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Biomechanical analysis of shooting performance for basketball players based on Computer Vision

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Abstract. Shooting technique is exceedingly crucial in basketball. In order to improve the shooting average, this study captured shooting technology action by computer vision technology, analyzed human posture in different gender and gave effective suggestions in routine training. Kinect Azure was used to collect the human skeleton information when the 10 players (5 males and 5 females) who experienced amateur basketball training shot. After smoothing and reducing noises of three-dimensional skeleton information, the kinematic parameters such as human joint angle and torso tilt angle were calculated by using Euclidean dot product formula and anti-triangular formula. The result showed that shooting average of male was higher than that of female ($P < 0.05$). When the players squatted to the maximum extent, the angles of the knee and hip of female were significantly bigger than that of male ($P < 0.05$). The torso was tilted to a certain extent, and the extent of female was significantly larger than that of male ($P < 0.05$). In conclusion, by computer vision obtaining data collection, this study suggested that the players should strengthen the muscle and master the range of flexion degree which was suitable for their own strength. At the same time, so as to improve the shooting average, they should pay attention to the coordination of upper and lower limbs during shooting.

1. Introduction

With the continuous improvement of the level of athletics, in the course of training, the traditional way that coaches with the naked eye judged the action technology, has great limitations on the further improvement of athletes' competitive level. At present, many competitive sports widely have used motion capture system for motion analysis. Capture systems including acoustic, mechanical, sensing and optical system^[1-3], which could be divided into marked and unmarked^[4] are common. Acoustic motion capture system has low accuracy and slow feedback, resulting that its application is not extensive. Compared with acoustic capture system, accuracy of the mechanical, sensing and marked optical motion capture systems is higher and the capture speed is faster, but wearing the relevant equipment would limit the range of motion^[2,5-7]. Meanwhile, marked optical system requires mark points which are bonded with soft tissue that might slip and result in errors^[2,8]. Due to the limitations of traditional capture systems, the use of monocular cameras for motion capture has become a better choice, such as deep camera Kinect^[9], which is based on computer vision technology for non-invasive measurement. Kinect is a no wearable device which can be used to obtain human skeleton information through machine learning algorithms^[1,10]. The kind of motion analysis has brought great conveniences, including low price, small size, portable and simple operation. In addition, in terms of reliability and validity, there were also studies to test performance of Kinect in gait analysis, and the results showed that the use of Kinect for motion capture was an effective and reliable method of obtaining kinematic parameters^[11,12].



In basketball, shooting is the core technology^[13]. Back-jumping, hooker shooting, close-up shooting and other shooting action techniques in basketball games are common^[14]. Although these shooting techniques have differences in the form of action, they still have common characteristics. At home and abroad studies carried out a large number of biomechanical research for the shooting technology, and most of them focused on the ball kinematic analysis, such as the ball's shooting speed, shooting angle, incident angle and the rotation of the ball^[15-19]. Xu Yan^[20] conducted three-dimensional video, and analyzed basketball players' shooting techniques, including characteristics of the athletes' main sports joints and the actions of the shooters. In jump shot technology, dynamic factors such as ground reaction forces^[21] also had an impact on the shooting rate. The fluid mechanics associated with the suitable flight trajectory and rotation of the ball have also been a hot topic in the study of motion biomechanics^[22].

The purpose of the study was to obtain skeleton information non-intrusively in the human shooting cycle for basketball players by using Kinect Azure, assess posture of players who have a certain basketball training basis but in need of a greater improvement, analyze the consistency and coordination of the shooting action technology, and explore the better program of shooting.

2. Materials and Methods

2.1 Experimental settings

Visual Studio 2019 was used to download and install microsoft Azure Kinect SDK from the Nuget package, referring to Kinect's official documentation^[23], and then set up the compiler configuration. The experiments in this study were conducted on computers with Intel ® CoreTM i5-8265U CPU with a 1.60GHz 1.80GHz processor and a 64-bit Windows 10 system.

The study used Azure Kinect camera to collect data. In order to ensure the stability and reliability of the operating state of the equipment, the environment of collection was indoors and the temperature was in the range of 10-25 degree Celsius^[24]. The main optical axis of the camera was parallel to the ground. Each subject made 10 consecutive shots at the free throw line (4.2m per length from the basket). As shown in Table 1, the camera of dataset acquisition was used by a narrow field of view mode. Ten (10) healthy subjects (including 5 boys and 5 girls) with a certain basketball training base but non-basketball specialty, participated in the measurements. After signing the subject's informed consent, the subjects warmed up and then shot ten times.

