applied sciences

MDPI

Article

A Kinematic Analysis of the Basketball Shot Performed with Different Ball Sizes

Cíntia França [1,2], Élvio R. Gouveia [2,3,*], Manuel J. Coelho-e-Silva [1,4] and Beatriz B. Gomes [1,4]

[1] Faculty of Sports Sciences and Physical Education, University of Coimbra, 3040-248 Coimbra, Portugal; cintia.franca@staff.uma.pt (C.F.); mjcesilva@hotmail.com (M.J.C.-e.-S.); beatrizgomes@fcdef.uc.pt (B.B.G.)
[2] LARSyS, Interactive Technologies Institute, 9020-105 Funchal, Portugal
[3] Department of Physical Education and Sport, University of Madeira, 9020-105 Funchal, Portugal
[4] CIDAF (uid/dtp/042143/2020), University of Coimbra, 3040-248 Coimbra, Portugal
* Correspondence: erubiog@uma.pt; Tel.: +351-291705313

Featured Application: This work is highly relevant to the teaching and learning of the basketball shot, which is considered a crucial and complex motor skill. Our data may contribute to adapting training strategies, particularly regarding the ball size used, among young people or more inexperienced basketball players.

Abstract: In youth basketball, the ball's size is adapted to fit the participants' physical capacities and improve the development of manipulative skills. The current study compared the kinematic parameters of the basketball shot (BS) performed with two different ball sizes. Twenty-seven adolescent females aged 12.1 ± 0.9 years (height: 153.3 ± 8.0 cm; body mass: 48.8 ± 12.8 kg) completed 10 BS trials from a frontal position at 5.75 m from the basket with two ball sizes: a smaller and lighter ball (size five, 480 g) and the standard ball size for their age (size six, 566 g). No statistically significant differences were observed for ball release variables or efficacy levels. Significantly greater shoulder flexion was detected at release while shooting with a size six ball ($F = 2.982$, $p \leq 0.01$). The shoulder's angular velocity at release was significantly lower while performing with a size six ball ($F = 3.089$, $p \leq 0.01$). No significant differences were found for the elbow or knee angles or angular velocities. Stature and upper-body strength were significantly correlated with selected kinematic parameters. A change in ball size may be a helpful strategy for coaches seeking to promote optimal shooting patterns, enhancing effectiveness and enjoyment, particularly among young people and more inexperienced players.

Keywords: motor action; biomechanics; youth; strength; anthropometry

check for updates

Citation: França, C.; Gouveia, É.R.; Coelho-e-Silva, M.J.; Gomes, B.B. A Kinematic Analysis of the Basketball Shot Performed with Different Ball Sizes. *Appl. Sci.* **2022**, *12*, 6471. https://doi.org/10.3390/app12136471

Academic Editors: Richie Gill, Alberto Leardini and Tung-Wu Lu

Received: 30 May 2022
Accepted: 23 June 2022
Published: 25 June 2022

1. Introduction

Youth sports such as basketball frequently adapt the length of the match, the dimensions of the court, and the size of the ball to fit the participants' physical capacities [1]. Regarding manipulative skills, early experiences of participation in basketball are extremely useful in the development of motor proficiency. It is implicitly assumed that motor learning and refinement are substantially affected by contextual constraints [1,2]. Moreover, the quality of the contextual conditions enhances the enjoyment and prevents premature dropout [3,4].

The basketball shot (BS) is considered a fundamental sport-specific skill [5,6]. It corresponds to the final tactical and technical action. Note, however, that the BS is a complex motor skill and, not surprisingly, within a single team, only one or two players are classified as "shooters" [5]. The technique is supposed to be taught by coaches and learned by youth players based on fundamental principles from biomechanics [6,7]. In addition, each player should be viewed as a unique biological system characterized by an individual style (motor signature), in part due to their anthropometric and perceptual characteristics, previous experiences, and, obviously, cognitive attributes such as self-regulatory skills to identify errors and find alternative strategies to fit the reference technical model [5].

The size of the ball represents a constraint that varies throughout the stages of long-term sports preparation. According to youth basketball literature, ball size tended to affect the level of efficacy seen in manipulative basketball skills [4,8,9]. Empirical studies concluded that a smaller ball tends to be associated with higher efficacy rates for shooting performance, with this trend also being consistently observed in other specific skills, such as passing and dribbling [1]. In parallel, one study did not provide evidence of any benefit for shooting performance when youth participants were exposed to manipulated equipment [8]. Among 576 European female basketball players who participated in the 2001, 2003, 2005, and 2007 under-16 European Championships, the effect of replacing ball size seven with ball size six was tested; size seven was the official size used in early editions of the competitions mentioned above [10]. It was not concluded that the smaller projectile caused any relevant improvement in shooting efficacy, except for free throws. Past literature excessively relied on effectiveness as the prime factor in assessing shooting performance [4,8,10,11].

