SIN-CHN SCIENTIFIC PRESS PTE.LTD.

Molecular & Cellular Biomechanics 2025, 22(1), 550.
https://doi.org/10.62617/mcb550

Article

Effect of basketball shooting distance and skill level on muscle activity and joint energy production of upper extremity

Zhitao Yang[1,†], Youngsuk Kim[2,†], Zihao Zhao[2], Weiping Feng[2], Junsig Wang[3,*], Sukwon Kim[2,*]

[1] School of Physical Education, Zhoukou Normal University, Zhoukou 466001, Henan, China
[2] Department of Physical Education, Jeonbuk National University, Jeonju, Jeollabuk 54896, Republic of Korea
[3] Department of Sports Medicine, Kyung Hee University, Yongin, Gyeonggi 17104, Republic of Korea
*** Corresponding authors:** Junsig Wang, jwang@khu.ac.kr; Sukwon Kim, rockwall@jbnu.ac.kr
[†] These authors contributed equally to this work.

CITATION

Yang Z, Kim Y, Zhao Z, et al. Effect of basketball shooting distance and skill level on muscle activity and joint energy production of upper extremity. Molecular & Cellular Biomechanics. 2025; 22(1): 550. https://doi.org/10.62617/mcb550

ARTICLE INFO

Received: 17 October 2024
Accepted: 15 December 2024
Available online: 9 January 2025

Abstract: The aim of this study was to elucidate the effect of shooting distance and skill level on the arm movements (kinematics, kinetics and electromyography) during the release phase of basketball shooting. 14 males were student-athletes from local college basketball teams(skilled) and 14 were recreational basketball players from local colleges(unskilled). Each participant completed three successful shots at two distance conditions (5 m, 6.8 m). The energy generated by the joint during the shot and electromyographic variables of the anterior deltoid (AD), triceps brachii (TB), and flexor carpi radialis (FCR) muscles were evaluated. The results showed that S and US groups showed decreases in shooting success with increasing shooting distance ($P < 0.001$), and increases in muscle activation and joint energy production in shoulder and elbow joints ($P < 0.001$). During longer distance shooting, S and Us groups showed significant differences in wrist flexion angle ($P < 0.001$). In addition, S demonstrated more energy production at the shoulder, elbow, and wrist joints ($P < 0.01$), and greater activation ($P < 0.05$) in the anterior deltoid (AD), triceps brachii (TB), and flexor carpi radialis (FCR) corresponding to the joints (MVIC%). These results suggest that the skills of shooting arm to produce proper force, and active muscle coupling of joints to produce energy are important for adaptation to different basketball shooting distance.

Keywords: shooting success; joint angle; jump shot; electromyography

1. Introduction

Jump shots are critical in basketball, contributing to over half of the total points in a game [1,2]. Jump shot in basketball is the most important and frequently used shooting technique in a game. It has been found that 60% of field goals in a basketball game come from jump shots [3]. Players who consistently score from greater distances, especially near the 3-point line, hold a distinct advantage in the game. Jump shots from different distances can expand the space of the offense and facilitate the implementation of multiple offensive plays, while greatly increasing the scoring efficiency, especially in the last minutes of close games, proving to be the key to success [4]. There is a growing body of research that demonstrates the importance of long-distance shooting skills in relation to game success.

Okazaki et al. considered to be the most complex basketball technique [5,6]. The importance of jump shots in a team's offense has led researchers to work on identifying the factors associated with its successful performance [7], Several researchers in the area of shot kinematics have found that the release velocity of the ball increases significantly with increasing shot distance [8,9]. Dupuy et al. argued that the variation in release velocity has the greatest effect on the arrival position in a precise throwing task [10]. Brancazio et al. argues that this constraint requires the thrower to alter the motor control strategy to maintain accuracy and generate a great impulse to drive the ball at the moment of release [11]. Despite the high demand for shooting skills, some inexperienced youth players are struggling to adjust to the increased shooting distance [12,13]. Therefore, understanding the adjustment mechanisms for shooting from different distances is expected to help players and coaches develop techniques to allow immature youth players to shoot more effectively from different distances.

Shumway et al. argued that the organization pattern of actions is governed by several factors, including the individual, the task, and the environment [14]. As the shooting distance task increases, players are able to increase the release speed by using a greater range of arm joint motion [15]. Release the ball earlier than the peak height of the jump, using more energy from the jump to optimize the impulse to release the ball [16–18], Individual differences can also affect shooting motions, and Miller and Bartlett [19] found that guards demonstrate more consistent kinematic adaptations during long-range shooting compared to centers, who exhibit more variability in joint angles and release timing [20]. In contrast, children and female players limit the freedom of movement of their joints, and this uncoordinated organization of movement does not allow the throwing arm joints to exert greater impulse on the ball [16,21,22], Experienced experts have the opposite strategy of motion control [23]. However, the above studies primarily focus on kinematic variables, such as peak velocity, which capture momentary data rather than providing a continuous assessment of motion. These approaches do not fully account for the role of muscle force and joint energy production, highlighting a gap in understanding the force dynamics during shooting

Nakano et al. examined how energy is continuously produced and transmitted through joints during shooting at various distances, highlighting changes in lower extremity energy output strategies as shooting distance increases in skilled players [24]. Tang, Shung et al concluded that short-distance shooting accuracy of skilled basketball players was correlated with isometric strength of wrist flexors, while a significant correlation was found between long-distance shooting accuracy and isometric strength of elbow extensors [2]. Because the average force produced by human skeletal muscles is proportional to the variability of the force produced by the muscles [25], we believe that controlling upper limb movements is more appropriate than controlling lower limb movements to accurately vary the magnitude of muscle contraction force [26,27], however, the effect of throwing arm muscles has not been evaluated, especially for multi-joint muscles [28].