Table 1 Narrow field of view mode of Kinect camera

Settings	Parameters
Mode	Narrow field of view
Resolution	640×576
Degree of freedom	75°×65°
Frames	30
Depth range	0.5m-3.86m
Exposure time	12.8ms

2.2 Skeleton information extraction

Kinect Azure could capture raw data about three broad categories, including deep data streaming, color video streaming and audio data, corresponding to skeleton tracking, identification and speech recognition. Skeleton tracking could be widely used in sports with small range of activities for motion posture estimation, such as obtaining skeleton information of shooting. Using the principle of Time of Flight^[24], the camera calculated depth information by measuring the transmission delay time between light pulses and projecting modulated light from the near-infrared spectrum into the scene, at the same time, it took to record light from the emission to the camera receiving light again indirectly measuring the time. And the sensor generated a deep image streaming at 30 frames per second to reproduce the 3D motion scene in real time.

The acquisition of human skeleton information mainly used computer vision technology to extract the moving human body from the background environment, as shown in Fig 1. The processes were as follows: 1) Kinect chips obtained deep data streams that were transmitted to the computer via USB ports; 2) Set the characteristic threshold of human classification and deeply process the data flow; 3) The captured moving body was divided with the background; 4) Discovered the moving body; 5) The body parts were classified through machine learning; 6) The three-dimensional coordinates of joint points were further identified, so as to achieve three-dimensional reconstruction^[24]. The depth image coordinate system was based on the center of the infrared camera. The Z axis was the optical axis of the infrared camera and perpendicular to the plane being photographed, and the XOY plane was parallel to the shooting image plane, as shown in Fig 2. The axes were in millimeter units.

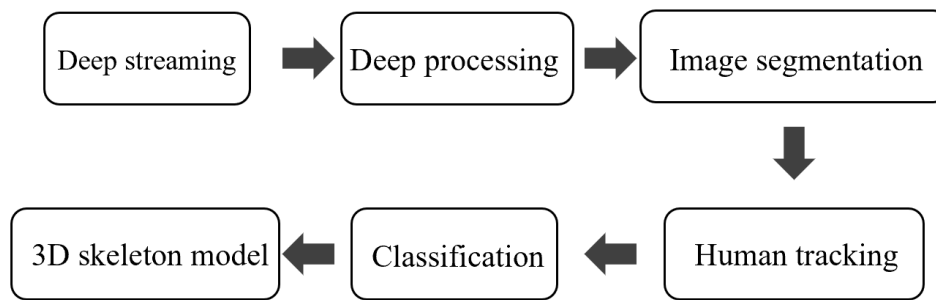


Fig 1 A process of human skeleton information extraction

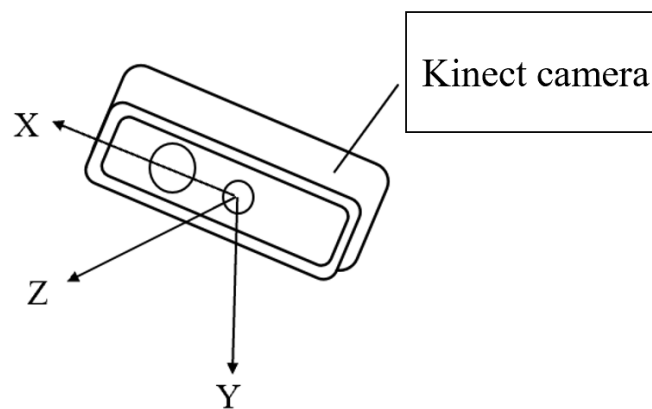


Fig 2 Camera coordinate system

The existence of errors and random errors in the camera system might affect the accuracy of the collected data. System error referred to the difference between the depth value and the actual depth value after noise was eliminated, as shown in Equation (1).

$$E_s = \frac{\sum_{n=1}^N d_n}{N} - d_{gn} \dots \dots \dots (1)$$

Where E_s was system error, d_n was the measurement depth at n , N was the number of frames which were used in the average process, and d_{gn} was the true depth.

