through swing. The weighted filtering of each resolved 3D coordinate curve is performed using the Savitzky Golay Filter, and the weighted weights are obtained by least-squares fitting of a given higher-order polynomial, which makes the filtered and smoothed data more effective in retaining the signal variation information (He et al., 2018).

Mathematical statistics
Descriptive statistics were performed on subjects' age, height, years of training, and test results as mean and standard deviation. Independent samples t-tests were conducted for different joint angular velocities of male and female athletes respectively using SPSS 19.0. Then, descriptive statistics for mean and standard deviation were conducted.

RESULTS

Power chain conduction sequence characteristics of smash
The statistics of the change of angular velocity of different joints during the smashes by high-level players are shown in Figure 5.
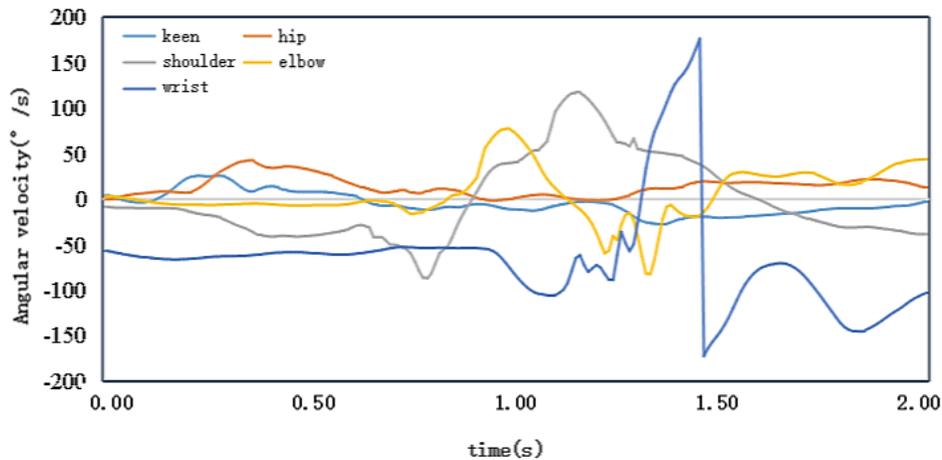

Figure 5. The curve of angular velocity of smashes conducted by high level players.

Table 5. Statistics of time difference and peak angular velocity of different joints.

Indicators	Joint	Males		Females	
		Average value	Standard deviation	Average value	Standard deviation
Time difference (s)	Knee → Hip	0.09	0.04	0.15	0.06
	Hip → Shoulder	0.13	0.03	0.18	0.07
	External shoulder rotation → Elbow flexion	0.15	0.04	0.3	0.08
	Elbow flexion → shoulder internal rotation	0.25	0.08	0.44	0.12
	Shoulder internal rotation → Elbow extension	0.37	0.09	0.52	0.12
	Elbow extension → wrist	0.56	0.06	0.94	0.08
	Total time	1.55	0.07	2.54	0.08
Peak angular velocity (°/s)	Knee	33.04	1.72	26.09	3.21
	Hip	48.34	1.91	39.82	5.36
	Shoulder external rotation	69.61	1.63	40.43	5.34
	Elbow flexion	98.54	1.16	54.75	6.12
	Shoulder internal rotation	129.45	5.06	85.65	5.47
	Elbow Extension	167.09	7.70	84.36	7.12
	wrist	173.14	4.65	143.37	5.71

From Figure 5, it can be seen that there are differences in the timing of the peak angular velocity of different joints: following the order of knee-hip-shoulder-elbow-wrist, and the peak angular velocity increases in this sequence. In addition, there are respectively two high and two low peaks in the shoulder joint and elbow joint. The peak maximum angular velocity of and the time difference between the occurrence of adjacent peaks of the five joints of knee, hip, shoulder, elbow and wrist during the smash of 40 male and female students were counted (Table 5). In Table 5, the mean value of the "*hip-knee*" time difference represents the difference between the moment of the peak velocity of the knee joint and the moment of the peak velocity of the hip joint, i.e.