Therefore, this study aims to investigate the differences in success factors between skilled and unskilled young student-athletes during basketball jump shots from various distances. The focus is on understanding how shooting distance and proficiency level influence energy production and muscle activation in the shooting arm joint. With the expectation of helping players and coaches develop techniques to allow immature players to shoot more effectively at different distances [29]. The hypothesis of this study was that, depending on the basketball player's level and shooting distance, shooting success would vary in terms of energy production and muscle activation percentage (effort) at the shooting arm joint during the shooting phase, and that these differences would affect the success of the shot [30].

2. Methods

2.1. Participants

Twenty-eight healthy active male subjects volunteered to participate in this study. All subjects were active and answered a personal information questionnaire (age, height, weight, etc.) prior to volunteering for the study. The participants were all right-handed on the dominant side, [age = 20.5 ± 2.4 years, weight = 78.6 ± 6.5 kg, height = 182.1 ± 7.9 cm (mean ± standard deviation)] The participants were divided into two groups (skilled and unskilled), student-athletes(S) and recreational players (US), based on the number of years of participation in training (5.2 ± 1.2 years for S and no professional training for US). The experiment was performed in a biomechanics laboratory, and participants gave written consent after being informed of the potential risks and procedures of the protocol, and the study was approved by the Ethics Committee of Jeonbuk University, Korea (JBNU2022-04-008-002).

2.2. Experimental procedure and apparatus

Experimental data were collected using 13 infrared cameras (Opti Track, LEYARD, USA) capturing kinematic data for each participant at a sampling rate of 240 Hz. In the experiment, matching markers were 14 mm reflective markers and each subject was marked with 57 reflective skin markers (as shown in **Figure 1**), and ground reaction force data were collected at 1200 Hz using an OR6-6-2000 force platform (AMTI, Inc.) from Newton, MD, USA, with a maximum latency of 6 ms. EMG data acquisition equipment was selected from Delsys, Inc. EMG acquisition system manufactured by Trigno Avanti Sensor, Inc. For EMG signal acquisition, we used the Trigno Avanti Sensor (Delsys, Natick, MA, USA; 3.7 cm × 2.7 cm). All EMG sensors (Trigno Avanti Sensor) had a common mode rejection ratio of 80 dB and were synchronized with kinematic and kinetic data by recording software (Opti Track, LEYARD, USA) with an EMG sampling frequency of 1200 Hz. surface electrodes were selected from the anterior deltoid bundle (AD), triceps brachii (TB), and Flexor carpi radialis (FCR).

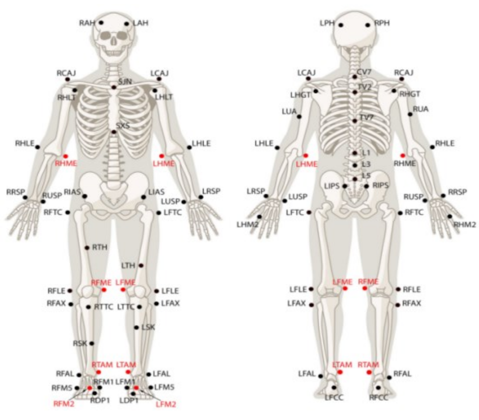

Figure 1. Reflective marker attachment positions.

Note: 57 markers were put on landmarkers to build a predefined model by Motive (NaturalPoint Inc., OR, USA).

The locations were chosen as follows: 70% of the line connecting the rostral process and the deltoid node (AD). The acromion angle and medial epicondyle 40% towards the middle (TB). 90% of the medial epicondylar radial stem (FCR). Prior to electrode attachment, the hair at the adhesive site was removed and cleaned with alcohol wipe. After allowing the skin to dry, the EMG electrodes were implanted. At the same time, the electrodes were fixed using motion tape to reduce motion artifacts.20 Maximum voluntary isometric contraction (MVC) was tested for 5 s for each muscle in the following manner. To assess the anterior deltoids (AD), the subject sits with the main arm hanging freely at the side of the body, the elbow flexed 90 degrees, the shoulder slightly abducted, and then exerts maximum forward force in a plane parallel to the trunk. In order to evaluate the triceps brachii, subjects were seated with the upper arm immobilized and the wrist facing forward. Starting with 90 degrees of elbow flexion and with the tester stabilizing his/her forearm, the subject performed maximal elbow extensions lasting 5 s each. Finally, to assess the Flexor carpi radialis (FCR), participants were asked to place their forearms in a brace, straighten their hands outward with palms facing inward, form a fist, and then apply maximal force in the direction of flexion for 5 s.

Subjects performed a 10-min warm-up exercise (jogging, static stretching) followed by a shooting experiment task. Shots were performed in the following order: three medium distance condition shots and three long distance condition shots, as adaptation to increased shooting distance shooting skills is a common problem and should be investigated for increased rather than decreased distance. Participants were asked to release the ball after jumping up from the force plate (FP), shoot it successfully in the way they were most comfortable and used, without the aid of the rim, and then land anywhere they liked. Complete three successful shots in medium and long conditions. A key part of the basketball jump shot motion is the release phase where the shooting arm propels the ball. The laboratory design (as shown in **Figure 2**) basketball stand holders were located at two different distances from the force plate (FP), they were set such that the vertical projection of the center of the basket on the ground was at a distance of 5 m and 6.8 m from the front of the force plate (FP), respectively, and the subjects were shooting at two distances. subjects wore uniform clothing and used a uniform basketball.

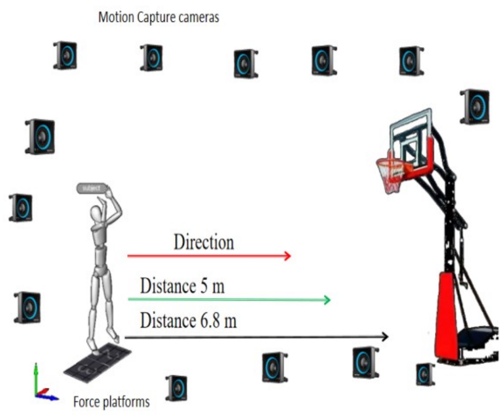

Figure 2. Experimental set-up.

Note: EMG and Motion data were synchronized by Motive.

