The Effect of Shooting Distance on Energy Generation in the Shooting Arm Joint

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Abstract: This study aims to investigate the effects of shooting distance and technical proficiency on arm movement during the release phase of basketball shooting. The study participants included 10 male student athletes from a local high school basketball team (technically skilled) and 10 amateur basketball players from a local high school (technically unskilled). Each participant completed three successful shots under two shooting distance conditions (5 m and 6.8 m). The study evaluated the angular characteristics of the joints and the energy variables generated by the joints during the shooting process. The results showed that as the shooting distance increased, the flexion angle of the shoulder joint decreased at the moment of shooting initiation in both the skilled and unskilled groups ($P<0.001$). The energy output of the shoulder and elbow joints increased ($P<0.001$). Intergroup comparisons revealed that the skilled group had more elbow extension and wrist flexion ($P<0.001$). The skilled group had higher energy output in the shoulder, elbow, and wrist joints ($P<0.001$). These results indicate that the ability of the joints of the shooting arm to actively couple to generate energy is critical for adapting to different basketball shooting distances.

Keywords: Basketball Shooting Training; Joint Angle; Energy Generation

1. Introduction

The outcome of a basketball game ultimately depends on the number of points scored by shooting the ball into the basket within the specified time [1, 2]. As the sole means of scoring, shooting technique is undoubtedly the most critical technical aspect of basketball. Players with the ability to shoot accurately from various distances—especially beyond the three-point line—can significantly expand offensive space, diversify tactical options, and enhance scoring efficiency during games [3], which is particularly crucial in tight, high-stakes moments. Therefore, gaining a deep understanding of the factors influencing shooting performance, particularly the complex and core jump shot technique, is a key direction in basketball research.

Increased shooting distance poses significant biomechanical challenges to shooting technique. Research indicates that the angle at which the ball enters the basket is a key physical factor determining shooting success [4, 5]. A larger angle of entry into the basket implies a larger effective “basket width” [6, 7]. However, the angle of entry into the basket is determined by the ball's vertical displacement, horizontal displacement, and speed during flight. Among these, horizontal displacement is directly related to the distance between the shooter and the basket: the farther the distance, the greater the horizontal speed required for the ball to reach the basket. These three flight parameters (vertical displacement, horizontal displacement, and speed) are directly influenced by the ball's release parameters (speed, angle, and height) [7]. Therefore, as shooting distance increases, players must adjust their movement patterns to precisely control release parameters, particularly by increasing the ball's release velocity [4].

The generation and regulation of shooting movements follow action control theory, resulting from the interaction of factors such as the individual (shooter), task (shooting distance and accuracy requirements), and environment [8]. To meet the demands of different distance tasks (especially increasing release speed), the nervous system must coordinate the musculoskeletal system to produce corresponding mechanical outputs. Researchers have categorized and described the kinematics of shooting actions and quantified their spatiotemporal characteristics9]. However, kinematic descriptions alone are insufficient to explain the causes of the action. Human movement is fundamentally an energy transfer and conversion process under the control of the nervous system, with muscles as the power source, bones as levers, and joints as hinges [10].

Studies have shown that different shooting distances place different demands on limb energy generation and transfer. Short-range shooting accuracy may be related to wrist strength, while long-range shooting relies more on elbow extensor strength [11]. Nakano et al. (2020) further revealed that as the shooting distance increases, skilled players output more energy through their lower limbs to meet the speed requirements, while the shooting arm (the movement chain composed of the shoulder, elbow, and wrist joints) adjusts its movements to optimize energy transfer and coordination between joints (i.e., "energy flow") to generate greater force while minimizing changes in release parameters, thereby maintaining accuracy. This joint energy optimization and compensation mechanism is crucial for skilled players to maintain precise shooting accuracy at different distances[12].

Although there is a preliminary understanding of energy transfer in the shooting arm, the internal mechanisms of how muscles actively coordinate and control joint torque and how to precisely regulate the skeletal lever system to produce a stable and efficient energy output pattern have not yet been clearly explained. This challenge is particularly prominent for adolescents who are not skilled at long-distance shooting, and coaches often find it difficult to instruct them. Currently, there is a lack of biomechanical research on jump shots at different distances for this group, especially in-depth research on the coordination mechanism between the joint movement pattern of the shooting arm and energy generation.