As can be seen from Table 5, the whole hitting phase was divided into 6 parts: knee → hip, hip → shoulder, shoulder external rotation → elbow flexion, elbow flexion → shoulder internal rotation, shoulder internal rotation → elbow extension, and elbow extension → wrist. The time differences among different joints of male athletes were smaller than their female counterparts. Meanwhile, the mean value of the total time difference for male players was 1.55s, which was 0.99s less than female players, whose time difference was 2.54s. The data also showed that the average time spent on smashes was shorter for male athletes. In addition, the angular velocity of the males' wrist was 173.14°/s, which was 29.77°/s higher than the 143.37°/s of the females, indicating that the former were faster than the latter.

Upper limb kinematic characteristics of badminton smash
As mentioned in the previous section, in badminton smash action, the velocity change of the upper limb joints is significantly greater than that of the lower limb, and this part mainly analyses the angular velocity change characteristics of the three joints of the upper limb in the three techniques (see Figure 7).
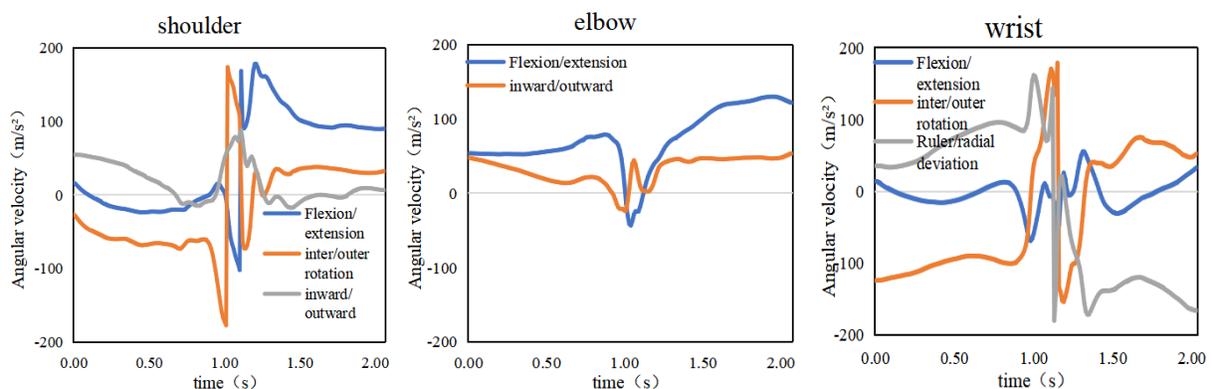

Figure 7. Upper limb joints movement diagram during the smash.

The shoulder joint has three dimensions of change, flexion/extension, rotation, inward/outward respectively. In terms of time sequence, external rotation appeared first, followed by inward and extension, then turned to internal rotation and flexion; the elbow joint has changes in two dimensions, flexion/extension and inward/outward respectively. The elbow joint changes from flexion to extension at the moment of hitting the ball, with no significant changes in inward and outward dimensions, and the angular velocity change of the elbow joint was much smaller than that of the shoulder and wrist joints; the velocity change of the wrist joint was larger than that of the shoulder and elbow, with significant changes in the angular velocity of the ulnar deviation and radial deviation and rotation dimensions, and the angular velocity change of the ruler/radial deviation and rotation dimensions The change in angular velocity in the flexion/extension dimension was smaller.

As mentioned in the previous section, the shoulder joint of the racket holder needs to be externally rotated and then internally rotated during the smash. Since the shoulder joint is the most complex joint in the human body and plays an important role in the dynamic chain transmission, The data were summarized for the 3D movement time characteristics of the shoulder joint, as shown in Table 4.

Table 4. Shoulder joint time difference and peak angular velocity statistics.

Indicators	Joint	Males		Females	
		Average value	Standard deviation	Average value	Standard deviation
Time difference(s)	External rotation → Internal retraction(A→B)	0.05	0.05	0.05	0.07
	Inward → flexion(B→C)	0.22	0.04	0.56	0.09
	Flexion → Abduction(C→D)	0.07	0.03	0.08	0.03
	Abduction → External rotation (D → E)	0.35	0.08	0.56	0.09
	External rotation → internal rotation (A → E)	0.69	0.06	1.19	0.06
	Inward → Outward (B → D)	0.05	0.05	0.05	0.07
Peak angular velocity (°/s)	External rotation (A)	-110.08	4.67	-81.92	3.14
	Inbound (B)	47.08	7.31	37.73	7.54
	Flex(C)	154.89	17.7	119.10	7.69
	Outreach (D)	-58.43	9.01	-66.75	8.22
	Internal rotation (E)	138.30	6.9	107.61	6.48