2.3. Data collection and analysis

A critical part of the basketball jump shot action is the release phase where the shooting arm propels the ball. Most researchers define this as the moment when the elbow joint begins to accelerate in extension until the ball leaves the hand (as shown in the **Figure 3**). This study focuses on the parameters of the shooting arm in the sagittal plane, with kinematic and kinetic data processed by Visual 3D (C-Motion, Inc. USA). A whole-body model was created in Visual3D software using the CODA (pelvic segmentation model used by Charnwood Dynamics) pelvic coordinate system (Charnwood Dynamics Ltd., UK) and a pelvic coordinate system was defined. The CODA system automatically determines the hip joint centers using Bell and Brand regression equations [31,32]. The torso model was created according to the guidelines of the International Society of Biomechanics (ISB), and the joint centers of the ankle, knee, elbow, and wrist were defined as the midpoints between the medial and lateral markers [33,34]. For simplicity of the model, the reaction force of the ball was not included in the analysis. Combined with force plate data, kinematic data and inertial parameters, joint moments were calculated using an inverse kinetic approach, normalizing the kinetic variable force to the subject's body weight ($\times$ kg^{-1}). The joint energy production was quantified by joint power analysis, and the work done by the joint moment component was defined as the numerical integral of the joint power in the time domain (product of joint moment and joint angular velocity), which was calculated as zero for this study based on the nature of basketball shooting, assuming that the contact force between the ball and the left hand was sufficiently small. EMG activity data were calibrated and smoothed using the auxiliary software of the EMG acquisition system (Trigno Avanti transducer from Delsys, USA) with a band-pass filter of 10-400 Hz, and EMG signals were calibrated and smoothed by the root-mean-square (RMS) over a 50-ms window. The average RMS amplitude was calculated for three trials for each muscle, and the RMS was normalized by maximum voluntary isometric contraction (MVIC).

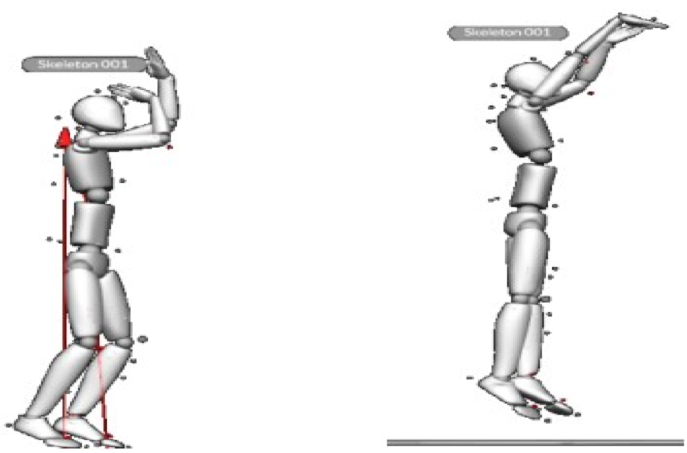

Figure 3. Shooting arm shooting phase.

2.4. Statistical analysis

The power is integrated over the time domain using MATLAB to calculate the statistics. Statistical analyses were performed using GraphPad Prism 9.2.0 (GraphPad

Software, La Jolla, CA, United States). The data are expressed as mean ± SD, and statistical significance was accepted as $p < 0.05$. Variables were analyzed using Two-way mixed design ANOVA (group × distance). Once the individual main effects were significantly different in the variance results, multiple comparisons were performed using the Tukey-Kramer method for the shooting action parameters of group and distance.

3. Results

3.1. Comparison between the success rate

There was a significant difference in shooting success rate in terms of distance main effect (**Table 1**).

Table 1. Shooting success rate at different distances for S and US (mean ± SD, %).

	US 5 m	US 6.8 m	S 5 m	S 6.8 m	Distance	Group	interaction
Success %	52.5 ± 23.0	23.0 ± 7.6[a]	87.0 ± 17.5[a]	60.8 ± 11.4[bc]	$P < 0.001$	$P < 0.001$	$P = 0.69$

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

Post hoc multiple comparisons showed significant differences (**Table 1**). The success rate of shooting decreased significantly as the shooting distance increased and US group had a greater decrease in group power, decreasing by nearly 30% with a low success rate. Post hoc multiple comparisons revealed significant differences between the two groups at 5 m distance ($P = 0.001$) and at 6.8 m distance ($P < 0.001$), with the skilled group having a higher success rate at both distances, especially at the 6.8m shot. The interaction effect was not significant ($F = 0.16$, $P = 0.69$).

3.2. Comparison between the joint angle

There was a significant difference in the distance main effect of shoulder joint angle at the moment of the start of the shot ($F = 20.7$, $P < 0.001$, **Table 2**). Post hoc multiple comparisons showed a significant difference at 5 and 6.8 m comparison for the unskilled ($P = 0.01$), with a smaller shoulder joint angle at the moment of shot release onset for both groups as the shot distance increased, with a significant difference in shoulder flexion angle for the unskilled group. There was a significant difference in the group main effect for shoulder joint angle ($F = 9.2$, $P = 0.005$) and a significant difference in the post hoc multiple comparisons between the skilled and unskilled groups at 6.8 m ($P = 0.041$), with the skilled group having a greater shoulder joint angle of nearly 90° at 6.8 m compared to the unskilled group. The difference of interaction effect is not significant ($F = 1.1$, $P = 0.29$, **Table 2**). At the moment of the end of the shot release (E5), There was no significant difference in shoulder joint Angle in distance from the main effect ($F = 0.14$, $P = 0.70$). There was no significant difference in the main effect of the shoulder joint ($F = 2.5$, $P = 0.1$), and no significant difference in the interaction effect ($F = 0.51$, $P = 0.47$).

Table 2. Angle of the joint at the beginning and end of the shooting motion (mean ± SD, degree).

