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A kinematic analysis of the basketball shot performance: impact of distance variation to the basket

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Purpose: The aim of the current study was to examine the variation on the kinematic parameters in the basketball shot associated with the shooting distance. *Methods*: Twenty-seven female adolescent basketball players aged 12.1 ± 0.9 years completed 10 BS trials from a frontal position of 4.75 m and 5.75 m from the basket. Nine anatomical markers were placed on the participants' dominant side to assess the kinematic variables. The following variables were analyzed: angle, velocity, and height at ball release; centre of mass horizontal displacement and maximum height attained; maximum hip height and hip height at release; shoulder, elbow, and knee angular position and velocity at ball release; deepest knee flexion during the preparatory phase; the peak of the angular velocity of the shoulder, elbow, and knee joints. *Results*: At release, the angle decreased while velocity increased significantly at 5.75 m. During the release, greater shoulder flexion and increased joint (shoulder and knee) angular velocity were observed. The deepest knee flexion and the centre of mass horizontal displacement were accentuated at 5.75 m. The ball release occurred before the peak of the jump phase. *Conclusions*: To compensate for the long ball trajectory to the basket, participants perform a set of adjustments in the body segmental organization to increase the ball velocity at release. The coaches' feedback should focus on the shooting arm's positioning and in the jump phase (to jump as close to vertical as possible). Also, a consistent shooting technique should be acquired close to the basket before expanding the shooting range.

Key words: *youth, motor action, female, biomechanics, strength*

1. Introduction

The basketball shot (BS) is considered a fundamental motor skill and the most used shooting technique in the basketball game [15], [21], [25]. The BS learning and teaching processes are supported by a reference movement pattern, which emerged from basic biomechanics principles [11], [15]. However, each player has a unique shooting style due to their interpretation of the reference movement pattern and individual characteristics such as anthropometry, physical capacities, and previous motor experiences [15]. Thus, even in elite players with similar percentages of shooting efficacy, it is possible to observe inter-individual differences in the motor action used while performing in comparable game-related conditions [10].

Literature has mentioned intra-individual variation on the BS performance by comparing the motor action used under different game-related conditions, particularly when the distance to the basket is manipulated [6]. Among game-related conditions, the increase of shooting distance has been pointed out by athletes and coaches as the primary influencer of the shooting efficacy and form [12]. Indeed, efficacy is consensually assumed as the main discriminant between winning and losing teams [5], [10]. However, the ratio between scored and missed attempts limits the feedback needed for the shooter's improvement, particularly among youngsters and more inexperi-

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enced players. Therefore, the analysis of the kinematic variables has emerged as relevant to understanding the dynamics of the motor action, the ball trajectory, and the shot's outcome [13].

Motor abilities play an important role in determining the players' long-term development [3]. Thus, previous studies aimed to evaluate the effects of the shooting distance on the shooting action to better understand the mechanisms that support the successful performance [13], [14], [18]. The study of the ball trajectory is defined by the angle, velocity, and height at ball release [14], [15] and intermediates the players' action and the shot's outcome. Among boys shooting at several distances from the basket, authors reported that the mean ball release angle ranged between 57.9 ± 3.4° and 68.7 ± 3.3°, while the mean of ball release velocity varied between 5.43 ± 0.16 m/s and 7.37 ± 0.20 m/s. At longer shots, the angle has decreased and velocity has increased significantly [17]. The same trend regarding the angle and velocity at the release point was observed in experienced basketball players. In males, the mean of ball release angle ranged between 69.3 ± 10.6° and 78.9 ± 8.8°, and velocity ranged between 4.39 ± 0.36 m/s and 6.89 ± 0.62 m/s [16]. In females, lower mean angle and velocity at release was observed (angle: 52.8 ± 4.1° to 52.1 ± 3.7°; velocity: 6.60 ± 0.40 m/s to 7.90 ± 0.30 m/s) [6].

Additionally, variables concerning the shooter's behavior and body's segment organization have also been examined, such as the displacement of the centre of mass (CoM), and joints angular position, displacement, and velocity [16], [18], [25]. Overall, the authors reported several performance adaptations on the BS associated with the distance to the basket. Also, efficacy tended to decrease significantly at longer shooting ranges.