This study aims to deeply explore the active coordination mechanism of the shooting arm muscles and reveal how it optimizes and compensates for force generation to adapt to different distance requirements. The research results are expected to provide scientific basis for the technical development of players, help coaches design more effective training methods, and particularly assist unskilled players in improving the efficiency and stability of shooting at different distances, which has important theoretical value and practical significance.

2. Materials and Methods

2.1 Subjects

In this study, we recruited 20 male participants, including 10 male student athletes from the local high school basketball team and 10 amateur basketball players from the local high school. All participants were healthy and active prior to voluntarily participating in the study and completed a personal information questionnaire (age, height, weight, etc.) (Table 1). All participants were right-handed. Based on the number of years of training, participants were divided into two groups: the skilled group (Abbreviation: S) and the unskilled group (Abbreviation for US). These tests were conducted in a biomechanics laboratory.

Table 1. Subject Characteristics

Characteristics	Unskilled (N=10)	Skilled (N=10)
Age (years)	16.6±1.4	16.1±0.7
Height (cm)	178.4±3.6	181.8±6.3
Body Mass (kg)	75.5±9.1	76.8±6.3
Training Experience(years)	0	5.3±1.6

2.2 Preparation for Testing

As shown in Figure 1, the subjects stood on a force platform (FP) to perform three-point jump shots. The shooting distance was set based on the vertical projection point of the center of the basket on the ground to the front edge of the force platform (FP), at 5 meters and 6.75 meters, respectively. Prior to testing, we clearly explained the experimental procedure and research objectives to each participant. Participants first completed a 10-minute warm-up (including jogging and static stretching) before performing the shooting task. Participants were instructed to jump off the force platform (FP) and release the shot using their most familiar and commonly used shooting technique, without using the backboard or facing defensive interference, with no restrictions on landing position. After each shooting attempt, participants rested for 30 seconds before the next attempt. Reflective markers were attached to 57 anatomical landmarks on the participants' bodies (Figure 2). A motion capture system (Opti Track, LEYARD, Buffalo Grove, IL, USA) equipped with 13 high-speed infrared cameras, combined with

Motive Body 2.2.0 software, was used to collect three-dimensional kinematic data at a sampling frequency of 240 Hz. Ground reaction forces were simultaneously recorded using a force plate embedded in the floor (OR6-6-2000, AMTI Inc., Plano, TX, USA) at a sampling frequency of 1200 Hz.