Group	Distance	SA Start	SA End	EA Start	EA End	WA Start	WA End
Us	5 m	85.5 ± 9.3	133.4 ± 12.7	74.3 ± 8.7	174.8 ± 7.1	108.5 ± 7.8	192.9 ± 15.5
	6.8 m	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	5 m	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]
	6.8 m	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		$P < 0.001$	$P = 0.71$	$P = 0.081$	$P = 0.25$	$P = 0.046$	$P = 0.7$
Group effect		$P < 0.001$	$P = 0.1$	$P = 0.036$	$P < 0.001$	$P < 0.001$	$P < 0.001$
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 5 m, b—difference when compared to US 6.8 m, c—difference when compared to S 5 m. 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.

At the beginning of the shooting motion, elbow Angle had no significant difference in distance main effect ($F = 3.2$, $P = 0.081$, **Table 2**), and elbow Angle had no significant difference in group main effect ($F = 4.8$, $P= 0.036$). Post-comparison showed that shoulder Angle had no significant difference between groups. There was no significant difference in the interaction effect of elbow joint Angle ($F = 1.8$, $P = 0.18$). At the end moment of the shot release (E5) there was no significant difference in elbow joint angle for the distance main effect ($F = 1.3$, $P = 0.25$), a significant difference in elbow joint angle for the cluster main effect ($F = 53.1$, $P < 0.001$), a significant difference in elbow joint angle when comparing skilled and unskilled at 5 m ($P < 0.001$), and a significant difference in elbow joint angle when comparing skilled and unskilled at 6.8 m ($P < 0.001$). There was a significant difference in elbow joint angle ($P < 0.001$) when comparing skilled and unskilled, and at the moment of the end of the shot release, the elbow joint angle was greater in the skilled compared to the unskilled, meaning that the skilled had a large extension of the elbow joint and even a hyperextended action posture. There was no significant difference in interaction effects ($F = 0.42$, $P = 0.51$).

At the moment of the start of the shooting action (E3), wrist joint angle differed significantly in terms of distance main effect ($F = 4.3$, $P = 0.046$, **Table 2**), but in post hoc multiple comparisons showed no significant difference between the skilled and unskilled groups when shooting at different distances. Wrist joint angle differed significantly in terms of group main effect ($F = 118.7$, $P < 0.001$), with a significant difference between skilled and unskilled at 5 m ($P = 0.0014$). There was a significant difference ($P < 0.001$) in wrist joint angle between skilled and unskilled at 6. 8 m. In terms of wrist joint angle of the ball carrier, the skilled group had a greater wrist joint angle and the unskilled group had a greater dorsiflexion posture of the wrist joint. There was no significant difference in interaction effects ($F = 4.1$, $P = 0.051$).

At the end moment of the shot release (E5), the wrist joint angle differed significantly in terms of group main effect ($F = 141.1$, $P < 0.001$, **Table 2**) where there was a significant difference in wrist joint angle between skilled and unskilled at 5 m ($P < 0.001$) and a significant difference in wrist joint angle between skilled and unskilled at 6.8 m when comparing ($P < 0.001$), the wrist joint angle of the ball carrier

In terms of wrist joint angle, the skilled group had a greater wrist joint angle and the unskilled group had a greater flexion posture of the wrist joint. There was no significant difference in wrist joint angle for both the distance main effect ($F = 0.15$, $P = 0.7$) and the interaction effect ($F = 0.23$, $P = 0.63$).

3.3. Comparison of the work done by the shooting arm joint

At the release phase of the shot (RE), a significant difference was found in the distance main effect of shoulder joint work ($F = 17.6$, $P < 0.001$, **Figure 4**). The difference was significant at 5 m and 6.8 m for the skilled ($P < 0.001$), As the shooting distance increased, the skilled group produced more energy in the shoulder joint when shooting at 6.8 meters. The work done by shoulder joints was significantly different in the group main effect ($F = 7.8$, $P < 0.01$), and post hoc comparisons revealed a significant difference between skilled and unskilled at 6.8 m ($P < 0.01$), with the skilled group producing more energy in the shoulder joint at both distances of shooting compared to the unskilled, especially at the 6.8 m shot. The interaction effect difference was significant ($F = 4.5$, $P = 0.041$).

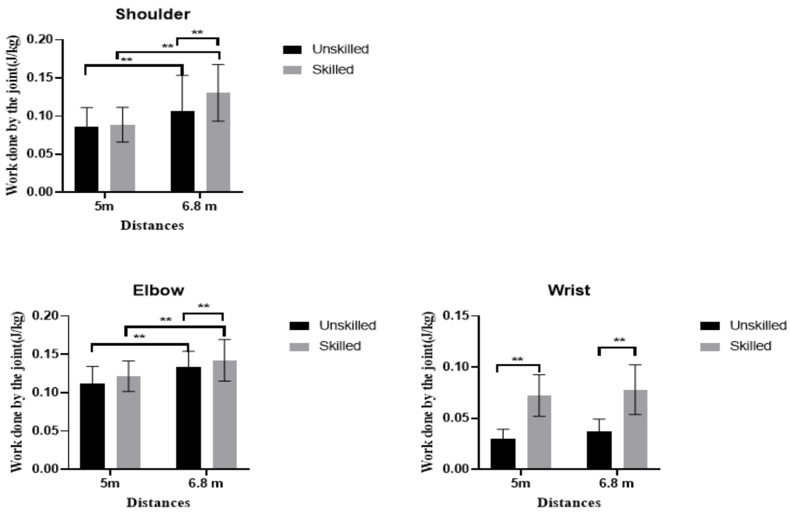

Figure 4. Work done by the shooting arm joint at different distances for unskilled and skilled shooters (mean ± SD, J/Kg).

Note: * $p < 0.05$, ** $p < 0.005$.

