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Motion Analysis of Chinese Bajiquan Based on Three-dimensional Images of Biomechanics

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Abstract: *With the development of sports biomechanics, human motion mechanical characteristics have received more and more attention from plenty of researchers. Therefore, how to analyze the biomechanics of the living body has become the principle problem at the present stage. In this study, the three-dimensional (3D) image was adopted for a sport dynamics analysis of the riding style of the Chinese Bajiquan. First of all, the change rules of the temporal characteristic parameters when the research objects in the experiment group and the control group completing the riding style action were analyzed based on the characteristics of the action; in the initial stage of the action, the movement speed was relatively slow, and with the center of gravity of the right feet moving down, stable support was formed. Secondly, parameters such as hip joint angle and knee joint angle, etc., were tested from the perspective of dynamics sensors and a rigid block model was constructed to accurately calculate the joint angle. The hip joint guaranteed the stability of center of gravity during movement; the fluctuation of the ankle joint was relatively small, while the maximum fluctuation range of the trunk angle during movement was small, which could keep the upper limbs up straight as well as reduce fluctuation, and the lowering of the center of gravity was good for the stability of the lower limbs. When the riding style action was completed, the toes of the research objects in the experiment group would buckle subconsciously to control the balance of the body. Therefore, the riding style requires the interaction among different parameters, which conforms with the characteristics of the Chinese Bajiquan.*

Keywords: *Multi-sensor system, Information fusion, Fire monitoring, Neural network.*

Introduction

Currently, sensors are extensively applied to the field of sports bio-mechanics, which further improves the accurate measurement and analysis of movements. As the sensor technology constantly develops and improves, there will be more and more types of sensors that can be applied to the field of sports biomechanics. Thus, the analysis of movements becomes more accurate, which has a positive effect on improving Wushu sport performances as well as innovating movement [1, 8, 10]. Some researches indicated that sports biomechanics was mainly used to analyze highly difficult actions in competitive sports [5, 11, 12], which provided analysis of classical Chinese martial arts movements using biomechanics methods with theoretical supports.

Zhang [17] carried out a study and found that frequent exercises of Bajiquan were beneficial to the health of human body. Therefore, it is of significance to promote the Chinese Bajiquan. Experts in the field of the Chinese Bajiquan believed that, although the Chinese Bajiquan had been included in the national intangible cultural heritages [15], future development of Chinese Bajiquan would still face great challenges according to its current development status, which was mainly reflected in the lack of scientificity, deepness and systematization in its research means, etc. [9]. Facing the inheritance dilemma in a new period, Wang [14] analyzed as well as put forward relevant countermeasures. Besides, the whole boxing school lacked overall planning and the inheritors lacked a scientific theoretical system [16]. Moreover, the lag-behind inheritance pattern was also the main reason which hindered extensive development of the Chinese Bajiquan. Therefore, combining the three-dimensional image technology with biomechanics sensors, this study discusses the biomechanics characteristics of the riding style of Chinese Bajiquan, aiming to accurately detect and analyze the movement data and provide theoretical basis for the innovation and improvement of the Chinese Bajiquan.

General Information

Basic information

Twenty professional trainers from the Heilongjiang Bayiquan Association in China were selected as the research objects in this study, and the riding style action of Chinese Bajiquan of each of them was subjected to a biomechanical test. The selected 20 trainers were in good health condition and proficiency in action, which was easy for analysis. Besides, 20 Chinese Bajiquan beginners in the Association were selected as the control group and were given biomechanics researches. All research objects signed an informed consent before the study.

Research methods

The main contents of human sport dynamics include applied kinematics and dynamics [6]. The movement of creatures results from the synergistic effect of the muscular system, the skeletal system and the nervous system [2]. In this study, according to the main requirements of the three-dimensional (3D) direct linear transformation (DLT) method, two digital cameras operated synchronously during the shooting of 3D images; cameras were set up 1.2 m above the ground, the viewfinder coverage was 3 m and the shooting frequency was 50 Hz; both cameras shot in fixed point and fixed focus. After the experiment, data of the center of the body weight, the trunk, the displacement speed of the articulation points, the angle between each articulation point and the trunk and the duration of each time period of each movement were analyzed by biomechanics teachers using a 3D kinematics analysis software; besides, the digital filter method was adopted for smooth processing of the initial data and the cutoff frequency was 10 Hz. During the joint angle measurement, angle sensors should be fixed at the hip joint, the knee joint as well as the ankle joint. The angle sensor was composed of two measuring arms and a wire-wound potential meter.

