

Kinematic analysis of the basketball jump shot with increasing shooting distance: comparison between experienced and non-experienced players

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Purpose: Basketball jump shot success is determined mainly by the height, velocity and angle of ball release. To achieve a successful shot, these variables need to be adjusted according to the player's position on the court. This study aimed to identify the changes in kinematics variables of the basketball jump shot with an increasing shooting distance performed by players with varying skill levels. *Methods:* Seventeen male subjects, divided into experienced ($N = 9$), and non-experienced ($N = 8$) players, performed three successful jump shots from the free-throw line (4.23 m) and the 3-point line (6.75 m). All attempts were recorded at 120 Hz with a camera perpendicularly to the sagittal plane, and the kinematics variables were calculated using Tracker software. *Results:* The increase in shooting distance shows a decrease in height and angle of ball release. In contrast, the velocity of ball release increased for both groups at longer distances. Experienced players presented a higher mean value of the height of ball release in both distances, which allowed for a lower velocity of ball release. *Conclusions:* The most meaningful improvement for players training the jump shot technique is to increase the release height of the ball, jumping higher and shooting the ball near the peak of the jump.

Key words: kinematics, basketball, jump shot, sports science, shooting distance

1. Introduction

The most used shooting technique in a basketball game is the jump shot [26], mainly performed at the 3-point line [7]. The jump shot enables the player to shoot from a longer distance to the basket. The outcome of the jump shot is determined mainly by the angle, velocity and height at ball release [12], [13], [16]. The height of the ball release is determined by the height of the player and the height of the performed jump phase [16]. The velocity of ball release is mainly determined by the velocity of the extension of the elbow and the flexion of the wrist [3] and is also affected by the velocity of knee extension [1].

A basketball shot can give different points depending on the player's position on the court. Differ-

ent positions also mean different distances of shooting that require adjusted release conditions and shooting kinematics. Research has shown that increasing the shooting distance requires a greater release velocity [9], [13], [15] and increased movement of the player's centre of gravity [12], especially horizontal movement in the direction of the basket [18]. Meanwhile, the angle of ball release tends to decrease with the increasing shooting distance due to the increase in velocity [12]. The height of ball release also tends to decrease [13] since players frequently shoot the ball before reaching the peak of their jump phase [18]. These adjustments in the jump shot technique affect the player's stability during the movement performance [15] since it is necessary for a greater elbow extension velocity to achieve a greater velocity of ball release [13]. Therefore, the longer shoot-

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ing distance contributes to more variability during the performance [3], [12], [20], consequently reducing the success rate [15].

The jump shot technique is a complex motor action [16], including coordination and synchronization between different segments' movements [3]. According to the literature, the technique can be divided into five phases: i) preparation, ii) ball elevation, iii) stability, iv) release; and v) inertia [16]. The first three phases are the most important to control the ball release variables. An experienced basketball player must modify their segments movement to adjust ball release conditions [24], considering his position on the court and shooting distance.

The jump shot performed on different shooting distances was already studied in various studies with different populations, including professional, university and young players of both sexes [9], [12], [15], [18]. However, details regarding the differences in the shooting performance according to the players' skill and experience level are still lacking. The comparison between experienced and non-experienced players is important for coaches and players by providing an insight into which adjustment to the player's technique may be more advantageous to improve the overall performance of the jump shot. Therefore, this study approaches the kinematics differences that occur with an increasing shooting distance, between the free-throw line and the 3-point line. This study aimed to analyse how an experienced player adapts to the increasing shooting distance, compared to a non-experienced player and also to understand what separates both groups regarding the jump shot by analysing the kinematics outputs of the different jump shots. It was hypothesized that experienced and non-experienced players present different mean values of height, angle and velocity of ball release when performing a jump shot. It was also hypothesized that both groups, along with the increase in shooting distance, present a similar trend in terms of the changes of the kinematic variables, however, in different magnitudes.