At the release phase of the shot (RE), a significant difference was found in the distance main effect of work done by the elbow joint ($F = 60.3$, $P < 0.001$, **Figure 4**). The difference was significant at 5 m and 6.8 m for unskilled individuals ($P = 0.0016$) and at 5 m and 6.8 m for skilled individuals ($P < 0.001$), with both groups producing more energy at the elbow joint at 6.8 m when shooting at increasing distances. The work done by the elbow joint was significantly different in the main effect of the group ($F = 14.1$, $P < 0.01$), and post hoc comparisons revealed a significant difference between skilled and unskilled at 6.8m ($P < 0.001$), with the skilled group producing more energy in the elbow joint when shooting at both distances compared to the unskilled, especially at the 6.8m shot. The interaction effect difference was not significant ($F = 3.8$, $P = 0.058$).

At the release phase of the shot (RE), The work done by the wrist was significantly different in the group main effect ($F = 144.8$, $P < 0.001$, **Figure 4**), and in post hoc multiple comparisons, there was a significant difference in the work done by the wrist between skilled and unskilled at 5 m ($P < 0.001$), and at 6.8 m between skilled and unskilled ($P < 0.001$), compared to the unskilled The skilled group produced more energy in the wrist joint compared to the unskilled group at both distances of the shot and the difference was significant. There was no significant difference in the main effect of distance ($F = 4.1$, $P = 0.052$) and interaction effect ($F = 0.023$, $P = 0.87$) for the work done by the wrist.

3.4. Comparison of hitting performance variables

At the release phase of the shot (RE), there was a significant difference in the percentage of anterior deltoid (AD) activation with respect to the distance main effect ($F = 45.9$, $P < 0.001$, **Figure 5**). Post hoc multiple comparisons showed significant differences in AD activation percentage between the unskilled ($P = 0.046$) and skilled ($P < 0.001$) groups at both the 5 m and 6.8 m shot, with a significant increase in anterior deltoid (AD) activation percentage in the shooting arm as the distance of the shot increased. There was a significant difference in anterior deltoid (AD) activation percentage in terms of group main effect ($F = 9.9$, $P < 0.01$), and post hoc multiple comparisons showed a significant difference between the unskilled and skilled groups at the 6.8m throw ($P < 0.001$), with a greater percentage of AD activation in the skilled group. There was significant variability in the percentage of anterior deltoid (AD) activation in terms of interaction effects ($F = 7.1$, $P = 0.015$).

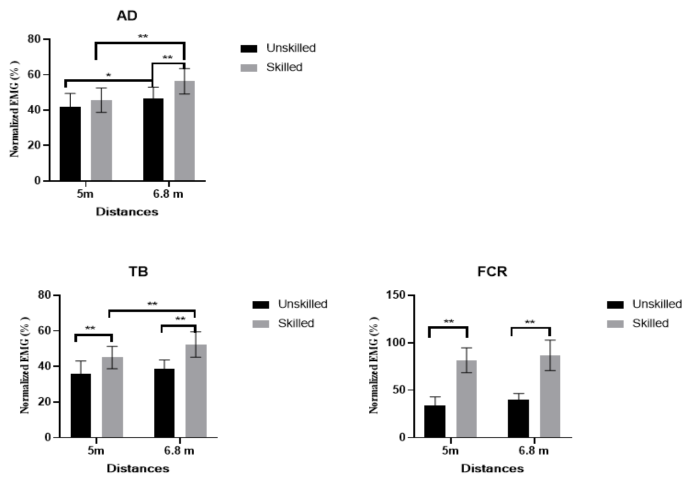

Figure 5. Muscle activation during shooting at different distances for unskilled and skilled individuals (%MVIC).

Note: * $p < 0.05$, ** $p < 0.005$.

There was a significant difference in triceps (TB) activation percentage in terms of distance main effect ($F = 11.4$, $P < 0.01$, **Figure 5**) and post hoc multiple comparisons showed a significant difference between the skilled group at the 5 m and 6.8 m shot ($P < 0.001$), with more TB activation in the skilled group at the 6.8 m shot. There was a significant difference in the percentage of triceps activation in terms of group main effect ($F = 51.6$, $P < 0.001$), and post hoc multiple comparisons showed a significant difference between the skilled and unskilled groups at the 5 m shot ($P < 0.001$) and at the 6.8 m shot ($P < 0.001$), with greater activation of TB in the skilled group at both distances. There was no significant difference in interaction effects (F = 4.3, P = 0.052).

The percentage of Flexor carpi radialis (FCR) activation was significantly different in terms of group main effect (F = 249.0, P < 0.001, **Figure 5**) and post hoc multiple comparisons revealed that post hoc multiple comparisons showed a significant difference between the skilled and unskilled groups at the 5 m shot (P < 0.001) and at the 6.8 m shot (P < 0.001), with the FCR in the skilled group showing There was greater activation in both distance shots. There was no significant difference in the main effect of distance (F = 0.054, P = 0.81) and no significant difference in the interaction effect (F = 4.3, P = 0.052).

4. Discussion

In this study, we evaluated the kinematic parameters, kinetic parameters and electromyographic activity of the upper extremity during the projection phase of basketball 3-point shooting in skilled and unskilled individuals during jump shots from different distances. Our main findings were that there were differences between skilled and unskilled individuals during shooting at different distances: 1) in the success rate of the shot, 2) in the angle at the beginning of the shot and the angle at the end of the shot for each joint of the shooting arm, 3) in the energy produced by each joint during the shooting phase, and 4) in the percentage of muscle activation. The degree of effort of active coordination of the organizing force of the muscles of the throwing arm during the throwing release phase differed between skilled and unskilled individuals as the throwing distance increased, which is consistent with our hypothesis.

4.1. Shooting success rate

We demonstrate that the shot success rate decreases for both groups as the shooting distance increases, due to the fact that the horizontal virtual target decreases as the shooting distance increases, and therefore the further the shooting distance, the greater the spatial accuracy constraint that the shooter must master [6,18]. In addition, because of the increase in the distance the ball travels, the angle of release decreases, and the angle of entry when the ball reaches the rim decreases, thus increasing the requirement for a successful shot [8]. As the shooting distance increases, the unskilled group power decreases more and the skilled group power decreases less. The release velocity of the ball increases when the shooting distance increases, and the skilled group adjusts the muscles dominating the joints to produce energy to regulate the generation of impulse when the shooting distance increases so that the ball completes the necessary flight parameters.