As the riding style action started, resistance values of the wire-wound potential meter changed accordingly and electrical signals were output [13]. When the next action started, the joint angle sensors recorded the relative angles of each joint. However, due to the interference of alternating electrical signals, the loosening of the sensors or other external force factors, the relative center of rotation of each joint could change, resulting in measurement errors. Therefore, this study constructed a rigid block model of sensors.

Detection indexes

In Table 1 the characteristics and parameters of the riding style action are shown.

Detection of joint angle parameters based on the angle sensor

The rigid block model regards the human body as a composition of joints and links, which is expressed by the degree of freedom. Links are the rigid body that has shapes and quality, just like the constituent parts of human body. Therefore, the human body model is usually regarded as a multi-rigid-body system that is composed of multiple links (rigid body) and joints.

Table 1. Characteristics and parameters of the riding style action

Characteristic parameters	
Movement stages	Description
Double-leg support – one-leg support (v1)	The moment from double-leg support to the rear foot off the floor
One-leg support – horse stance with one leg touching the floor (v2)	The moment when the rear foot was lifted off the floor and moved backwards till the heel touched the floor
Horse stance with one leg touching the floor – finish (v3)	The moment when the heel of the rear foot touched the floor and the whole sole supported the center of gravity

We assumed that there was a sensor at a random place in the rigid block model. After the known sensor data were processed, the output value of the sensor of any movement was calculated. For the convenience of calculation, the sensor was mathematically described first. We assumed that that the difference between the upward accelerated speed and the acceleration of gravity of the sensor was S and $S=(a-g)n$. In the equation, n refers to the upward unit vector of the sensor, thus the expressions of the sensor on axis X and axis Y were $S_X=(a-g)u_X$; $S_Y=(a-g)u_Y$, respectively. Derivation of the angular speed of the rigid body to the unit vector was $\omega=n\frac{\partial n}{\partial t}$.

To simplify the model, the motion decomposition state of the rigid body was designed as the linear motion of the non-inertial reference point P. Thus, the relationship between the output value of sensor and the sensor output value at the P point was

$$R_\kappa\begin{bmatrix}S_X\\S_Y\end{bmatrix}=R_\lambda\begin{bmatrix}S_X\\S_Y\end{bmatrix}+\frac{\partial^2 R}{\partial^2 t} \tag{1}$$

In the equation, R_κ, R_λ were the rotation matrix of the P sensor and the original sensor with respect to the vector R.

The vector R direction and the normal direction were decomposed respectively:

$$\frac{\partial^2 R}{\partial^2 t}=\frac{\partial}{\partial t}(\dot{R}u_R)=-R\frac{\partial R}{\partial t}u_R+R\frac{\partial^2 R}{\partial^2 t}u_\theta \tag{2}$$

The right side of the equal sign could be solved through output values. The output value of the original sensor was the same as this result.

The Eq. (2) was substituted into Eq. (1), thus the relationship between the output values of the P sensor and the original sensor could be obtained:

$$\begin{bmatrix} S_X{}' \\ S_Y{}' \end{bmatrix} = R_{-\kappa}\left(\begin{bmatrix} S_X \\ S_Y \end{bmatrix} + \begin{bmatrix} -R\omega^2 \\ R|\omega| \end{bmatrix}\right) \quad (3)$$

Sensors were installed at random places in the rigid body. Output values of sensors at the joints were calculated respectively. Because the angular speed of the same point during movement was fixed, the calculated results of the two groups were considered to be the same. Considering the angular difference between the two groups of coordinate systems, the expression could be

$$\begin{bmatrix} S_X 1 \\ S_Y 1 \end{bmatrix} = R_{\varphi}\begin{bmatrix} S_X 2 \\ S_Y 2 \end{bmatrix} \quad (4)$$

Its polar coordinate form was $S_1 = e^{i\theta 1}S_1; S_2 = e^{i\theta 2}S_2$, thus the joint angle was $\varphi = \theta 1 - \theta 2$. A collection of joint angles is shown in Tables 3, 5, 6 and 7.