Most previous research has privileged studies with experienced and male basketball players. The research focused on analyzing the shooting performance among youngsters is lacking, particularly in girls [7]. If significant adjustment mechanisms were observed in the movement pattern used by experienced players while shooting at longer distances to the basket, it would be expected that those adjustments would be more considerable in youngsters. Besides, female novice players present less strength and power than their male counterparts [23], which may be relevant to motor action performance. Knowing the strategies used by players to throw the ball at longer trajectories is critical for the coaches' feedback, particularly to know what to look for [21] and to encourage consistency on the acquisition of the shooting action [6].

Therefore, the current study aimed to examine the variation of the kinematic parameters in the BS performed at two shooting distances (4.75 m and 5.75 m) among adolescent female basketball players. We hypothesized that several adjustment mechanisms on the body segments organization are performed to increase the ball release velocity to overcome the longer ball trajectory to the basket.

2. Materials and methods

Participants

Twenty-seven female adolescent basketball players aged 12.1 ± 0.9 years, height: 153.3 ± 8.0 cm, and body mass: 48.8 ± 12.8 kg, from clubs of Madeira Island participated in the study. All participants had at least two years of basketball training experience and were not injured at the time of data collection. At the time of data collection, participants had an average of three training sessions per week. The current study received ethical approval from the committee of the University of Coimbra (CE/FCDEF-UC/00482019). Procedures were conducted according to the standards established by the declaration of Helsinki [9]. Legal guardians were informed about the nature of the study, including objectives, protocols and related risks, and signed informed consent. Participants were told that their participation was voluntary and all provided consent after being informed that they could withdraw from the study at any time.

Procedures

Before data collection, participants completed a 15-minute warm-up that included jogging, dribbling, shooting, and dynamic stretching. After the warm-up, each participant performed 10 BS trials from a frontal position at two distances to the basket: 4.75 m, and 5.75 m. All participants started by the 4.75 m position, followed by the 5.75 m position. All trials were performed with the standardized ball size for their age (Wilson Evolution Size 6, 566 g). One investigator caught the rebound of each shot, and the ball was given back to the shooter through a direct pass to maintain identical shooting conditions. After receiving the ball, participants were asked to shoot as they were in a game context, and for that reason, the stationary performance was not allowed. A second investigator was responsible for filming each BS attempt with a digital camera (Sony Cyber-Shot RX100, 120 Hz) positioned in the sagittal plane at 7 m from the participant's dominant side, 1.20 m from the floor (Fig. 1). According to the shooting position, the camera was moved perpendicularly to the sagittal plane of the movement. The distance between the camera and the players allowed us to visualize the total movement and part of the ball trajectory after leaving contact with the athlete. A third investigator recorded the BS outcome using an efficacy rating system composed of two levels: (0) missed, and (1) scored.

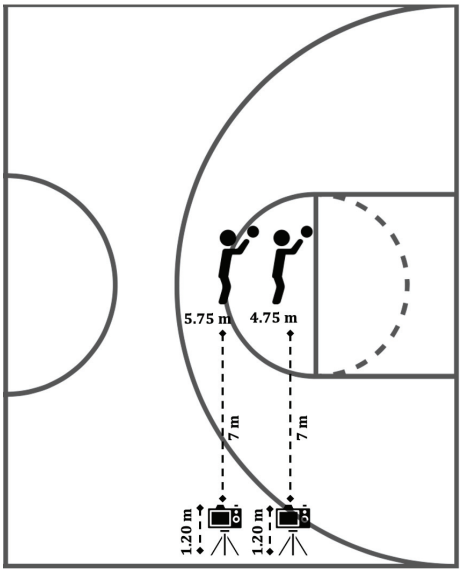

Fig. 1. Schematic representation of data collection

For the 2D kinematic analysis of the BS on the sagittal plane, nine anatomical markers (1.5 cm of diameter) were identified: on the tragus to define the ear; on the greater trochanter of the humerus to define the shoulder; on the lateral epicondyle of the humerus to define the elbow; on the ulnar styloid process to define the wrist; on the head of the fifth metacarpal to determine the hand; on the greater trochanter of the femur to define the hip; on the lateral epicondyle of the fibula to define the knee; on the lateral malleolus of the fibula to determine the ankle; on the head of the fifth metatarsal to define the foot [16]. A single investigator placed all markers on the participant's dominant side.