As can be seen from Table 4, the average time taken by male athletes to go from external to internal rotation was 0.69s, which was 0.50s lower than that by male athletes, who took 1.19s, i.e. the former finished the smash faster than the latter. During the backward lead of the upper arm, the time difference between internal and external rotation was smaller and almost simultaneous, 0.05s for males and 0.07s for females, indicating that the internal and external rotation movements were almost simultaneous. For the shoulder joint movement in all 5 directions, the peak angular velocity of joint flexion was the largest, indicating the higher importance of shoulder joint flexion forward and downward during the action. The peak angular velocity of joint flexion was 154.89°/s for male players, 34.79°/s faster than female player, who took 119.10°/s. This also explained why male athletes could finish the smash in a shorter period of time than their female counterparts.

Characteristics of the relationship between the position of the body's centre of gravity at the moment of initiation and the effect of smash

The distance from the mapping point of the player's centre of gravity on the ground to the support line at the moment of initiation is calculated. A positive value indicates that the mapping point is on the front side of the support line, i.e., the body leans forward at a greater angle, and a negative value indicates that the mapping point is on the back side of the support line, i.e., the body leans back more. The relationship between this distance and the wrist acceleration during the stroke of the kill technique is shown in Figure 8.

The following characteristics can be seen from Figure 8. With the change of the distance between the gravity mapping point and the support line, the smash show regular changes, and the wrist acceleration values are the largest at the 0 point position; to the left of point 0, the acceleration decreases rapidly with increasing distance; and to the right of point 0, the acceleration decreases relatively slowly with increasing distance. In order to further explore the relationship between the position of the centre of gravity and the hitting effect at

the moment of player initiation, Pearson correlation analysis was conducted on the distance and the wrist acceleration at the moment of hitting, and the result is 0.716.
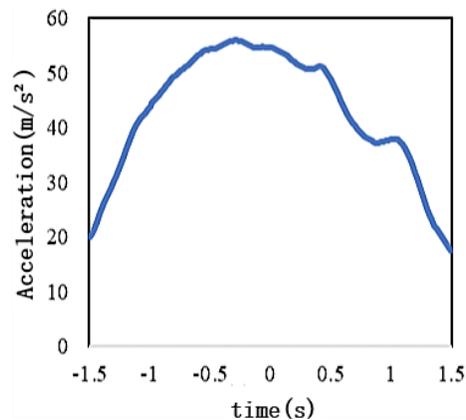

Figure 8. Relationship between mapping point distance and wrist acceleration.

DISCUSSION

Power chain characteristics of badminton players' smash action
Structurally, the human body is connected together by joints to form a complete power chain, and when the end of the power chain is needed to generate maximum speed, the body behaves as a sequential acceleration from the proximal link to the distal link, and this action of making the end link generate maximum speed is also called whipping action (Liu, 2004). The power chain plays a central role in the action process in the field of competitive sports and plays an important role in the completion of action techniques and the monitoring of training quality (Jiang, 2013).

The dynamic chain system of badminton smash action comes from the lower limb muscles doing work to generate torque, which is transmitted up to the elbow and wrist through the knee, hip and shoulder, activating the trunk and upper limb muscles in turn to maximize the angular velocity of the bones, and finally transmitted to the arm to complete the action. The power source during this process comes from the lower limb stirrup turn to make the body produce faster speed, from the lower limb to the upper limb in turn to produce braking, forming the wrist whipping action. The conduction of the dynamic chain allows the joints to twist in a speed that continues to spike to the maximum, and thus the sequence of time is knee - hip - shoulder - elbow - wrist. In previous studies, the order of badminton power chain transmission presents two views, one view that the power source of badminton backcourt technique is in the core area, from which the power is transmitted upwards, driving the shoulder, elbow and wrist joints to accelerate in turn (Lam et al., 2018), the second view that the ankle joint is the power source of badminton backcourt technical movements, from the bottom upwards in order of ankle-knee-hip-shoulder-elbow-wrist, the results of this study support the second view.