The camera took multiple pictures of the same person under the same conditions in the scene, and the data jitter caused by the instability of the system made the depth of each picture slightly different, which was random error, as shown in Equation (2).

$$E_r = \sqrt{\frac{\sum_{n=1}^N (d_{nt} - \bar{d})^2}{N}} \dots\dots\dots (2)$$

Where E_r was random error, N was the number of frames which were measured in depth, d_n was depth measurements at time n , and \bar{d} was the average depth value at all moments.

After the series processes of algorithm, the motion human depth data stream was obtained by the Kinect Azure, and the system provided 32 key points of human characteristics information. Because the feature points of the head and foot contributed limitedly throughout the shooting cycle, in order to be easy to process and calculate, 16 joint points were selected in this study to form a streamlined model, as shown in Fig 3 and Table 2.

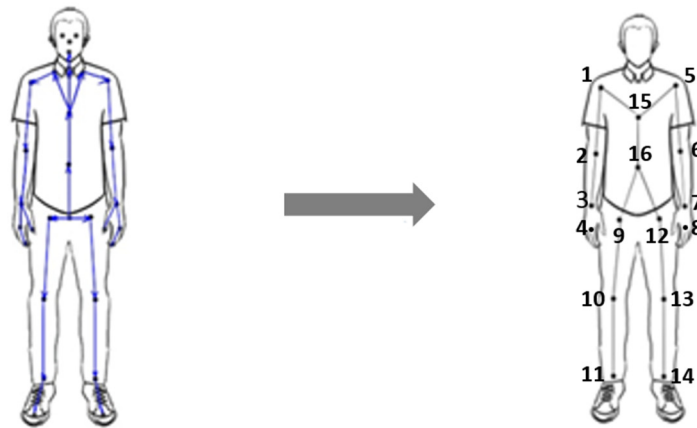


Fig 3 A simple model of the human skeleton

Table 2 The number of the model and its corresponding joint name

number	joint	number	joint
1	Right shoulder	9	Right hip
2	Right elbow	10	Right knee
3	Right wrist	11	Right ankle
4	Right hand	12	Left hip
5	Left shoulder	13	Left knee
6	Left elbow	14	Left ankle
7	Left wrist	15	Spine-chest
8	Left hand	16	Spine-naval

2.3 Data processing

2.3.1 Second-order double exponential smoothing

Due to some factors such as lighting conditions and imaging environment, Kinect Azure might introduce noise, and subtle surface feature information could be misjudged as noise when collecting data. Azure Kinect used algorithms such as Poisson equations to filter out system noise^[24], but due to the limitations of hardware sampling accuracy, the depth picture of the human body obtained through Azure Kinect scanning was still uneven. In addition, because of the real-time computing, instability of the system could cause data to shake, resulting in random errors. Therefore, in order to reduce the error, the raw data was filtered by the secondary exponential smoothing method^[25].

Set the raw data was X_n , n was the number of frames, $Y_n^{(1)}$ was an exponential smoothing value, $Y_n^{(2)}$ was the secondary exponential smoothing value, and a was the smoothing factor value per frame. $Y_n^{(1)}$ was X_n and $Y_{n-1}^{(1)}$ weighted average, whose expression was:

$$Y_n^{(1)} = aX_n + (1-a)Y_{n-1}^{(1)} = a \sum_{n=0}^n (1-a)^n X_{n-1} \dots \dots \dots (3)$$

Secondary smoothing values $Y_n^{(2)}$ was $Y_n^{(1)}$ and $Y_{n-1}^{(2)}$ weighted average, whose expression was:

$$Y_n^{(2)} = aY_n^{(1)} + (1-a)Y_{n-1}^{(2)} = a \sum_{n=0}^n (1-a)^n Y_{n-1}^{(1)} \dots \dots \dots (4)$$

In our experiment, the initial value of the bone joint point was set to $Y_0^{(1)} = x_1$. Using the above formula to reduce noise, after many debugging of the parameters, it was found that the best results were found when $a=0.9$.

For variables with obvious trends, the smoothing algorithm had a significant time lag, and its lag error became a constant value, which introduced a moving trend increment to eliminate the error. This mobile trend increment b_n could be expressed as:

$$b_n = \gamma \Delta X_n + (1-\gamma)b_{n-1} \dots \dots \dots (5)$$

Where: ΔX_n was the first-order forward differential model of the raw data, which could be derived from $X_n - X_{n-1}$, and γ weight was the current trend increment.