After data collection, all video recordings were exported and analyzed using Tracker software (Open-Source Physics – Video Analysis and Modelling Tool, 5.1.5) to assess the kinematic variables. The video calibration was made using a reference object with known dimensions placed in the plan of the movement. The calibration factor was evaluated using a 2D-DLT (Direct Linear Transformation) [2], [20], considering the vertical and horizontal dimensions of the reference object. A single investigator performed all analyses. A previous pilot study to assess our methods was conducted on 10 female basketball players aged 14.7 ± 0.6 years. From a total of 300 videos recordings collected, 30 files were randomly selected to calculate the intra-observer reliability coefficient (R). For the ball release variables, the following results were obtained: angle (R = 0.91), velocity (R = 0.87), and height (R = 0.90), which shows a good consistency of the analysis.

For the BS analysis, the following kinematic parameters were assessed: ball release variables (angle, velocity, and height); the 2D position of the centre of mass – CoM (total horizontal displacement and the maximum height attained); the position of the hip (maximum height and height at ball release); shoulder, elbow, and knee joints angular position at ball release, and the minimum angle formed by the knee (transition between the first and the second phases of the movement) for the sagittal plane of movement (flexion-extension); angular velocities of the shoulder, elbow and knee joints (the peak of angular velocity and the angular velocity at the ball release), also for the sagittal plane.

The ball release was defined by the last perceptible frame where the player's hand was in contact with the ball. The ball trajectory was studied at the ball release point, and five frames before and after the ball release point [24]. The ball release velocity was defined by the velocity value immediately after the ball release. This value was calculated by Tracker software using the ball displacement between frames and their respective time. The ball release height was expressed by the distance between the center of the ball and the floor at ball release. The ball release angle was given by the absolute angle formed by the center of the ball between the ball release and the moment immediately after. The coordinates of the release frame and the frame immediately after were exported to the Excel software. Then, the angle of ball release was calculated using trigonometric formulas.

For the 2D CoM assessment was made using a segmental model. The coordinates that defined the center of each marker during all movements were inserted into the Excel software. After, the CoM of the several anatomical segments was assessed through specific equations available in the literature, which considered the percentage of the distance travelled by each marker and the proportion of total body weight [8].

Tracker calculated the joints' angular position and velocity through the markers positioning during the movement. For all analyses performed, a visual inspection to detect an error of track was made and corrected if needed.

Past literature divided the BS movement pattern into three phases: 1) the preparatory phase, defined between the start of the shooting motion to the deepest knee flexion; 2) the action phase, which starts with the deepest knee flexion until ball release; 3) the follow-through phase, identified immediately after ball release to landing [21]. In the current study, the knee joint minimum angular position (deepest knee flexion) was analyzed in the transition between the first and the second phases of the movement.

Height and sitting height were measured using a portable stadiometer (SECA 213, Hamburg, Germany) to the nearest 0.1 cm. The estimated leg length was estimated through height minus sitting height. Body mass was measured using a portable scale (SECA 760, Hamburg, Germany) to the nearest 0.1 kg.

Statistics

Descriptive statistics included mean and standard deviation. All data were checked for normality using the Shapiro–Wilk test. Paired *t*-test was used to evaluate the impact of the increased distance to the basket on the kinematic parameters. Effect size was interpreted using Cohen's *d* as follows [4]: $d < 0.2$ (small), $0.2 \le d < 0.6$ (moderate), $0.6 \le d < 1.2$ (large), $1.2 \le d < 2.0$ (very large). All analyses were performed using the Statistical Package for Social Sciences (IBM SPSS software, version 26). The level of statistical significance was adjusted to 0.01 to minimize Type 1 errors [19].

3. Results

Descriptive statistics on chronological age (CA) and anthropometry are presented in Table 1. Except for CA, all variables fit the assumption of normal distribution.