2. Materials and methods

2.1. Participants

The participants of this study were 17 basketball players. Nine experienced players, all playing at the time of the study in a team competing in the second national division with at least five years of experience. Eight non-experienced players were university students with practi-

cal basketball classes, so they knew how to perform the jump shot technique. Both groups presented similar values regarding the anthropometric variables, except for height (Table 1). The experienced players were higher compared to the non-experienced players, and all were right-handed. According to the Declaration of Helsinki, all players provided their written consent and participated voluntarily in the study that the Institutional Ethical Committee (CE/FCDEF-UC/00412019) had approved.

Table 1. Participant's description and anthropometric data (mean \pm standard deviation)

<i>N</i>	Non-Experienced	Experienced	
	8	9	ρ
Age [years]	20.84 \pm 0.97	20.68 \pm 1.74	0.972
Height [cm]	175.6 \pm 7.1	184.2 \pm 4.9	0.044*
Body mass [Kg]	77.04 \pm 9.40	79.50 \pm 8.70	0.732
Upper limb length [cm]	78.1 \pm 2.9	81.0 \pm 2.4	0.078

* Statistical significant differences ($\rho < 0.05$).

2.2. Procedures

After an initial warm-up, when players could shoot the ball and familiarize themselves with the basket, each player performed a maximum of three successful jump shots at each distance from the basket (4.23 m and 6.75 m). All players had a maximum of 10 attempts for each distance to perform a maximum of three successful shots, otherwise, were only accounted for the successful shots made in the 10 attempts. The players always started from a shorter shooting distance. For the kinematic analysis, three markers with 22 mm of diameter were attached on the right leg of each player: 1) on the greater trochanter of the femur to define the hip; 2) on the lateral epicondyle of the fibula to define the knee; 3) on the lateral malleolus of the fibula to define the ankle. All attempts were recorded at a video frequency of 120 Hz using a Sony DSC-RX100M5A camera (Sony Corporation, Minato, Tokyo, Japan), placed in line and perpendicularly to the jump shot position, at 5.50 m from the shooting position and a height of 1.20 m, capturing all the players' movement.

2.3. Data analysis

After all the attempts were performed, the three successful shots were exported to Tracker software (Open-Source Physics – Video Analysis and Model-

ling Tool – 5.1.5) to calculate the kinematics variables, and the raw data were used to determine the results. The calibration was performed according to software instructions and using the same object with known dimensions. The method of Direct Linear Transformation (DLT) made it possible to evaluate the calibration factor transforming the 2D virtual coordinates into real coordinates [2], [19]. From a total of 91 successful jump shots analysed, 9 were randomly selected to calculate the Intraclass Correlation Coefficient (ICC) for the ball release variables. The test was performed by two investigators, with experience in basketball kinematic analysis, and obtained the following results: velocity of ball release (ICC = 0.835); the height of ball release (ICC = 0.953); and angle of ball release (ICC = 0.831). The scores demonstrate the consistency and objectivity of the results obtained by the two investigators.

Velocity, angle and height of ball release were calculated at the moment of ball release, defined by the last frame where the player had contact with the ball. The velocity of ball release was calculated as the value of velocity immediately after the moment of ball release. The velocity was calculated using Tracker software, the raw data of the trajectory of the ball were exported to MATLAB (Version: 9.13.0 (R2022b)) and were filtered using a 4th-order Low Pass Filter with a cut-off frequency of 20 Hz. The percentage of variance between curves (VAF) [14] was calculated to assess the variation between the raw data curve and the curve with the filter applied, showing differences of less than 2% for all digitised coordinates. The height of the ball release was calculated as the distance between the centre of the ball and the floor. Besides, it was also calculated the normalized height of the ball release regarding the height of the ball release and the player's height, to verify whether the height of the player has any influence on the release moment. The angle of ball release was calculated as the absolute angle, with the horizontal of the vector created between the centre of the ball at the moment of ball release and the moment immediately after it.