4.2. Shooting arm joint angles

Based on statistical analysis, we demonstrated that the shooting distance had an effect on the beginning and end joint angle variables of the shooting arm during the shooting phase, with both groups showing a trend of decreasing initial shoulder joint angle with increasing shooting distance, which is consistent with the findings of Okazaki et al. [6], Shooting from a distance requires a large impulse to drive the ball through a long trajectory to the basket [17,19,35]. This suggests that in order to meet the requirements of the task of generating large amounts of energy, both groups reduced the flexion angle of the shoulder joint, which in turn increased the joint motion amplitude. The unskilled group had less flexion angle at the initial moment compared to the skilled group, suggesting that the unskilled relied more on the magnitude of shoulder flexion to meet the requirements of the completion task. Although no significant differences in shoulder joint angle at the end moment of the shot were observed in distance and group, we found that the skilled group had a greater flexion angle, which may be related to the increased height of the shot and angle of release [35]. As the shooting distance increased, no significant difference was found in the initial elbow flexion angle between distances and groups, and at the end of the shooting moment, the elbow joint of the unskilled group was not fully extended, compared to the skilled group, which had more consistency of fully extended movements, and whether the elbow joint was fully extended at the moment the ball was shot was an important sign to judge the shooting level [7]. The unskilled had a smaller initial wrist angle, but the skilled had a greater flexion angle at the end of the shot, and the skilled group had a large wrist flexion angle consistent with the study by Rodacki et al. [36], and the unskilled had a smaller wrist angle at the initial moment, which can be considered to be related to a greater use of muscle energy stored in the wrist joint. The skilled group has a large wrist flexion angle, which is considered to be the active work of the wrist flexors to generate more energy, in order to increase the rotation of the ball thus reducing the release speed of the basketball, increasing the speed of the ball's upward flight, affecting the flight trajectory and thus the angle of the basketball into the basket, which has an impact on the accurate shot [17].

4.3. Energy produced by the shooting arm joints

The energy produced by the shoulder and elbow joints increased with the shooting distance in both groups. At 6.8 m shooting, more energy was produced by the shoulder and elbow joints in the skilled group than in the unskilled group, and the energy produced at the wrist joint did not increase with the shooting distance. However, the skilled group produced more energy in the wrist joint than the unskilled group. When the shooting distance increases, the shoulder and elbow joints located at the proximal end increase the energy production to optimize the energy produced by the lower limbs, but the skilled group increases the energy more, thus increasing the upward impulse and changing the trajectory of the basketball flight [6]. Uncontrollability has been reported to increase when the speed of movement increases rapidly [37,38], It is an important factor that affects the consistency and shooting accuracy of the shooting motion [15,39]. Therefore, it has been suggested that basketball shooting reduces the angular velocity of the joint during the shot [8,23]. However, the increased energy generated by the shoulder and elbow joints during ball release is a strategy that prioritizes the increased impulse at ball release, which may explain the observed lower accuracy at long distances compared to close distances. This strategy leads to an increase in ball release velocity and is considered to be a characteristic of players with low ball release ability [7,24]. Skilled group of wrist joints larger wrist flexion did more work, can increase the rotation of the ball thus reducing the speed of the release ball, increasing the speed of the ball upward flight

[17,40], We believe this may be a stabilization adjustment strategy for the end segment.

4.4. Electromyography of the shooting arm

Group and shooting distance influenced electromyographic variables, with previous studies suggesting that the lower extremity increased energy output to obtain the desired ball velocity and the shooting arm regulated movement to reduce variation in release parameters [24,41]. The variability of the force produced by skeletal muscle is proportional to the average force produced by the muscle [25], Compared to the upper limb muscles, the lower limb muscles are able to generate more force, so they are not as accurate as the upper limb muscles in controlling tiny accuracy. When the shooting distance changes, the player may change the energy output of the lower limb to transfer to the upper limb [8,19]. Adjusting the movement of the shooting arm to compensate for the changes caused by the movement of the lower limbs is very important for accurate shooting.

The present study found that both AD and TB activation percentages increased significantly when shooting distance increased, with more increase in AD and TB activation percentages in the skilled group, and it was reported that short-range shooting accuracy was significantly correlated with wrist isokinetic strength, and long-range shooting accuracy was significantly correlated with elbow extensor isokinetic strength, suggesting that specific isokinetic strength should be emphasized in training [2,42]. It can be understood that it does not require much impulse to make the ball reach the basket when shooting from a short distance [6], It can also be interpreted that the reduced involvement of large joints such as the proximal shoulder and elbow during close range shooting makes it easier to make proprioceptive feedback for motion correction and produces less neural noise [18,37], This is out of stable control of the throwing arm action, as large velocities are not conducive to stable accuracy [38], Long distance shooting requires a huge impulse to propel the ball close to the basket, generating a large velocity, although not conducive to accurate and stable shooting, is a compromise to accomplish the task of increasing distance, and previous studies have reported that elbow extensor strength plays a major role in compensating and increasing lower extremity energy in successful long distance shooting actions of skilled players [2,40]. Tasks requiring lower strength can usually be accomplished using muscles of a single joint; as strength requirements increase, more joint muscles and necessary neutralizing muscles need to be called upon [43,44]. The long head of the triceps is a “preparatory” elbow extensor, and it is the largest multi-joint muscle in the triceps, suitable for tasks that require high performance. The long head of the triceps extends the elbow joint while pulling the shoulder joint into extension when the shooting arm is throwing, so when the anterior deltoid flexes the shoulder, the elbow is also extending rapidly and the anterior deltoid must be able to counteract the shoulder extension moment generated by the long head of the triceps [45]. The large activation of AD and TB observed in this study demonstrates that the motion of the throwing arm is consistent with this physiological view. The upper limb is primarily driven by polyarticular muscles that operate at an inclination relative to the corresponding axis of rotation. Therefore, these polyarticular muscles are also multifunctional, as they produce several torque components at several different joints at the same time. Thus, when they contract in order to perform a desired action at one joint, they usually elicit several other desired actions at some other joints [46,47]. Therefore, we believe that the large activation of AD and TB plays a stabilizing coupling role on shoulder flexion and elbow extension, so that the shoulder and elbow joints accelerate and decelerate in turn, and this stabilizing coupling will affect the release of distal joint forces to achieve the "wave effect" of human power transmission [48], Driving the basketball more upward and forward to form a large parabola is the main influencing factor for accurate shooting [49]. We found that the FCR activation level per distance shot was significantly greater in the skilled group than in the unskilled group. This, combined with the large wrist flexion amplitude and wrist energy production, suggests that the skilled group had more wrist flexor force, which also seems to confirm the "wave effect" idea. The main effect of the large wrist flexion amplitude and the large wrist flexion force is to give the ball a force toward the basket, and in addition, the wrist flexion allows the fingers to pivot the ball for backspin, increasing the lift of the ball, which increases the angle of the shot and the angle of entry into the basket.