Statistical method

All acquired biomechanics data in this study were analyzed using SPSS 19.0 software and the results were expressed in the form of mean ± SD; the standard of significance was $\alpha = 0.05$; $p < 0.05$ means that there was a statistical difference, and $p < 0.01$ means that there is a significant statistical difference.

Research results and analysis

General information of research objects

The general information of research objects is shown in Table 2.

Table 2. General information of research objects

Group	**Number**	**Age (years old)**	**Height (cm)**	**Weight (kg)**	**Body mass index**	**Training years**
Experiment group	20	65.28±3.64	164.03±4.28	86.54±7.38	26.34±4.57	3.32±0.84
Control group	20	66.15±3.52	163.86±3.96	78.62±7.54	25.71±3.64	0.59±0.13

Body postures

Changes of the trunk angle, the center of body weight and the toe angle have a decisive effect on the stability of body while performing the riding style action.

The trunk angle mainly reflects the upright condition of body during movement [7]. Movements should be standard and the body should be upright to guarantee that the posture is correct. According to the changes of the trunk angle of the research objects in the two groups, the maximum fluctuation range of the trunk angle of the experiment group was 6.15±2.18°, which was significantly different from that of the control group (10.03±4.14°) ($p < 0.01$). Therefore, the trunk of the research objects in the experiment group was relatively stable when the action was completed, and such kind of upright status could guarantee that the center of body weight was located within the bearing surface of the feet.

Changes of the center of body weight refer to the changes of general gravity center of the human body [4]. 3D images showed that the bigger the fluctuation range of the gravity center of the body, the higher the requirement on the muscle during movement; thus, relevant muscle force was needed to overcome the resistance increased by the gravity changes. Therefore, it could be concluded that big fluctuation of the gravity center of the body in the non-movement direction should be avoided during movement. As shown in Table 3, in the initial stage of the action, the gravity center of the research objects showed no difference; as the right foot touched the floor, the gravity center of the right foot showed a certain degree of decline, which was beneficial to the stability of the lower limbs.

The Chinese Baijiquan also includes toe buckle, thus changes of toe angle were also explored in this study. Results showed that the fluctuation of the toe angle of the research objects in the experiment group kept in a small range, while the fluctuation range of the control group was big, especially the moment when toes touched the floor, the toe angle reached 23.12±4.84°. Thus we could know that when research objects in the control group accomplished the riding style action, their toes were obviously outward. When the toe buckle increased the movement range of internal rotation of the knee joint, the bearing surface formed by the forward toes was bigger than the trapezoidal bearing surface formed by the outward toes; with the increase of the bearing surface, the stability of the gravity center of the body also increased. Detailed data are shown in Table 3.

Table 3. Changes of trunk angle, center-of-gravity position and toe angle of research objects in two groups

Group	**Trunk angle**		**Center-of-gravity position**	
	Experiment group	**Control group**	**Experiment group**	**Control group**
Time of lifting the right foot	5.27±1.85	6.20±1.48	82.31±2.63	81.37±3.23
Time of the right foot touching the floor	6.13±2.01	7.37±2.29	78.67±2.71	77.66±2.55
Finish time	7.81±2.12**	12.15±1.91	58.48±3.16**	67.88±3.71
Maximum movement range	6.15±2.18**	10.03±4.14	23.76±3.45	13.53±3.14

Group	**Toe angle of the left foot**		**Toe angle of the right foot**	
	Experiment group	**Control group**	**Experiment group**	**Control group**
Time of lifting the right foot	8.52±1.26	10.56±1.32	12.20±1.64	17.62±3.14
Time of the right foot touching the floor	9.23±1.01	15.94±1.54	7.63±1.52	23.12±4.84
Finish time	5.16±0.74	17.82±1.03	4.87±0.89	13.50±1.86

Note: compared with the control group, * means $p < 0.05$ and ** means $p < 0.01$.

Dynamics test analysis

As shown in Table 4, during the whole process of the riding style action, the change rate of the gravity center was slow, which was related to the characteristics of the riding style action. As the right foot lifted and fell, the center of gravity also changed so as to keep the balance of body. The ankle angle kept at around 38° during the process of lifting and falling of the right foot. However, although the change speed of the knee angle was fast, there was no significant difference between the two groups ($p > 0.05$).