In Table 2, descriptive statistics and paired *t*-test results for the shooting efficacy, movement duration and ball release variables are summarized. In terms of efficacy percentage, the scored attempts corresponded to 47.5% at 4.75 m and 42.5% at 5.75 m, with no significant differences observed. At ball release, significant statistically differences were observed in the angle ($t = 3.438$, $p \le 0.01$, $d = 0.46$), and in the velocity ($t = -115.437$, $p \le 0.01$, $d = -1.70$). The ball release angle decreased at longer shots, and the ball release

Table 1. Descriptive statistics of female adolescent basketball players ($n = 27$)

Variable		Mean		SD	Shapiro–Wilk	
		value	(95% CI)		value	*p*
Chronological age	[year]	12.07	(11.73 to 12.41)	0.85	0.213	≤0.01**
Body mass	[kg]	48.8	(43.8 to 53.9)	12.8	0.136	0.30
Stature	[cm]	153.3	(150.1 to 156.5)	8.0	0.166	0.14
Sitting height	[cm]	69.8	(68.3 to 71.3)	3.8	0.143	0.43
Estimated leg length	[cm]	83.5	(81.0 to 85.9)	6.2	0.089	0.45

95% CI (95% confidence interval), SD (standard deviation), ** $p \le 0.01$.

Table 2. Descriptive statistics and paired t-test results to examine mean differences for efficacy and ball release variables obtained in the 4.75 m and 5.75 m. basketball shooting among adolescent basketball players ($n = 27$)

Variables	Descriptive statistics				Mean comparisons		
	4.75 m		5.75 m		*t*	*p*	*d*
	Mean (95% CI)	SD	Mean (95% CI)	SD			
Efficacy							
Scored [%]	47.5 (42.5 to 50.0)	12.5	42.5 (35.o to 47.5)	12.5	1.559	0.13	0.41
Ball release							
Angle [°]	60.4 (58.7 to 62.1)	4.3	58.7 (57.4 to 59.9)	3.2	3.438	≤ 0.01**	0.46
Velocity [m/s]	6.98 (6.78 to 7.18)	0.50	7.63 (7.54 to 7.72)	0.23	–115.437	≤ 0.01**	–1.70
Height [m]	1.92 (1.86 to 1.98)	0.15	1.90 (1.85 to 1.94)	0.12	1.305	0.20	0.15

95% CI (95% confidence interval), SD (standard deviation), ** $p \le 0.01$.

Table 3. Descriptive statistics and paired t-test results to examine mean differences for kinematic parameters related to the shooter obtained in the 4.75 m and 5.75 m basketball shooting among female adolescent basketball players (n = 27)

Variables	Descriptive statistics				Mean comparisons		
	4.75 m		5.75 m		*t*	*p*	*d*
	Mean (95% CI)	SD	Mean (95% CI)	SD			
Centre of mass							
Horizontal displacement [m]	0.14 (0.12 to 0.16)	0.06	0.23 (0.18 to 0.27)	0.11	–5.901	≤0.01**	–1.04
Maximum height [m]	1.12 (1.09 to 1.16)	0.09	1.14 (1.12 to 1.17)	0.06	–1.979	0.06	–0.27
Hip							
Maximum height [m]	1.05 (1.01 to 1.09)	0.09	1.07 (1.04 to 1.09)	0.06	–1.495	0.15	–0.27
Release height [m]	1.02 (0.98 to 1.06)	0.09	1.02 (0.99 to 1.05)	0.07	0.00	1.00	0.00
Shoulder							
Release angular position [°]	111 (107 to 115)	10	109 (105 to 113)	11	–11.060	≤0.01**	0.24
Elbow							
Release angular position [°]	159 (155 to 162)	10	158 (154 to 162)	11	–0.447	0.66	–0.04
Knee							
Minimum angular position [°]	114 (110 to 119)	11	111 (108 to 114)	9	3.364	≤0.01**	0.34
Release angular position [°]	170 (168 to 172)	6	170 (167 to 172)	7	0.774	0.45	0.08
Shoulder							
Peak angular velocity [°/s]	1114 (1029 to 1199)	214	1175 (1094 to 1256)	204	–2.958	≤0.01**	–0.52
Release ang velocity [°/s]	470 (420 to 520)	127	637 (532 to 743)	267	–5.164	≤0.01**	–0.81
Elbow							
Peak angular velocity [°/s]	795 (712 to 877)	209	860 (784 to 936)	192	–3.333	≤0.01**	1.42
Release angular velocity [°/s]	611 (550 to674)	157	580 (523 to 637)	145	2.783	≤0.01**	0.22
Knee							
Peak angular velocity [°/s]	532 (474 to 590)	146	608 (548 to 669)	152	–6.097	≤0.01**	–0.62
Release angular velocity [°/s]	129 (108 to 151)	55	165 (124 to 206)	103	–2.305	0.03	–0.44

95% CI (95% confidence interval), SD (standard deviation), $^{**}p \leq 0.01$.

velocity increased. The mean of ball release height was comparable between shooting distances, with no significant differences observed.