Although efficacy is the central aspect of basketball games, it is crucial to understand the mechanisms that underlie performance [12]. The analysis of kinematic parameters may be relevant, particularly for youth players and coaches [6,12]. Several studies used kinematic parameters to evaluate BS performance, considering variations associated with distance from the basket [13–17], presence of opposition [18,19], and induced fatigue [20]. However, only two studies assessed the kinematic parameters while examining the effect of manipulated ball size, and both were focused on free throws performed by boys aged 10–13 years [21,22]. Note, however, that the recognition of age and sex as sources of variation in basketball-specific skills explains the decisions to adopt different equipment conditions, including ball size, for official games and competitions by FIBA [10]. Although evidence is lacking in the literature, it is intuitively assumed that equipment is crucial in developing specific skills.

On the other hand, the literature has mentioned that players who are less able to produce force, such as female players and children, must use more movement velocity while shooting [1,2]. A more significant contribution from the shoulder joint to generate impulse applied to the ball was found in female players, mainly due to their lower upper-body strength compared to their male counterparts [1]. Strength is an essential variable for shooting performance, although few data have been collected on this topic.

Therefore, the main purpose of this study was to compare the kinematic parameters of the BS performed with different ball sizes by adolescent female basketball players. We hypothesized that the angular velocities of the shoulder, elbow, and knee joints at ball release would be increased when shooting with the standard ball size rather than with the smaller ball size, since a greater impulse would be needed to shoot due to the weight of the heavier ball. We also hypothesized that participants' efficacy levels would be higher while shooting with the standard ball size for their age group, since they should be more familiar with it from their training sessions. The secondary purpose of this study was to assess the relationship between strength tests and the selected kinematic variables.

2. Materials and Methods

2.1. Participants

The current sample comprises twenty-seven female adolescent basketball players aged 12.1 $\pm$ 0.9 years (height: 153.3 $\pm$ 8.0 cm; body mass: 48.8 $\pm$ 12.8 kg) from clubs on Madeira Island. All participants had at least two years of basketball training experience, were competing at the regional level, and were not injured during data collection.

2.2. Procedures

The current study received ethical approval from the relevant committee of the University of Coimbra (CE/FCDEF-UC/00482019). Procedures were conducted according to the standards established by the declaration of Helsinki [23]. Legal guardians were informed about the nature of the study, including objectives, protocols, and related risks, and they signed informed consent. Participants were told that their participation was voluntary, and all participants provided consent after being informed that they could withdraw from the study at any time.

2.3. Anthropometry

Height and sitting height were measured using a portable stadiometer (SECA 213, Hamburg, Germany) to the nearest 0.1 cm. 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.

Skinfold thickness was measured to the nearest 0.1 mm at six sites (triceps, subscapular, suprailiac, abdominal, thigh, and calf) using a skinfold caliper (Harpenden Skinfold Caliper, West Sussex, UK). A single investigator took all measurements following the ISAK (International Society for the Advancement of Kinanthropometry) guidelines [24].

The percentage of predicted adult stature attained was calculated as an indicator of the maturity status using the Beunen–Malina–Freitas method [25]. Information regarding menarche was collected through an appropriate questionnaire.

2.4. Fitness Tests

The countermovement jump (CMJ) assessed lower limb explosive strength and power. The protocol included four data collection trials and was performed in the Optojump Next (Microgate, Bolzano, Italy) system of analysis and measurement. Participants rested for 45 s between each trial and five minutes between each test. Participants were directed to perform the CMJ "as they usually would" with a quick countermovement to a comfortable depth emphasized before exploding upwards to gain maximum height. Hands remained on the hips for the entire movement to eliminate any influence of arm swing. During testing, participants were encouraged to jump to maximum height. The best score was retained for analysis.

Three functional tests were applied to assess upper-body strength, with a five-minute recovery time between each test assessment. The handgrip protocol consisted of three alternating data collection trials for each arm using a hand dynamometer (Jamar Plus+, Chicago, IL, USA). Participants were instructed to hold a dynamometer in one hand, laterally to the trunk, with the elbow in a 90° position. From this position, participants were asked to squeeze the hand dynamometer as hard as possible, progressively and continuously for about two seconds. At no time could the dynamometer contact the participant's body. The recovery time between trials was set at 45 s. The best score was retained for analysis.

A sit-up protocol consisted of performing the highest possible number of repetitions for 60 s. Participants were instructed to start in a sitting position, torso vertical, hands behind their neck, bent knees (90°), and feet on the floor. From this position, participants were instructed to stretch out on their back, with shoulders in contact with the floor; then, they were asked to straighten up to the sitting position, bringing the elbows forward in contact with their knees and/or passing them through the knees. Counting took place the moment the elbows touched or passed the knees. An absence of counting meant that the repetition had not been correctly performed. The total number of repetitions performed corresponded to the test score.

The 2 kg medicine ball throw was based on three trials with 30 s of rest between tests. The throws were made above the head in a standing position and with parallel feet. The test was repeated if participants lost their balance or varied their position while throwing. Participants were incentivized to throw the medicine ball as far as they could. The best score was retained for analysis.

2.5. Shooting

Participants completed a 15-min warm-up that included jogging, dribbling, shooting, and dynamic stretching. After the warm-up, nine anatomical landmarks (1.5 cm in diameter) with reflective markers were placed over the skin and clothes in the following positions: 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 define 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; and on the head of the fifth metatarsal to define the foot [17]. A single investigator placed all landmarks on each participant's dominant side.