Through the analysis of muscle activation variables (%MVIC) during shooting at different distances in unskilled and skilled individuals, we clarified that the percentage of AD and TB activation increased more in skilled individuals compared to the unskilled group when shooting at increased distances, and this increase in muscle activation couples the upper extremity joints to produce more energy while stabilizing the joints. The greater activation of the distal wrist flexor FCR in the skilled group allowed for greater flexion moment production in the wrist joint to optimize and compensate for the changes in the proximal join.

4.5. Practical implications

Our findings emphasize that increasing the intensity of neuromuscular activation of the upper limb muscles can be effective in increasing power during shooting, which is consistent with the consensus that players should use the distal upper limb joints to compensate for the lower limb joints to generate more energy, and that the distal upper limb joints control shooting accuracy [24]. However, the importance of developing the muscles of the upper extremity, particularly their ability to control the shoulder, elbow, and wrist joints, is not realized for some young players who lack experience in long-distance shooting, especially as the shooting distance increases beyond the three-point line. This result suggests that specific muscle activation should be emphasized in training to generate appropriate energy, which may improve the three-point jump shot performance of college basketball players who are not proficient at shooting from a distance.

5. Conclusions

With the increase of shooting distance, the skilled group of shooting arm joints (shoulder and elbow joints) increased more energy production, and this increase of energy was a result of the work done by the coupled joints of the shooting arm muscles and a regulation of the large unstable impulse (wrist joint). As the distance of the shot increases, the ability of the skilled group to actively organize the coupled joints of the throwing arm muscles to produce energy during the release phase of the shot differs from that of the unskilled group, indicating that the technique of the throwing arm action can be acquired through learning and is not all about developing muscle strength.

Author contributions: Conceptualization, ZY, YK and SK; methodology, ZY, YK and SK; software, ZY, ZZ and WF; validation, JW and SK; formal analysis, ZY, YK and ZZ; investigation, ZY, ZZ and WF; resources, JW and SK; data curation, JW and SK; writing—original draft preparation, ZY and YK; writing—review and editing, JW and SK; visualization, JW and SK; supervision, JW and SK; project administration, YK. All authors have read and agreed to the published version of the manuscript.

Ethical approval: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Jeonbuk National University (protocol code JBNU2022-04-008-002). Informed consent was obtained from all subjects involved in the study.

Availability of data and materials: Data will be made available upon request by the corresponding author.

Conflict of interest: The authors declare no conflict of interest.

References

1. Erčulj, F. and E. Štrumbelj, Basketball shot types and shot success in different levels of competitive basketball. PloS one, 2015. 10(6): p. e0128885.
2. Tang, W.-T. and H.-M. Shung, Relationship between isokinetic strength and shooting accuracy at different shooting ranges in Taiwanese elite high school basketball players. Isokinetics and Exercise Science, 2005. 13(3): p. 169-174.
3. Williams, C.Q., et al., The effect of foot placement on the jump shot accuracy of NCAA Division I basketball players. Sport Journal, 2016: p. 1-15.
4. Ardigò, L.P., et al., Effect of heart rate on basketball three-point shot accuracy. Frontiers in physiology, 2018. 9: p. 75.
5. França, C., É.R. Gouveia, and B.B. Gomes, A kinematic analysis of the basketball shot performance: impact of distance variation to the basket. Acta of bioengineering and biomechanics, 2022. 24(1).
6. Okazaki, V.H.A. and A.L.F. Rodacki, Increased distance of shooting on basketball jump shot. Journal of sports science & medicine, 2012. 11(2): p. 231.
7. Hudson, J., Shooting techniques for smaller players. Athletic Journal, 1985: p. 22-4.
8. Miller, S. and R.M. Bartlett, The effects of increased shooting distance in the basketball jump shot. Journal of sports sciences, 1993. 11(4): p. 285-293.
9. Kimura, A., H. Nakashima, and Y. Inaba, Biomechanical role can vary depending on the conditions of the motor task. Human movement science, 2023. 92: p. 103150.
10. A. Dupuy, M., D. Mottet, and H. Ripoll, The regulation of release parameters in underarm precision throwing. Journal of Sports Sciences, 2000. 18(6): p. 375-382.
11. Brancazio, P.J., Physics of basketball. American Journal of Physics, 1981. 49(4): p. 356-365.
12. Arias, J.L., Performance as a function of shooting style in basketball players under 11 years of age. Perceptual and Motor Skills, 2012. 114(2): p. 446-456.
13. Podmenik, N., B. Leskošek, and F. Erčulj, THE IMPACT OF INTRODUCING A LIGHTER AND REDUCED-DIAMETER BASKETBALL ON SHOT PERFORMANCE IN YOUNG FEMALE BASKETBALL PLAYERS. Kinesiology, 2014. 46(1).
14. Shumway-Cook, A., Motor control: Translating research into clinical practice. Lippincoot Williams & Wilkins, 2007.
15. Satern, M., Performance excellence: Basketball: Shooting the jump shot. Strategies, 1988. 1(4): p. 9-11.
16. Elliott, B., A kinematic comparison of the male and female two point and three point jump shots in basketball. 1992.
17. Knudson, D., Biomechanics of the basketball jump shot—Six key teaching points. Journal of Physical Education, Recreation & Dance, 1993. 64(2): p. 67-73.