The low and high peaks of the shoulder joint represent the external and internal rotation of the shoulder joint during the lead, i.e., the time interval of the high and low peaks of the angular velocity of the shoulder joint represents the movement change of external rotation and then internal rotation of the shoulder joint during the lead. Likewise, the high and low peak angular velocities of the elbow joint represent the change in movement of flexion followed by extension. The preparation phase is composed of four movements: preparation, introduction, hitting and swinging. After preparation, the right foot stirrup turns to generate internal rotation of the knee joint, the hip and above joints produce braking, the dynamic chain is transmitted

upward, the hip joint starts to accelerate internal rotation, driving the torso to rotate forward, the body weight is transferred from the back foot to the front foot, the power chain is transmitted to the shoulder joint, firstly, the racket is introduced to the lower back, i.e. the shoulder joint is externally rotated, the large and small arms When the head of the racket reaches the bottom, the racket is finished. When the head of the racket reaches the bottom of the racket, the racket is finished. When the ball is hit, the shoulder joint rotates from external to internal rotation, and the racket is swung forward and upward, the elbow joint extends quickly, driving the wrist racket to the highest point, and then the wrist flashes downward quickly to hit the ball. Therefore, according to the sequence of high and low peak, the actions follow the order of knee - hip - shoulder external rotation - elbow flexion - shoulder internal rotation - elbow extension - wrist.

As for the dynamic chain transmission involving knee-hip-shoulder-elbow-wrist, the time difference increased sequentially for both sexes, from 0.09s to 0.56s for males and from 0.15s to 0.94s for females, probably due to the increasing joint movement from the bottom to the top, which required more time, leading to increased time difference between the peaks of different joints. The dynamic chain sequence of male and female athletes was the same, but the peak angular velocity of different joints and the time difference between the peaks were different. Due to different physiques, the explosive power and speed of male athletes were significantly higher than those of female athletes, so the peak angular velocity of joints of male athletes were both greater than those of female athletes, and the time required to complete the movement was shorter than their female counterparts (Pueo & Jimenez-Olmedo, 2019).

Kinematic characteristics of the Upper limb joints in badminton smash action
When the dynamic chain is transmitted to the shoulder joint, it enters the leading phase and the upper arm starts to do the leading loop to the back of the shoulder, and it rotates and accelerates gradually. In the previous dynamic chain analysis, we found that the order of transmission is shoulder, axis, wrist, so the speed of the upper arm external rotation should be the first to reach the fastest, the lower arm and wrist continue to lead the racket to the bottom to reach the fastest speed. Meanwhile, the shoulder joint turned to the inside, so that the racket can reach the bottom. When that happens, the angular speed of the shoulder joint extension reaches the maximum, and the lead phase ends. When entering the hitting phase, the shoulder joint drives the upper and lower arms to swing forward and upward, and they start to change from external rotation and extension to internal rotation and flexion, which drives the elbow joint to turn outward and gain momentum. The peak of forward flexion and internal rotation at the moment of hitting was greater in the kill technique, and this study concluded that the contribution of these two was higher at the time of hitting. This result is similar to the results of Takenori Awatani et al. which correlated shoulder flexion and extension and rotation velocity with racket speed in the backcourt killing technique, respectively, and showed that both shoulder flexion and extension velocity and rotation velocity were significantly correlated with racket speed with correlation coefficients of 0.652 and 0.728 respectively (Awatani et al., 2018).

By comparing the shoulder, elbow and wrist joints longitudinally it can be found that the peak angular velocity of the elbow joint is significantly smaller than that of the shoulder and wrist, a result similar to that of Yuvaraj Ramasamy et al. This study analysed the backcourt technical movements of elite Malaysian players and concluded that greater stirring power and swing speed could speed up the stroke, but at the same time, care should be taken that the elbow joint should not be too fast, otherwise it would lead to a block in velocity transmission (Ramasamy et al., 2021). In the flexion-extension curve, the angular speed of flexion remains relatively high in the lead phase, and the speed drops significantly in the stroke phase, with a downward spike. Analysing the reason, it may be due to the backward and downward lead phase, the need to flex the elbow to drive the small arm and hand downward to lead the racket, to obtain a greater acceleration distance, and the hitting phase to swing forward and upward, from flexion to extension (Hajdu-Szucs et al., 2018).

The results of previous studies concluded that the wrist rotation contributed the most (King et al., 2020). Unlike the results of previous studies, the test results of this study showed that the peak angular velocity of wrist ruler/radial deviation was similar to the peak of internal and external rotation, which means that the ulnar radial deviation also had a higher contribution. The reason for this result mainly lies in the fact that scholars have different opinions regarding the location of the hitting point, some scholars believe that it is above the front of the head, while some studies believe that it is above the front of the right shoulder (Chin et al., 1995).Combined with the badminton grip principle, when the hitting point is above the front of the head, there is no change of ruler and radial deviation, while when the hitting point is above the front of the right shoulder, the wrist is in ulnar deviation posture at the moment of hitting (Qiang, 2001). This study confirms the theory that the hitting point is above the front of the right shoulder.