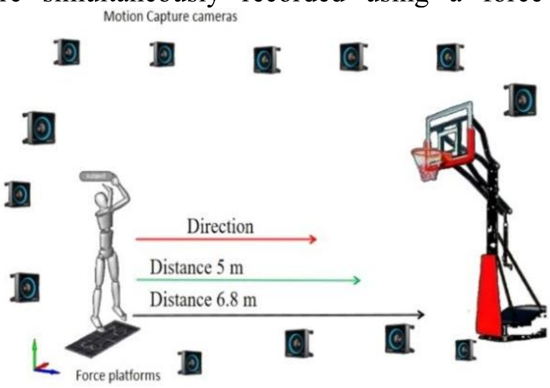

Figure 1. Experimental Set-up

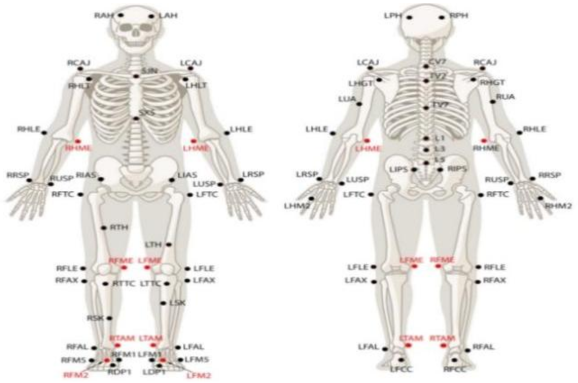

Figure 2. Reflective Marker Attachment Positions

2.3 Data Analysis

2.3.1 Kinematic and Kinetic Data

All participants' motion capture data were imported into Visual 3D Professional 6.0 software (C-Motion, Inc., Germantown, MD, USA) for modeling and analysis. Given the characteristics of the basketball shooting motion, the study focused on analyzing the kinematic and kinetic parameters of the right upper limb in the sagittal plane. The core of the basketball jump shot action is the phase where the shooting arm propels the ball until release. This study adopted the widely used definition, which begins with the acceleration of shoulder joint flexion and ends at the moment the ball leaves the hand. This study primarily examined the kinematic angles of each joint in the sagittal plane and related dynamic indicators during the aforementioned shooting phase. Combining ground reaction forces collected by a force plate, kinematic data, and human inertial parameters, inverse dynamics methods were used to calculate joint torques. All dynamic variables were normalized according to the subjects' body weight (units: × kg^{-1}). Joint torque power (JTP) is defined as the instantaneous power output of joint torque relative to joint angular velocity, calculated as: JTP = (joint torque) × (joint angular velocity). The energy generated by the joint throughout the entire movement phase is obtained by integrating the joint torque power (JTP) in the time domain. For the upper limbs, the time domain of the integration is clearly defined as: the moment when the shoulder joint begins to accelerate flexion to the moment when the ball is released.

2.3.2 Statistical analysis

Joint power was numerically integrated within the defined time domain using MATLAB software to obtain the energy values generated by the joints. All statistical analyses were performed using GraphPad Prism 9.2.0 software (GraphPad Software, La Jolla, CA, USA). Continuous variable data are reported as mean ± standard deviation (Mean ± SD). Statistical significance was set at $\alpha = 0.05$. The study variables were analyzed using a two-way mixed-design ANOVA to examine the main effects of "group" (between-subjects factor) and "shooting distance" (within-subjects factor) and their interaction. If the ANOVA results indicated statistical significance for the main effects of 'group' or "distance," further multiple comparison tests were conducted using the Tukey-Kramer method to identify specific differences.

3. Results

3.1 Comparison between the Joint Angle

At the start of the shooting release, there was a significant difference in the main effect of shoulder joint angle on throwing distance (F=29.8, P<0.001). Post hoc multiple comparisons showed that as shooting distance increased, the shoulder joint angle at the start of the shooting release decreased in both groups, and there was a significant difference in shoulder joint flexion angle in the non-skilled group. There was a significant difference in the main effect of shoulder joint angle between groups (F=9.2, P=0.005), and post hoc multiple comparisons at a distance of 6.8 meters showed a significant difference between the skilled and unskilled groups (P=0.041). The shoulder joint angle of the skilled group at a distance of 6.8 meters was close to 90°, significantly greater than that of the unskilled group. The interaction effect was significant (F=0.81, P=0.37). There was no significant difference in the main effect of elbow joint angle between groups (F=4.82, P=0.036), and post-hoc comparisons showed no significant differences in shoulder joint angle between different distances or groups. The interaction effect of elbow joint angle was not significant (F=1.46, P=0.23). . There was a significant difference in the main effect of wrist angle between groups (F=118.7, P<0.001), with significant differences between the skilled and unskilled groups at both distances (P<0.01). The wrist joint angle was larger in the skilled group, while the wrist joint exhibited a greater dorsiflexion posture in the unskilled group. There was no significant difference in the interaction effect (F=0.59, P=0.44).

At the moment of shot release, there was no significant difference in the main effect of shoulder joint angle distance (F=0.16, P=0.68). The main effect of shoulder joint angle group showed a significant difference (F=4.4, P=0.044), but post hoc comparisons revealed no significant differences in shoulder joint angle between groups. There was no significant interaction effect (F=0.30, P<0.58). There was no significant difference in elbow joint angle under the distance main effect (F=1.69, P=0.20), but there was a significant difference in elbow joint angle under the group main effect (F=49.9, P<0.001), with a significant difference between the skilled and unskilled groups at both distances (P<0.01). At the instant of completing the throwing action, the elbow joint angle of the skilled group was greater than that of the unskilled group, even exhibiting an overextended posture. The interaction effect showed significant differences (F = 7.1, P = 0.012). There were significant differences in wrist joint angle under the main effect of group (F = 109.7, P < 0.001), with the skilled group having a larger wrist joint angle and the unskilled group exhibiting a greater flexion posture (P < 0.01). There were no significant differences in wrist joint angles in terms of the main effect of distance (F=0.20, P=0.65) or the interaction effect (F=0.18, P=0.66). (As shown in Table 2).