Had brought this incremental (5) to the second-order exponential smoothing (4) available:

$$Y_n^{(2)} = aY_n^{(1)} + (1-a)(Y_{n-1}^{(2)} + b_{n-1}) \dots \dots \dots (6)$$

The data verification results showed that the sequence data curve after secondary exponential smoothing filtering was smoother than the raw data curve, as shown in Fig 4 and Fig 5.



Fig 4 X-axis smooth verification of Right shoulder

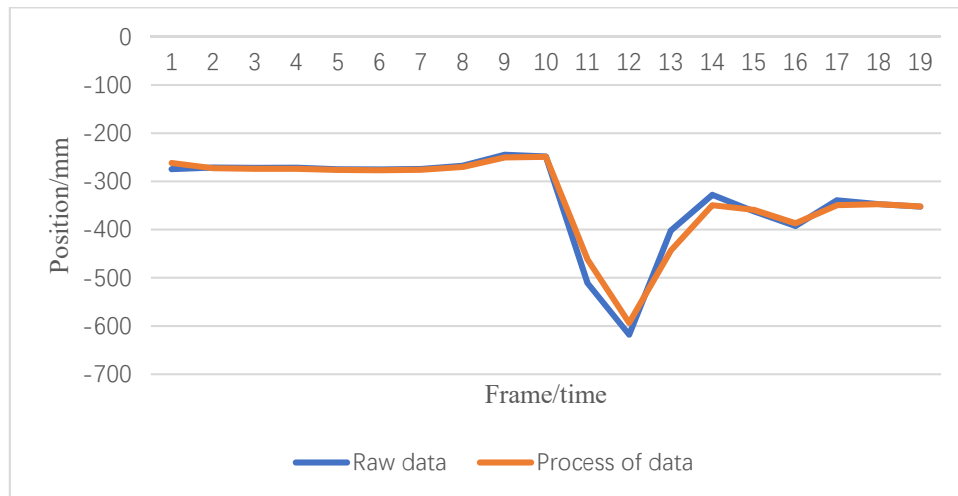


Fig 5 Y-axis smooth verification of Right shoulder

2.3.2 calculation

The noise of the raw data of the collected human skeleton information were reduced by the method of secondary exponential smoothing. According to the color chart to judge the shooting action cycle, the Euclidean dot product formula and the anti-triangular function were used to find the angle of the joints, as shown in the Equation (7).

$$\theta = \cos^{-1} \frac{\vec{a} \cdot \vec{b}}{|\vec{a}| |\vec{b}|} \dots\dots\dots (7)$$

Where \vec{a} was the two joint points of the constituent link, $|\vec{a}|$ was the vector length; \vec{b} was the two joint points of the constituent link, $|\vec{b}|$ was the vector length; θ was the angle of the two vectors.

Had found the angular velocity according to the angular velocity-time formula, as shown in Equation (8).

$$v = \frac{\theta}{t} \dots\dots\dots (8)$$

Where t was time and v was angular velocity.

2.3.3 Statistical analysis

The application statistics software spss.26.0 carried out a Chi-square test on the shooting rate, and independent sample T-tested the angle of the upper and lower limb joints, torso inclination and stretch angle speed, with a significance level of $\alpha = 0.05$.

3. Results and discussion

Ten subjects made 10 consecutive shots, with a statistical male shot rate of 90% and female shot rate of 74%, and there was a significant difference ($P < 0.05$). In order to explore the characteristics of male and female shooting posture, this study combined joint angle, torso tilt angle and shooting results to carry out the following four parts of analysis:

3.1 Analysis of the degree of bending of the lower limbs

The shooting action appears to be an upper limb involved in more movement skills, but according to anatomical and mechanic principles, the correct shooting posture is a knee-jerk squat action^[26], through the knee squat process to stretch the muscles so that the lower limbs store elastic potential energy. This study used deep camera shooting techniques to compare the degree to which players of different genders crouched down as shown in Table 3.