Therefore, the shoulder joint forward flexion contributes the most, the elbow joint speed should not be too fast, otherwise it will lead to the blockage of speed transmission, and the wrist joint rotation and deviation contribute more.

Characteristics of the relationship between the position of the body's centre of gravity at the moment of initiation and the effect of the killing technique
The implementation of badminton match tactics need to rely on reasonable techniques and footwork to complete, both sides take different tactics according to the situation on the field to maximize the mobilization of the other run, destroy the rhythm of the other side, cause the other side to be passive, and launch an attack when we take the initiative to win (Yu et al., 2008). Each technical action requires four steps: starting, moving, hitting, and returning. Start, move and return are all steps, and the three technical movements analysed above are strikes. At the moment of starting, whether the athlete's gravity line falls on the support surface is an important basis for judging whether the athlete is passive or not. After starting, the athlete moves to the position where the ball is to hit the ball through footwork, and early moving into place and active hitting can achieve better hitting effect. In addition to the technical level, does the hitting effect also have a relationship with the position of the centre of gravity? There are few studies on centre of gravity adjustment and hitting effect at home and abroad. Japanese scholars studied the centre of gravity sway characteristics of players and concluded that athletes with strong centre of gravity adjustment have better sports performance (Masu & Nagai, 2016).

In this study, an attempt was made to investigate the relationship between the position of the player's centre of gravity at the moment of initiation and the effectiveness of the stroke. In terms of the assessment of the stroke effect, since there are many factors that affect the effect of the technique, such as the player's technical level, physical state, and the position of the centre of gravity at the moment of stroke, this paper only discusses the effect of the position of the centre of gravity at the moment of stroke on the effect of the three techniques, using whether the acceleration of the player's hand at the moment of stroke is affected as the basis for judgment. It has been proved that wrist acceleration is highly correlated with racket head acceleration, and the faster the wrist acceleration, the faster the racket head acceleration follows, so the wrist acceleration can be used as a measurement of racket head speed (Kwan et al., 2011).

According to Pearson's critical criteria for correlation, r values between 0.6 and 0.8 are strongly correlated, the acceleration of the racket hand and the position of the centre of gravity are strongly correlated, therefore, a good position of gravity is beneficial for the player to start and move quickly and thus get more active opportunities to hit the ball. The distance has a great influence on the effect of smash.

Limitations and perspectives

Although the subjects were all national level athletes with a high level of athleticism and stability, there were still individual differences between players, which made it difficult to count our data. In the test of centre of gravity, the difference of athletes' physical fitness and physical condition also has some influence on the test data. Maintaining a good centre of gravity position at the moment of initiation has a facilitating effect on the effectiveness of kills and high balls. It is recommended to increase the practice content of centre of gravity adjustment ability in the training of athletes and to focus on the evaluation of shoulder pronation, elbow flexion, wrist internal rotation and ulnar deviation in the technical evaluation.

CONCLUSION

This study analyses the kinematic parameters of smash actions of high-level badminton players with the aid of motion capture technology. The dynamic chain of smash in badminton is knee → hip → shoulder → elbow → wrist, which can be further divided into knee → hip → shoulder external rotation→elbow flexion → shoulder internal rotation → elbow extension → wrist, with the joint torsion speed increasing gradually with the transmission of the dynamic chain, and upper limb joints contributed significantly more than lower limb joints. The shoulder joint forward flexion contributes the most, the elbow joint speed should not be too fast, otherwise it will lead to the blockage of speed transmission, and the wrist joint rotation and deviation contribute more.

The acceleration of the racket hand and the position of the centre of gravity are strongly correlated, therefore, a good position of gravity is beneficial for the player to start and move quickly and thus get more active opportunities to hit the ball. The distance has a great influence on the effect of smash.

AUTHOR CONTRIBUTIONS

SUPPORTING AGENCIES

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

AVAILABILITY OF DATA AND MATERIALS

All data generated and analysed during this study are included in this published article.

ACKNOWLEDGEMENT

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