Table 2. Joint Angles During the Shooting Phase (Mean ± SD, Degree)

Group	Distance	SA Start	SA End	EA Start	EA End	WA Start	WA End
US	5m	85.5 ±9.3	133.4 ±12.7	74.3 ±8.7	174.8 ±7.1	108.5 ±7.8	192.9 ±15.5
	6.8m	77.2 ±10.3[a]	133.9 ±8.3	73.6 ±9.1	177.8 ±9.9	103.4 ±8.6	194.9 ±16.8
S	5m	89.2 ±5.1	136.9 ±4.7	79.9 ±7.7	188.7 ±9.5[a]	121.1 ±7.1[a]	220.8 ±6.3[a]
	6.8m	84.1 ±6.4[b]	135.5 ±4.9	75.2 ±9.3	189.6 ±8.7[b]	120.2 ±4.5[b]	220.6 ±5.1[b]
Distance effect		< 0.001	P=0.71	P=0.081	P=0.25	P=0.046	P=0.7
Group effect		< 0.001	P=0.1	P=0.036	P < 0.001	P < 0.001	P < 0.001
P, interaction		P=0.29	P=0.47	P=0.18	P=0.51	P=0.051	P=0.63

Legend: a—difference when compared to US 5m, b—difference when compared to US 6.8m, c—difference when compared to S 5m. SA Start —Shoulder joint angle at the moment of shooting start, SA End— Shoulder joint angle at the moment of shooting end, EA Start— elbow joint angle at the moment of shooting start EA End—elbow joint angle at the moment of shooting end WA Start—wrist joint angle at the moment of shooting start WA End—wrist joint angle at the moment of shooting end.

3.2 Comparison of the Work Done by the Shooting Arm Joint

During the shot release phase, there was a significant difference in energy generation in the shoulder joint in terms of the main effect of distance (F=17.6, P<0.001). At distances of 5 meters and 6.8 meters, the difference between the skilled and unskilled groups was significant (P<0.001). As the shooting distance increased, the skilled group generated more energy in the shoulder joint when shooting from a distance of 6.8 meters. There was a significant difference in the main effect of the group on the energy generated by the shoulder joint (F=7.8, P<0.01). Post hoc comparisons showed that the skilled group generated more shoulder joint energy than the unskilled group at both shooting distances (P<0.01), which was particularly obvious at the 6.8-meter shooting distance. The interaction effect was significantly different (F=4.5, P=0.041). There was a significant difference in the main effect of elbow joint energy generation at different distances (F=60.3, P<0.001). As the shooting distance increased, both groups generated more energy at the elbow joint at 6.8 meters (P<0.001). There was a significant difference in the main effect of elbow joint work between the two groups (F=14.1, P<0.01). Post hoc comparisons showed that the skilled group generated more energy at the elbow joint than the unskilled group at both distances, especially at 6.8 meters (P<0.001). The interaction effect was not significant (F=3.8, P=0.058). There was a significant difference in the main effect of wrist joint energy generation between the two groups (F=144.8, P<0.001). Post hoc multiple comparisons showed that the skilled group generated more wrist joint energy at both throwing distances, and the difference was significant (P<0.001). There were no significant differences in the main effect of distance (F=4.1, P=0.052) and interaction effect (F=0.023, P=0.87) for wrist joint energy generation. (As shown in Table 3).

Table 3. Energy Generated by the Shooting Arm Joint (Mean ± SD, J/Kg)

Group	Distance	Shoulder	Elbow	Wrist
US	5m	0.085±0.026	0.11±0.022	0.030±0.010
	6.8m	0.11±0.047^{a}	0.13±0.021^{a}	0.037±0.012
S	5m	0.089±0.023	0.12±0.017	0.071±0.022^{a}
	6.8m	0.13±0.037^{bc}	0.15±0.020^{bc}	0.77±0.025^{b}
Distance		P<0.001	P<0.001	P=0.052
Group		P<0.01	P<0.001	P<0.001
interaction		P=0.041	P=0.058	P=0.88

Legend: a—difference when compared to US 5m, b—difference when compared to US 6.8m, c—difference when compared to S 5m.