In Table 3, the descriptive statistics and paired *t*-test results for the kinematic parameters related to the shooter are presented. The total CoM horizontal displacement increased significantly at 5.75 m compared to 4.75 m, suggesting a greater horizontal shift during the shooting performance (t = –5.901, $p \leq 0.01$, d = –1.04). Also, the mean of total CoM maximum height increased at the longer distance but not significantly. Regarding joints' angular position, statistically significant greater shoulder flexion was observed at the release point while shooting at 5.75 m. The elbow and knee's angular position were very similar between shooting conditions. However, the knee joint minimum angular position (transition between the first and second phases of the movement) suggests a substantially greater knee flexion when shooting at 5.75 m. The shoulder, elbow, and knee's peak of angular velocity was substantially greater while performing at 5.75 m. At ball release, only the elbow presents a lower angular velocity at 5.75 m compared to 4.75 m (t = 2.783, $p \leq 0.01$, d = 0.22).

4. Discussion

This study aimed to explain the variation in the BS performance through the analysis of the kinematic parameters according to the shooting distance. It was hypothesized that several adjustments could be made by novice female basketball players while shooting at a longer distance from the basket, mainly to increase the ball release velocity. At 5.75 m, participants used the deepest knee flexion (transition between the first and the second phases of the movement) to increase the time to generate velocity at the release point. Greater shoulder flexion and elbow extension of the shooting arm were observed at ball release. Also, the joints' angular velocities increased at the longer shooting distance, contributing to ball release velocity. The CoM horizontal shift was significantly greater at 5.75 m, indicating a greater movement variability in this shooting condition.

The ball release velocity is expected to increase at longer distances to overcome the greater horizontal displacement to the basket (ball trajectory) [14], [15]. As velocity increases, the ball release angle decreases since the relationship between both variables is characterized by an inverse behavior [11], [15]. Therefore, a minor variation in one variable will directly change the other. Indeed, previous empirical research has reported a lower mean angle combined with a superior mean velocity at the release point in experienced male [16] and female [6] basketball players, as well as in boys [17]. The comparison between 2- and 3-point shots among the previously mentioned studies indicate that the differences in the angle and velocity at ball release were more substantial in youngsters, suggesting greater movement variability than the one observed in experienced basketball players.

According to the literature, the distance over which the ball release velocity may be generated is increased by the crouched position adopted during the BS preparatory phase [6]. For that reason, the squat movement before the jump phase should be accentuated at longer shots. As expected, the deepest knee flexion (transition between the first and the second phases of the movement) occurred in this study while shooting from 5.75 m. At 5.75 m shooting distance, the mean of the deepest knee flexion was nearly by 3° lower compared to 4.75 m. In experienced basketball players, females showed variation in the deepest knee flexion of 1°, and males presented a variation of 2° [6], [16]. In boys, differences in the deepest knee flexion derived from the increase of the shooting distance were approximately 10° [17]. The data suggest the contribution of the lower body on the BS performance, particularly to produce velocity at ball release.

Meanwhile, the greater knee flexion observed while shooting from 5.75 m contributed to a substantial increase of the knee angular velocity both at its peak value and at the release point. As greater impulse is generated, these results were expected. Besides, since the trunk and the legs should be fully extended at ball release, it was also likely the increase of the joints' angular velocity of the shooting arm. Indeed, while performing at 5.75 m, the shoulder and elbow's peak angular velocity increased significantly compared to 4.75 m. Only the shoulder presented higher angular velocity at ball release at the longest distance. Overall, the greater angular velocities of the joints have allowed the increase of the ball release velocity.