Table 3 Changes in the angle of the lower limbs joints; * indicated a significant difference, with the significance level $\alpha=0.05$, the same below

Gender	Minimum hip angle (°)	Minimum knee angle (°)	Minimum ankle angle (°)
Male	158.89±6.16	141.23±11.82	108.39±10.58
Female	143.99±11.79*	130.40±14.65*	106.61±10.52

Female's hip and knees were more conceding than that of male, and there were significant differences. Female also had higher ankle back flexions than male, but there was no significant difference between the two groups, because most of the muscle groups around the ankles were small muscle groups and contributed less to flexion and stretching. According to kinematic principle, the ball was only subjected to gravity after shooting. When it was shot, the movement of the ball in the vertical direction depended on the height of the ball and the speed of the ball in the vertical direction, so the extension of the lower limb played an important role in the movement of the ball vertical direction. Due to the anatomical differences between male and female that the bursts of female's muscle were weaker than that of male and female had lower center of gravity, female could increase the speed of the ball in the vertical direction by more flexing, storing elastic potential energy and increasing the strength of upward stretching when shooting, so that the body got better vertical speed, which increased the speed of the ball in the vertical direction. However, excessive curvy would increase the load to the lower limbs, resulting in reducing the speed of stretching and affecting the movement of other parts of the body^[20]. Therefore, in the shooting training, due to anatomical and physiological differences, athletes should master a suitable degree of bending for their own force range.

3.2 Analysis of the tilt of the torso

Different players take different positions in other parts of the body when shooting, such as back-jumping techniques, which the athlete's torso has a large inclination on the Sagittal plane. The results of this study showed that the torso had a certain degree of tilt in the shooting moment compared with the beginning of the action, and female were larger than male. There was a significant difference between the two as shown in Table 4. The female's center of gravity movement was larger, which might be the cause of the lower shooting rate.

Table 4 The torso changes in angle at the moment of shooting compared with the moment of origin

The tilt of the torso	male	female
Inclination angle (°)	0.99±0.22	1.52±0.20*

3.3 Analysis of upper limb stretch

Full upper limb stretching not only allows the storage of energy to be released when bending the elbow in the shooting preparation stage, but also increases the time of force during stretching according to the momentum theorem, which increases the speed of the ball together when it is shot.

This study extracted the mean of the upper limb joint angle of the first two frames of the ball shot. The results showed that there was a significant difference between the upper limb joint angle of male and female, as shown in Table 5, but due to the frame rate limitation, Kinect camera for fast motion capture was limited, so the results couldn't indicate that female's stretching degree was not as full as male. This study analyzed the speed of elbow stretching angle before shooting, and found that female's elbows stretched more slowly than that of male, because female's explosive power was weaker than that of male. But there was no significant difference between the two.

Table 5 The angle changes in the first two frames of the upper limb

Gender	Shoulder angle(°)	Elbow angle (°)	Wrist angle (°)	Stretch angular velocity(°/s)
Male	125±14.44	117.05±15.22	130.76±21.96	962.68±558.70
Female	87.2±23.00*	94.76±28.65*	120.80±21.56*	825.84±641.44

Upper limb shooting action in the basic movements of the human body belongs to the "push". The action is completed by the end of the small segments, so the shooting movement as a fast action. Kinect camera couldn't currently track the rapid movement of the human body. Kinect Azure couldn't accurately capture the fast movement of the segment. So based on wrist position, hand joint points are mostly predicted. Accordingly, the wrist angle in this study was also speculative.

3.4 Analysis of coordination

When shooting, the coordination of upper and lower limb movements could reduce the body's energy consumption while avoiding the emergence of excess movements: on the one hand, the strength of the lower limbs through the torso is effectively transmitted to the upper limbs; On the other hand, the big segment drives the small segment to produce the larger ball's shooting speed. In the shooting technical action, the stretching action of the lower limb releases the elastic power stored with the knee squatting. At the same time, the players obtain the ground reaction force, and the force is transmitted from the torso to the upper limb to complete the action. If the upper limbs complete the action earlier^[27], the quality of the action will be affected, and it will reduce energy utilization. The results showed that male's upper limbs produced movement earlier than that of female, and the magnitude of lower limb flexion and stretching was not significant. Even if the male shot rate was higher than that of female, the upper and lower limbs coordination ability of the male was weaker than female, as shown in Fig 6 and Fig 7. Therefore, in the shooting training, so as to obtain a higher shot rate, players should also pay attention to the coordination of the upper and lower limbs.