Besides the linear kinematic variables relative to the ball, the horizontal displacement of the hip of the player was determined, as the difference between the horizontal coordinate of the hip at the end of the jump and at the beginning. The highest point of the hip marker reached during the jump shot was also determined. During the jump shot preparation phase, the knee angular displacement was determined and was analysed as the maximum knee flexion angle during the preparation phase. The beginning of the jump shot was defined as the moment when the

player starts the preparation phase (i.e., when the player starts the knee flexion) and the final moment when the player returns to contact with the floor after the shot.

2.4. Statistics

The data was exported to SPSS software (Version 26). All values were expressed as mean \pm standard deviation. The normality and homogeneity were assessed using the Shapiro–Wilk and Levene's tests. The Pearson correlation coefficient was used to check the correlation between variables regarding player experience and shooting distance. A one-way ANOVA was conducted to calculate the differences between the two groups on the same shooting distance, once the data presented normality and homogeneity, post-hoc test was conducted using Bonferroni correction. To compare the same experienced player on the two shooting distances was used the mean value of the successful shots performed by each player from each distance and the differences were calculated using the Wilcoxon signed-rank test. For non-experienced players, only six could successfully shoot from both distances, allowing the comparison between shooting distances. The effect size was calculated for all variables. For the *t*-test was used Cohen's *d*, classified as small ($d > 0.2$); medium ($d > 0.5$); large ($d > 0.8$); very large ($d > 1.2$) and huge ($d > 2.0$) [23]. Partial eta-squared (η^2) was used to calculate the effect size for the ANOVA, classified as small ($\eta^2 > 0.01$); medium ($\eta^2 > 0.06$); large ($\eta^2 > 0.14$) [6].

3. Results

A total of 91 successful jump shots of 275 attempts were analysed from the free-throw line and the 3-point line. From the shorter distance, experienced players made a total of 70 attempts and performed 27 successful jump shots (39%) and the non-experienced made a total of 63 attempts and successfully completed 20 jump shots (32%). From the longer distance, the 3-point line, the experienced players made 26 successful shots from a total of 65 attempts (40%) and the non-experienced made 18 successful jump shots from a total of 77 attempts (23%). The mean values for the kinematic variables in the analysis are shown in Table 2. The shots performed by the experienced and non-experienced players presented significant differences in the velocity and height of ball release (large effect

size, $\eta^2 > 0.14$), also in the normalized height of the ball release and the height of the hip at ball release (large effect size, $\eta^2 > 0.14$).

The jump shot performed on the free-throw line from both groups presented significant differences between the experienced and non-experienced players regarding the velocity of ball release since the non-experienced presented a higher velocity value. Experienced players present a higher mean value of the height of ball release and a higher vertical position of the hip in the moment of ball release when compared with non-experienced players. However, the height of ball release normalized to the height of the players did not show significant differences between experienced and non-experienced players in this shooting distance.

Regarding the shots performed from the 3-point line, were observed significant differences between the two groups of players. Experienced players presented lower values of velocity of ball release and presented a greater height of ball release. Also, the normalized height of ball release showed significant differences between the two groups for the shots performed from the 3-point line, being the group of experienced players that had higher values. Experienced players presented a higher maximum knee flexion angle during the preparation phase of the jump shot, which indicates that players performed a greater squat.

In Table 3, the performance of the non-experienced and experienced players was compared, considering the two shooting distances. For non-experienced

Table 2. Compared results of the shots performed by experienced and non-experienced players in function of the shooting distance (mean \pm standard deviation)