4. Discussion

4.1 Shooting Arm Joint Angles

As the shooting distance increases, the shoulder joint flexion angle decreases. This finding is consistent with the research by Okazaki et al. [5]. To throw the ball to a greater distance, a larger momentum must be generated to complete the ball's flight trajectory [13, 14]. The reduction in initial flexion angle suggests that both groups of athletes reduced shoulder joint flexion amplitude to meet the high energy output requirements for long-distance shooting. Notably, the unskilled group had a significantly smaller shoulder joint flexion angle at the start of the shot compared to the skilled group. This indicates that unskilled athletes may rely more on reducing shoulder joint flexion amplitude as a strategy to adapt to increased distance. Shoulder joint angles at the end of the shot did not show significant main effects of "distance" or "group." However, observational data suggest that the skilled group tended to have larger shoulder joint end flexion angles. This trend may be related to their optimization of release height and angle [14], but should be interpreted with caution. The initial elbow flexion angle was not significantly affected by shooting distance or group. At the end of the shot, a significant group effect was observed. The unskilled group exhibited incomplete elbow extension, while the skilled group demonstrated a highly consistent pattern of complete extension. The initial wrist angle of the unskilled group was significantly smaller than that of the skilled group. This may reflect the strategy of unskilled athletes to pre-store wrist muscle elastic potential energy in the initial posture. At the end of the shot, the skilled group exhibited a significantly larger wrist flexion angle, consistent with the findings of Rodacki et al. (2005)[15]. The larger wrist flexion angle at the end of the shot in skilled athletes is due to the active contraction of the wrist flexor muscles. Its biomechanical significance lies in: (1) increasing ball rotation; (2) allowing the desired flight distance to be achieved at relatively low ball release speeds through the stabilizing effect of rotation; (3) optimizing the ball's flight trajectory and basket entry angle, ultimately improving shooting accuracy [13].

4.2 Energy Generated by Shooting Arm

Joints

Statistical analysis shows that the energy generated by the shoulder and elbow joints during shooting increases significantly with increasing shooting distance. At a shooting distance of 6.75 meters, the energy generated by the shoulder and elbow joints in the skilled group was significantly higher than that in the unskilled group. Unlike the proximal joints, the energy generated by the wrist joint did not show significant changes with increasing shooting distance. However, the energy generated by the wrist joint during shooting was significantly higher in the skilled group than in the unskilled group. As the shooting distance increases, the increase in energy output from the proximal joints (shoulder and elbow) is a strategic adjustment to optimize the use of the lower limbs to generate energy. The skilled group showed a greater increase in energy at the proximal joints, mainly because their muscular system was able to generate greater joint torque and drive higher joint angular velocity. Research indicates that rapid acceleration of joint movement (high angular velocity) significantly increases the difficulty of movement control [16], posing a challenge to maintaining consistency and accuracy in shooting movements [17]. Therefore, it has been suggested that the rate of increase in joint angular velocity should be controlled during basketball shooting [4]. This strategy, which relies on increasing release speed, is considered a typical characteristic of players with poor release control [12, 18]. The skilled group exhibited greater wrist flexion angles and higher energy output. The biomechanical significance lies in the fact that active contraction of the wrist flexors significantly increases ball rotation [13]. Ball rotation has a stabilizing effect, allowing the desired flight distance to be achieved at relatively low release speeds and helping to optimize the flight trajectory. We believe that this pattern of utilizing wrist joint work to increase rotation and assist in controlling release speed represents a refined stabilizing control strategy for the distal motor segment (hand-ball system), which helps maintain movement control while enhancing force output.

5. Conclusions

This study investigated the effects of training experience on energy production in upper limb joints during shooting at different distances, as well as the characteristics of joint angles during the shooting release phase. As shooting distance increased, the skilled group produced more energy in the shooting arm joints (shoulder and elbow joints), and this increase in energy was attributed to the work performed by the coupled joints of the shooting arm muscles and the regulation of large unstable impulses at the wrist joint. As the shooting distance increased, the skilled group differed from the unskilled group in their ability to actively organize the coupled joints of the throwing arm muscles to generate energy during the shooting release phase, indicating that shooting technique can be acquired through training and that unskilled players should focus on training the coordination of upper and lower limb forces. In terms of strength training, comprehensive training of upper limb joints should be emphasized, such as using heavy balls and equipment for endurance and explosive power training. These adjustments will help improve the trajectory of the basketball, increase the angle of entry into the basket, and thereby enhance the efficiency of long-distance shooting.

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