From the preparatory phase of the movement, players must coordinate the body segments to produce the required position and the desired velocity at release [6]. Greater shoulder flexion was observed at the release point while performing at 5.75 m. The shoulder flexion movement is crucial for the BS as it produces much of the upward force for the elevation of the ball [1]. For that reason, this movement has been related to the ball release height [15]. In our study, the shoulder angular position at the point of release ranged between 109 and 111°, while in boys, results varied between 101 and 111° [17]. Both male (128–137° [13]; 118–122° [16]); and female experienced basketball players (107.3–113.8° [6]) showed lower shoulder flexion at ball release when compared to youngsters. Also, among experienced players, previous findings suggest increased shoulder flexion by females compared to males to provide a good arc to the ball trajectory. Probably, males do not need increased shoulder flexion to throw the ball from longer trajectories, which is related to their characteristics in terms of anthropometry and strength.

In this study, the elbow angular position at ball release was similar between shooting distances. Previous data of experienced basketball players indicates a slight increase of elbow flexion during the ball release at longer shooting distances [6], [13], [16]. In contrast, boys presented more significant elbow extension when performing at increased distances from the basket [17]. Although our results were not substantial, the analysis of the mean values of each shooting condition shows greater elbow extension by female adolescent participants compared to boys and experienced basketball players. The lack of participants' upper body strength could probably justify these data since much of the power for the shot comes from the elbow extension [1].

Meanwhile, the significant increase of the CoM horizontal displacement while performing at longer distances has been reported in previous research and was also observed in this study. The literature points out to the need for some horizontal motion to shoot at longer distances from the basket. However, highly skilled shooters have presented a less horizontal shift than their less skilled peers [11]. The BS reference technical model supports the ability of players to land in the same spot as take-off without floating slightly backwards or forward after release [1]. Indeed, efficacy should be improved with a more stable base [11]. The level of experience of our participants on the coordination of the motor action and the attempt to approximate the basket to reduce the ball trajectory, could justify the significant increase in the CoM horizontal motion. Therefore, coaches should encourage players to jump as close to vertical as possible while shooting, maintaining the trunk upright and not leaning backwards or forward during the release point and the follow-through phase. Finally, the analysis of the hip variables allows us to conclude that the ball release occurs before the peak of the jump phase. Probably, this should represent the attempt to use the vertical velocity of the body during the upward phase of the jump to assist the development of velocity at the point of release due to the participants' lack of upper body strength [6].

The current study aimed to evaluate the effects of the shooting distance on the BS performance among adolescent female basketball players, since previous literature has been mainly focused on experienced and mostly male basketball players. The sample size, the lack of randomization on the shooting order, and the use of a 2D analysis represent limitations of this study. Indeed, a 3D analysis would be far more informative and precise on the data collection. On the other hand, the lack of control of players' characteristics such as anthropometry and functional capacities, particularly strength, is also a limitation of this study. However, note that data available on this topic among youth is few, particularly in females.

Thus, our results bring critical practical implications for the ones involved in youth basketball. Youngsters performed a set of adjustments mechanisms at the longer shooting distance mainly to increase the ball release velocity. The participants' lack of strength, particularly in the upper body, seems to represent a considerable constraint when the distance to the basket is increased. Future research on this topic should consider the evaluation of the interrelationship between anthropometry, functional capacities and kinematic parameters. During the early stages of sport-specific skills acquisition, players should be encouraged to shoot closer from the basket with an adequate movement pattern before expanding the shooting range. Coaches should focus their feedback on the correct positioning of the shooting arm and the jump phase by incentivizing players to jump as close to vertical as possible. The shooting technique should be consistent between the shooting distance.

5. Conclusions

The slight increase by 1 m in the shooting distance produced a set of adjustments mechanisms on the BS motor action performed by adolescent female basketball players: (a) deepest knee flexion (transition between the first and the second phases of the movement); (b) greater shoulder flexion at ball release; (c) the increase of joints' (shoulder, elbow, and knee) angular velocities; (d) significant increase of the CoM's horizontal motion. There is an increase of the ball trajectory at longer shots, which demands an increase in the ball release velocity. The set of adjustments previously mentioned is mainly supported by increasing the velocity at the release point. During the early stages of long-term development, coaches should encourage players to acquire a consistent shooting technique close to the basket before expanding the shooting range.

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