	Free-throw line (4.23 m)		3 – Point line (6.75 m)		$F_{(3,87)}$	p	ES
	non-experienced	experienced	non-experienced	experienced			
N	20	27	18	26			
V_{ball} [m.s ⁻¹]	6.99 \pm 0.40	6.59 \pm 0.36	8.50 \pm 0.42	8.10 \pm 0.39	120.53	<0.001 ^{†‡}	0.806
A_{ball} [°]	52 \pm 4	53 \pm 5	50 \pm 5	51 \pm 5	1.68	0.176	0.055
H_{ball} [m]	2.31 \pm 0.14	2.45 \pm 0.09	2.20 \pm 0.17	2.37 \pm 0.08	15.12	<0.001 ^{†‡}	0.343
$H_{normalized}$ [m]	1.31 \pm 0.07	1.33 \pm 0.04	1.25 \pm 0.05	1.29 \pm 0.04	10.62	<0.001 [‡]	0.268
DH_{hip} [m]	0.29 \pm 0.15	0.32 \pm 0.09	0.50 \pm 0.18	0.52 \pm 0.14	16.10	0.001	0.357
$H_{peak_{hip}}$ [m]	1.16 \pm 0.07	1.19 \pm 0.07	1.18 \pm 0.10	1.23 \pm 0.07	6.41	0.029	0.098
$H_{release_{hip}}$ [m]	1.10 \pm 0.07	1.18 \pm 0.07	1.10 \pm 0.08	1.15 \pm 0.06	3.14	<0.001 [†]	0.181
A_{knee} [°]	105 \pm 8	105 \pm 11	108 \pm 5	102 \pm 10	1.24	0.300	0.041

V_{ball} – velocity of ball release, A_{ball} – angle of ball release, H_{ball} – height of ball release, $H_{normalized}$ – normalized height of ball release with player's height, DH_{hip} – horizontal displacement of the hip marker, $H_{peak_{hip}}$ – peak height of the hip marker, $H_{release_{hip}}$ – height of the hip at the moment of ball release, A_{knee} – maximum angle of knee flexion, F – F -value, ES – effect size (η^2).

[†] – Bonferroni test ($p \leq 0.05$) between groups in free-throw line.

[‡] – Bonferroni test ($p \leq 0.05$) between groups in 3-point line.

Table 3. Compared results of the shots performed by non-experienced and experienced players in both shooting distances (mean \pm standard deviation)

	Non-experienced ($N = 6$)				Experienced ($N = 9$)			
	free-throw line (4.23 m)	3-point line (6.75 m)	ρ	ES	free-throw line (4.23 m)	3-point line (6.75 m)	ρ	ES
V_{ball} [m.s ⁻¹]	6.90 \pm 0.14	8.48 \pm 0.36	0.028*	3.554	6.60 \pm 0.35	8.12 \pm 0.36	0.008*	4.583
A_{ball} [°]	53 \pm 3	50 \pm 5	0.116*	0.767	53 \pm 4	51 \pm 4	0.028*	0.925
H_{ball} [m]	2.32 \pm 0.15	2.19 \pm 0.19	0.043*	0.901	2.45 \pm 0.09	2.37 \pm 0.08	0.015*	1.208
DH_{hip} [m]	0.26 \pm 0.12	0.48 \pm 0.17	0.028*	2.797	0.32 \pm 0.09	0.52 \pm 0.14	0.008*	2.617
$H_{peak_{hip}}$ [m]	1.16 \pm 0.08	1.19 \pm 0.12	0.015*	0.357	1.19 \pm 0.07	1.23 \pm 0.07	0.015*	1.310
$H_{release_{hip}}$ [m]	1.10 \pm 0.08	1.09 \pm 0.09	0.462	0.453	1.17 \pm 0.07	1.15 \pm 0.06	0.173	0.566
A_{knee} [°]	106 \pm 7	108 \pm 4	0.173	0.433	105 \pm 11	102 \pm 10	0.066	0.637

V_{ball} – velocity of ball release, A_{ball} – angle of ball release, H_{ball} – height of ball release, $H_{normalized}$ – normalized height of ball release with player's height, DH_{hip} – Horizontal displacement of the hip marker, $H_{peak_{hip}}$ – peak height of the hip marker, $H_{release_{hip}}$ – height of the hip at the moment of ball release, A_{knee} – Maximum angle of knee flexion, ES – effect size (Cohen's d).