Table 4. Dynamic data

Group	Velocity of the gravity center, (cm/s)	Velocity of the ankle angle, (°/s)	Velocity of the knee angle, (°/s)
Experiment group	-12.48±0.64	-38.16±2.14	101.02±2.14
Control group	-13.21±0.83	-37.59±2.23	98.12±3.23

Changes of hip joint angle

Flexibility of the hip joint is closely related to the movement range [3]. Angle sensors were installed at the hip joints to collect parameters of the hip joints. Table 5 shows that the difference between the two groups was significant at the end moment. However, there was no significant difference in the data at the initial stage of movement, while the hip joint of the research objects was completely open and in an upright status. 3D images showed that at the moment when the right foot touched the floor, the gravity center moved to the right, and the coronal plane of the left hip joint was abducted; however, the movement of the sagittal plane was small, thus the range of left hip joint around the coronal axis was small when the right foot touched the floor. At that moment, there was no significant difference in the data of the research objects in the two groups; moreover, flexion and extension of the right hip joint around coronal axis were basically the same as these of the left hip joint.

Analysis of the data in Table 5 showed that there was a regular pattern in activity of the hip joint. The initial stage of the movement was to step towards the right and the angle of the hip joint declined slowly; the next stage of the movement was a quick motion from a single-foot support to horse standing with one leg touching the floor, and the angle of the hip joint declined quickly at that moment; at the finish stage, the angle of the hip joint reached a stable status rapidly.

Table 5. Flexion and extension of the left and right hip joint of testers around the coronal axis (°)

Group	Experiment group		Control group	
	Left hip joint	Right hip joint	Left hip joint	Right hip joint
Time of lifting the right foot	89.81±3.15	89.25±2.45	88.41±2.72	88.53±2.58
Time of the right foot touching the floor	84.43±2.96	80.56±2.93	82.23±3.19	76.34±3.11
Finish time	39.15±3.72*	39.78±3.50*	45.38±4.13	44.96±4.32
Range of motion	50.65±3.45*	49.52±3.15*	43.17±3.12	43.67±3.48

Note: compared with the control group, * means $p < 0.05$ and ** means $p < 0.01$.

As shown in Table 6, when the right foot was lifted, the abduction angle of the hip joint had no significant changes, however, the angle of the experiment group was slightly lower than that of the control group; at the moment when the right foot touched the floor, the angle of the hip joint of the experiment group increased rapidly and was significantly bigger than that of the control group ($p < 0.05$). The size of the abduction angle determines the range of motion of the hip joint around the sagittal axis; the bigger the angle, the bigger the range of motion of the hip joint. Results showed that the ranges of motion of the abduction angle of both left hip joint and right hip joint of the experiment group were significantly higher than these of the control group

($p < 0.05$). Therefore, the squat range of the research objects in the experiment group was big in order to lower the center of gravity and thus form a stable support for body.

Table 6. Abduction angles of the left and the right hip joint
around the sagittal axis of testers in the two groups

Group	**Experiment group**		**Control group**	
	Left hip joint	**Right hip joint**	**Left hip joint**	**Right hip joint**
Time of lifting the right foot	2.83±0.42	4.66±0.43	3.16±0.34	4.76±0.33
Time of the right foot touching the floor	30.76±4.21	34.54±3.87	27.82±3.52	31.61±3.52
Finish time	1.43±3.53*	40.15±3.23*	34.69±5.33	35.07±4.48
Range of motion	37.87±4.16*	35.50±3.64*	29.93±4.40	30.32±4.09

Note: compared with the control group, * means $p < 0.05$ and ** means $p < 0.01$.

Changes of the knee joint angle

The knee joint plays a leading role in the riding style action. Sensors were also installed at the left and right knee joints to collect changes of the knee joint angles. Table 7 shows that all research objects in the two groups stood straight at the initial stage of movement, only the height of the knee joint of the experiment group was slightly higher than that of the control group. During the process of the riding style action, the change rules of the right knee joint angle were different from these of the left knee joint. When the right foot was lifted, there was a decline process of the knee joint, and the knee joint angle of the experiment group (163.32±7.11°) was bigger than that of the control group (154.52±6.79°) ($p < 0.05$), and its average value was also bigger than that of the control group ($p < 0.01$). When the right foot touched the floor, the left knee joint angle of both groups declined slightly ($p > 0.05$) and the rate of descent increased later on. When the movement was finished, the angle of the right knee joint of the experiment group decreased significantly, and the ranges of motion of the right knee joint of the two groups were significantly different ($p < 0.01$).