18. Cabarkapa, D., et al., Impact of distance and proficiency on shooting kinematics in professional male basketball players. Journal of Functional Morphology and Kinesiology, 2022. 7(4): p. 78.
19. Miller, S. and R. Bartlett, The relationship between basketball shooting kinematics, distance and playing position. Journal of sports sciences, 1996. 14(3): p. 243-253.
20. Herdiawan, S., et al., The effect of current power, arm strength and coordination on jump shoot skill basketball skills. International Journal of Physical Education, Sports and Health, 2020. 7(1).
21. Okazaki, V.H.A. and A.L.F. Rodacki, Basketball jump shot performed by adults and children. Human movement, 2018. 19(1): p. 71-79.
22. Okazaki, V.H.A., et al., Coordenação do arremesso de jump no basquetebol de crianças e adultos. Revista Brasileira de Biomecânica, 2006. 7: p. 15-22.
23. Okazaki, V.H., A.L. Rodacki, and M.N. Satern, A review on the basketball jump shot. Sports biomechanics, 2015. 14(2): p. 190-205.
24. Nakano, N., S. Fukashiro, and S. Yoshioka, The effect of increased shooting distance on energy flow in basketball jump shot. Sports biomechanics, 2020. 19(3): p. 366-381.
25. Kudo, K., et al., Compensatory coordination of release parameters in a throwing task. Journal of motor behavior, 2000. 32(4): p. 337-345.
26. He, Y., et al., Lower limb biomechanics during the topspin forehand in table tennis: a systemic review. Bioengineering, 2022. 9(8): p. 336.
27. Pandy, M.G., et al., How muscles maximize performance in accelerated sprinting. Scandinavian Journal of Medicine & Science in Sports, 2021. 31(10): p. 1882-1896.
28. Marin, M.I., et al., A Biomechanical Evaluation of the Upper Limb Kinematic Parameters of the Throwing Action in Handball: A Case Study. Applied Sciences, 2024. 14(2): p. 667.
29. Guimarães, E., et al., The role of growth, maturation and sporting environment on the development of performance and technical and tactical skills in youth basketball players: The INEX study. Journal of sports sciences, 2021. 39(9): p. 979-991.
30. Zhang, M., et al., Determining the relationship between physical capacities, metabolic capacities, and dynamic three-point shooting accuracy in professional female basketball players. Applied Sciences, 2023. 13(15): p. 8624.
31. Leardini, A., et al., Multi-segment trunk kinematics during locomotion and elementary exercises. Clinical Biomechanics, 2011. 26(6): p. 562-571.
32. Cabarkapa, D., A. Fry, and M. Deane, Differences in kinematic characteristics between 2-point and 3-point basketball shooting motions-a case study. J. Ad. Sport Phys. Edu, 2021. 4: p. 19-23.
33. Wu, G., et al., ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—part I: ankle, hip, and spine. Journal of biomechanics, 2002. 35(4): p. 543-548.
34. Wu, G., et al., ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand. Journal of biomechanics, 2005. 38(5): p. 981-992.
35. Motoyasu, Y., et al. EFFECTS OF JOINT MOVEMENT ON THE ACCURACY OF 3-POINT SHOOTING IN BASKETBALL. in ISBS-Conference Proceedings Archive. 2008.
36. Rodacki, A., et al. The effect of distance increased on the basketball shot coordination. in 11o Brazilian Congress of Biomechanics, July 9-11, João Pessoa-Brazil, Book of Articles. 2005.
37. Schmidt, R.A., et al., Motor-output variability: a theory for the accuracy of rapid motor acts. Psychological review, 1979. 86(5): p. 415.
38. Meyer, D.E., et al., Optimality in human motor performance: ideal control of rapid aimed movements. Psychological review, 1988. 95(3): p. 340.
39. Slegers, N. and D. Love, The role of ball backspin alignment and variability in basketball shooting accuracy. Journal of Sports Sciences, 2022. 40(12): p. 1360-1368.
40. Miller, S. The kinematics of inaccuracy in basketball shooting. in ISBS-Conference Proceedings Archive. 1998.
41. Brandão, H.C.P., M.M. de Andrade, and J.C.d. Carmo, The correlation between Rate of Force Development Maximal Strength and Electromyography Variables of Basketball Athletes. bioRxiv, 2024: p. 2024.01. 31.578254.
42. Akcay, N., et al., Investigation of parameters affecting throwing velocity and accuracy in handball. Journal of ROL Sport Sciences, 2023: p. 706-720.
43. Neumann, D.A., Kinesiology of the musculoskeletal system. St. Louis: Mosby, 2002: p. 25-40.

44. Cabarkapa, D., et al., Kinematic differences based on shooting proficiency and distance in female basketball players. Journal of Functional Morphology and Kinesiology, 2023. 8(3): p. 129.
45. Eovaldi, B.J. and M. Varacallo, Anatomy, shoulder and upper limb, shoulder muscles. StatPearls. Treasure Island, FL: StatPearls, 2018.
46. Kornecki, S., A. Kebel, and A. Siemieński, Muscular co-operation during joint stabilisation, as reflected by EMG. European Journal of Applied Physiology, 2001. 84: p. 453-461.
47. Yamagata, M., et al., Influence of lower-limb muscle inactivation on medial and lateral knee contact forces during walking. Medical Engineering & Physics, 2022. 108: p. 103889.
48. Ellenbecker, T.S., M. De Carlo, and C. DeRosa, Effective functional progressions in sport rehabilitation. 2009: Human Kinetics.
49. Elliott, B. and E. WHITE, A kinematic and kinetic analysis of the female two point and three point jump shots in basketball. 1989.