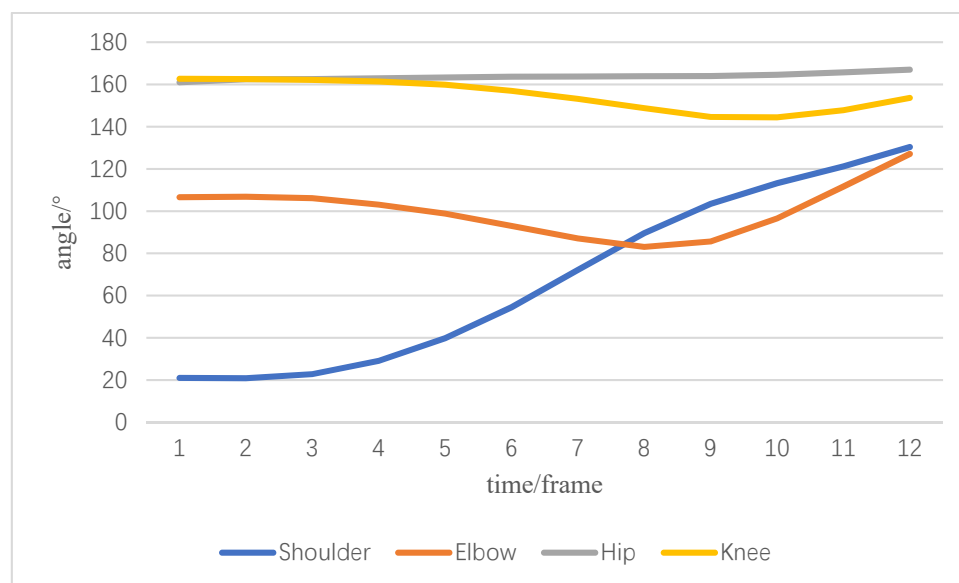


Fig 6 joint angle changes of male

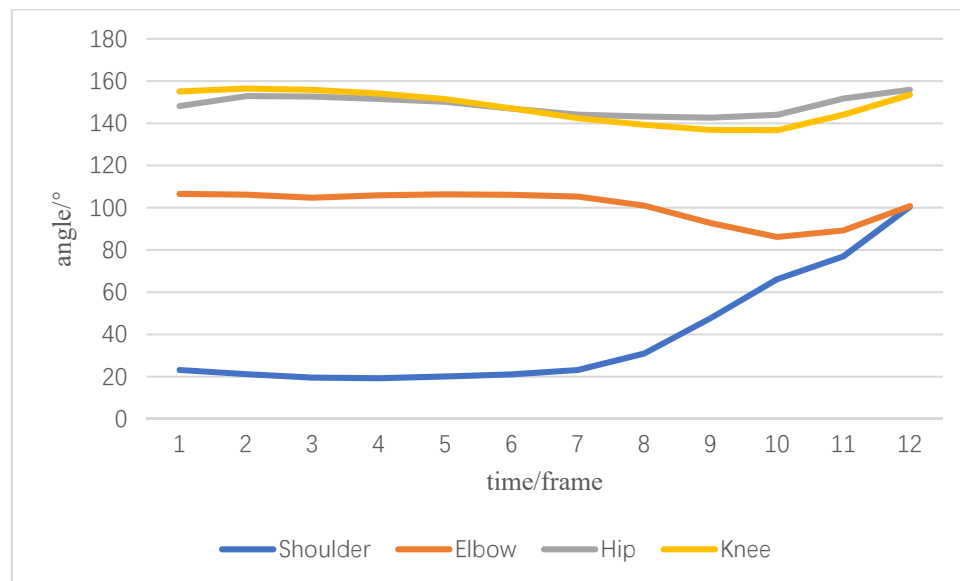


Fig 7 joint angle changes of female

4. Conclusions

This study used Kinect Azure for data collection, which could very conveniently obtain three-dimensional human motion information. By this way, the study found that the shot rate of male players was more than female players in the subject group. The female player's torso tilt changed greatly, so the center of gravity moved more, which might lead to a reduction in shooting rate. In daily training, players could strengthen the lower limbs and torso strength training. Male players had greater muscle strength, but the coordination was insufficient. In the process of shooting practice, coaches could pay more attention to the improvement of player's coordination ability.

However, the frame rate of camera was low relative to the motion camera, which wasn't enough to accurately capture the fast action of the shooting shot moment. Therefore, this study didn't analyze hand movement posture. For the above problems, interpolation and other techniques would be used to try to solve.

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