* – Statistical significant differences ($p \leq 0.05$).

players, the height, angle and velocity of ball release presented significant differences between the two shooting distances. The velocity of the ball release increased (huge effect size, $d > 2.0$), and the height of the ball release decreased with the increase in shooting distance (large effect size, $d > 0.8$). The horizontal displacement of the hip increased, (huge effect size, $d > 2.0$) and the peak height reached by the hip marker decreased, (small effect size, $d > 0.2$). For the experienced players, significant differences were observed in the velocity, height and angle of ball release, similar to the non-experienced players. With the increased shooting distance, the velocity of ball release increases (huge effect size, $d > 2.00$). At ball release, the angle and the height decreased with the increase of the shooting distance. The height of the ball release presents a very large effect size ($d > 1.20$), and the angle of the ball release presents a large effect size ($d > 0.8$). The results also showed an increase in the peak height of the hip with a very large effect size ($d > 1.20$).

Considering the shots performed by the experienced players, a positive correlation between the velocity of ball release and the horizontal displacement of the hip ($r = 0.53$, $\rho < 0.01$) was observed, as well as the velocity of ball release showed a negative correlation with the height of ball release ($r = -0.40$, $\rho < 0.01$). Also, the height of the ball release presented a positive correlation with the peak height of the hip ($r = 0.42$, $\rho < 0.01$) and with the height of the hip at ball release ($r = 0.76$, $\rho < 0.01$). The height of ball release also correlated with the maximum knee flexion angle ($r = 0.31$, $\rho < 0.05$), i.e., players who made a deeper squat presented a higher height of ball release.

4. Discussion

This study aimed to identify the kinematic differences in the jump shot performed by experienced and non-experienced basketball players, with an increasing shooting distance. The study also intended to examine differences in shooting techniques used by experienced players when the distance to the basket is increased. As hypothesized, results showed that the jump shots performed by experienced and non-experienced players presented differences regarding the kinematic variables, velocity, height and angle of ball release. In the shots performed in both shooting distances, experienced players presented a lower velocity of ball release and a higher height of ball release. With the increase in the shooting distance, it was observed that

both experienced and non-experienced players increased the velocity of ball release and presented a decrease in the height of ball release. The experienced players also showed a decrease in the angle of ball release with the increase in shooting distance.

The height of the ball release is determined by the player's stature and the vertical jump impulsion reached during the jump shot [15]. Experienced players in both distances presented a greater height of ball release. In the shots performed in the 3-point line, the experienced players presented a higher value of the normalized height of ball release, which indicates that this group of players release the ball higher, independently from their height and the fact that the group of experienced players were significantly higher than the non-experienced. The maximum height reached during the jump does not show significant differences between experienced and non-experienced players, when compared in each distance. However, experienced players showed a higher height of the hip at the moment of ball release than non-experienced players in both shooting distances, although not statistically significant in the shots performed in the 3-point line. This suggests that although both groups have a similar jump height, experienced players release the ball higher (i.e., near the jump shot's peak height).

At both shooting distances, the non-experienced players presented a greater velocity of ball release, which is related to greater angular velocity [17], mainly in the elbow extension. Consequently, more movement variability emerges during the performance [18]. Experienced and non-experienced players needed to increase the ball release velocity due to the shooting distance increase. However, experienced players could have lower velocities of ball release due to the higher height of ball release and the superior stature of the players, which seems to be an advantage. The higher height of the ball release allows for a lower release velocity necessary to execute the shot successfully [11]. The fact that experienced players can successfully shoot the ball with a lower release velocity means that a lower elbow extension velocity is necessary, which means that the experienced players performed a more controlled movement. Players also use the upper body's rotation to transfer energy to the ball to increase releasing velocity. The experienced players showed in both distances a higher angle of ball release. Although there were no significant differences between the values of experienced and non-experienced players, the higher angle of ball release allowed for a smaller release velocity that allowed enhanced efficacy. Indeed, a greater release angle will result in a higher entry angle of the ball in the basket [10].