The analysis above showed that the research objects in the experiment group mainly adopted a low posture, which was due to the fact that the riding style action consisted of high, medium and low postures. From the aspect of biomechanics, a low posture makes it easy to form a stable support and thus provide a stable power generation. The research objects in the control group who had little experience adopted a relatively high posture which could result in instability.

Table 7. Angle changes of the left and the right knee joint of testers

Group	**Experiment group**		**Control group**	
	Left knee joint	**Right knee joint**	**Left knee joint**	**Right knee joint**
Time of lifting the right foot	170.12±6.93	158.88±8.14*	164.38±7.67	146.41±7.24
Time of the right foot touching the floor	160.20±7.68	163.32±7.11*	154.61±6.45	154.52±6.79
Finish time	108.75±6.83*	113.96±6.27*	123.01±8.69	122.94±7.22
Range of motion	64.38±6.50	49.40±7.22**	41.41±8.48	31.53±8.59

Note: compared with the control group, * means $p < 0.05$ and ** means $p < 0.01$.

Changes of ankle joint angle

During the process of movement, toes should point forward and the whole sole should touch the floor. According to the change curves of the two groups (Fig. 1), the angle of the left ankle joint showed a downtrend in both groups; the left ankle joint of the experiment group showed a rising peak when the right foot touched the floor, which might be due to the fact that the relative strength of the left foot drove the displacement of the gravity center.

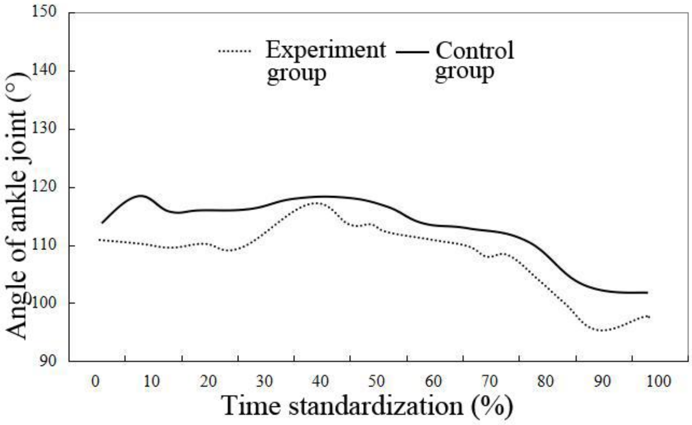

Fig. 1 Comparison of the left ankle joint of the two groups

However, from an overall perspective, the fluctuation of the left ankle joint was small, indicating that the left ankle joint mainly played a role of supporting in order to keep the balance of body.

Conclusion

3D image technology can be used to acquire 3D image models that have a photo sense of reality during the movement process of the research objects, as well as record parameter values of each moment in detail. Based on the combination of a sports biomechanics analytical method and 3D image technology, this study analyzes each characteristic parameters of the riding style action of the Chinese Bajiquan. Dynamical sensors were installed at the hip joint, the knee joint and the ankle joint to accurately measure each joint angle. According to data of each dynamical sensor, such kind of a sensor has good linearity and repeatability. Besides, a two-dimensional rigid motion model is constructed to calculate joint angles based on a degree of freedom, and a joint angle measurement mode that has flexible installation is put forward. Combining the dynamical sensors and the three-dimensional technology, accurate information is acquired and data changes are analyzed at the same time. Parameter changes at each stage are explored using the control group as a reference. Compared with other studies, this study presents the body postures and motions more directly based on the three-dimensional technology. Meanwhile, the angles of the hip joint, the ankle joint and the knee joint are better expressed. However, due to the limitations of time and other conditions, only three joints and the center of gravity are studied while other parts of the body are not further analyzed. Finally, we conclude that coordination of all parameters is needed when people do the riding style action, which is in accordance with the combination of hardness and softness of the Chinese Bajiquan.

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