In all jump shots analysed angles below 100° were not observed. The smaller knee flexion angle was observed in the shots performed by the experienced players in the 3-point line ($102 \pm 10^\circ$). On the other hand, a higher peak height of the hip marker (1.23 ± 0.07 m) was also observed in the shots performed by the group in the same distance. These values are close to the values suggested by Chen [5] for optimal knee flexion (97.6°) when attempting to jump higher. The preparation phase is one of the most critical moments of the jump shot since it is when the player initiates the kinematic chain. However, with the increasing distance, the results do not show any significant difference regarding the value of maximum knee flexion.

With the increase in shooting distance, the velocity of ball release also increased, and the height of ball release decreased, which was previously reported in the literature [9], [11]–[13], [15]. Indeed, a greater velocity is crucial to overcome the long distance to the basket. Both experienced and non-experienced players showed increased velocity of ball release when the distance to the basket was increased. However, comparing the two groups, non-experienced players in both distances presented a greater velocity of ball release. The increase in horizontal displacement of the player's hip toward the basket, was observed with the increase in shooting distance by both groups. Especially at longer shooting distances, can be a strategy to increase the ball's release velocity. However, the shooting velocity increases by losing stability during the shooting performance [18].

The height of ball release results shows that experienced players in both distances released the ball higher than the non-experienced players. The jump height and the height at the moment of ball release contribute to the outcome of a successful shot, especially in shots performed from the 3-point line [4]. Experienced players use the height of the jump to release the ball higher. Analysing the differences between shooting distances, the height of ball release decreases, not due to a shorter jump, but because players released the ball before reaching the peak height [13], [18], [25], [27]. Releasing the ball before the peak height appears to be a strategy of players to transfer energy from the jump momentum to the ball [18] to increase release velocity.

The release angle was smaller in the jump shots made in the 3-point line. A smaller release angle suggests a smaller shoulder angle at the moment of ball release [21], which indicates that players, at longer shooting distances, are trying to shoot forward instead of upward. This is also supported by the increase in the horizontal displacement of the hip with the increasing distance [12], [15], [22], which may indicate

an attempt by the players to reduce the shooting distance.

Although the findings presented in this study are valuable for coaching practice, some limitations need to be acknowledged, namely, the jump shots were only recorded with one camera on the sagittal plane of movement which allows for a two-dimensional analysis. This way was not possible to track the rotational movement of players during the jump shot. Also, the limit of attempts for each player limited the number of successful jump shots analysed, especially in the non-experienced players, which demonstrated a lower success rate.

The results also show differences between the two groups in both shooting distances, mainly in the velocity and height of ball release. Experienced players showed a higher height of ball release in both distances, mainly because the group of experienced players were taller, and presented a higher height of the hip at the moment of ball release. This means that experienced players shoot the ball near the maximum height of the jump, allowing for a more stable shot and less release velocity. Results show that the velocity of ball release decreases with the higher height of ball release. The increasing shooting distance affected the kinematic variables of the jump shot. Therefore, during the early stages of the basketball training process, increasing the shooting distance by just one meter means a significant kinematic change in the movement [8]. In both groups, the velocity of ball release increased, which is accomplished, in part, with the greater horizontal displacement in the direction of the basket. The height of ball release decreases with the increasing shooting distance in the shots performed by both groups, although, in the shots performed by experienced players, the maximum height of the jump increases. In the shots performed in the 3-point line, the decrease in the height of ball release occurs because players release the ball before reaching the jump peak height. Also, the smaller angle of the ball release contributes to the smaller height of the ball release.

5. Conclusions

This study showed kinematic differences between experienced and non-experienced players in both shooting distances. Results show that for a low-skilled player who wants to improve his jump shot technique, the most significant kinematic improvement to the success of the jump shot is to increase the height of the ball release. Increasing the height of the ball release

does not mean only jumping higher but taking advantage of the height reached in the jump, releasing the ball near the jump peak height. The increase in the angle of ball release will also be a critical adjustment on the shot of the non-experienced players. The greater release angle will translate into a greater entry angle of the ball in the basket.

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