Each participant performed 10 BS trials from a frontal position at 5.75 m from the basket with both ball sizes: a smaller and lighter ball (Wilson MVP Size 5, 480 g); and the standard 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. 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 and 1.20 m from the floor (Figure 1). A third investigator recorded the BS outcome using an efficacy rating system composed of five levels [6]: (4 points) successful attempts that did not hit the rim; (3 points) successful attempts that hit exclusively any part of the rim; (2 points) successful attempts that hit the backboard or any part of the rim; (1 point) unsuccessful attempts that hit either the rim or the backboard; and (0) unsuccessful attempts that did not hit anything ("air ball").

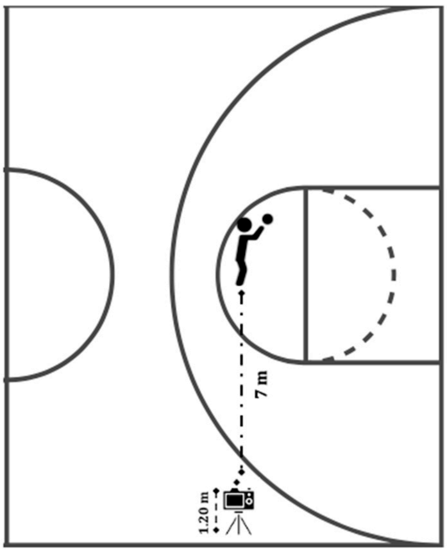

Figure 1. Schematic representation of data collection.

After data collection, a total of 540 video recordings (20 from each participant) were exported and analyzed using Tracker software (Open-Source Physics—Video Analysis and Modelling Tool, 5.1.5) to assess the kinematic variables. Video calibration was performed using a reference object with known dimensions placed in the plane of the movement. The calibration factor was evaluated using a 2D-DLT (direct linear transformation) [26,27], 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 ten female basketball players aged 14.7 $\pm$ 0.6 years. From the 300 video 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); these values show 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 center of mass (CoM) (total horizontal displacement and the maximum height attained); the position of the hip (maximum height and height at ball release); the shoulder, elbow, and knee joint angles at ball release and the minimum angle formed by the knee (transition between the first and second phases of the movement) for the sagittal plane of movement (flexion–extension); the angular velocities of the shoulder, elbow, and knee joints (the peak of angular velocity and the angular velocity at ball release), also for the sagittal plane.

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 [28]. The ball release velocity was defined by the velocity value immediately after ball release. This value was calculated by Tracker software using the ball's displacement between frames and their respective time points. 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 considered a line between ball's release and its position in the frame immediately after in relation to the floor. The coordinates of the release frame and the frame immediately after were exported to the Excel software package. Then, the angle of ball release was calculated using trigonometric formulas.

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 package. Afterward, the CoM of the various anatomical segments was assessed through specific equations available in the literature, which considered the percentage of the distance traveled by each marker and the proportion of total body weight [29].

2.6. Statistics

Descriptive statistics included mean and standard deviation. A one-way between-groups analysis of variance (MANOVA) was used to investigate the variation in the kinematic parameters according to the ball size. Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance, and multicollinearity, with no serious violations noted. Effect size was interpreted using d-Cohen as follows [30]: $d < 0.2$ (small), $0.2 \leq d < 0.6$ (moderate), $0.6 \leq d < 1.2$ (large), and $1.2 \leq d < 2.0$ (very large). The Pearson product–moment correlation coefficient was used to assess the relationships between the kinematic variables, CA and basketball experience, anthropometry (stature, percentage of predicted stature, and body mass), and fitness tests (CMJ, sit-ups, handgrip, and 2 kg ball throw). All analyses were performed using the Statistical Package for Social Sciences (IBM SPSS software, version 26). The level of statistical significance was kept at 5%.

3. Results

Descriptive statistics on anthropometry, biological maturation, and fitness tests are presented in Table 1. Except for CA and basketball experience, all variables fit the assumption of normal distribution.

Table 2 summarizes the descriptive statistics and MANOVA results. The efficacy levels were very similar between shooting conditions (ball size five: 1.7 ± 0.6 points; ball size six: 1.7 ± 0.5 points). No significant statistical differences were observed for ball release variables (angle, velocity, or height). However, the mean ball release velocity was greater, and the mean ball release angle was lower, in shots performed with the size five ball. The CoM variables did not differ significantly between shooting conditions (horizontal displacement: $F = 0.005$, $p = 0.95$, partial eta squared = 0.000; maximum height: $F = 0.034$, $p = 0.85$, partial eta squared = 0.001), indicating a similar jump phase while shooting. Among the angles formed by the joints at the release point, significant differences were observed exclusively for the shoulder ($F = 2.982$, $p \leq 0.01$, partial eta squared = 0.208). Although greater knee flexion during the preparatory phase (knee minimum angle) was detected while shooting with the size six ball, the differences were not statistically significant

(F = 0.541, p = 0.47, partial eta squared = 0.010). Overall, the peaks of the joints' angular velocities were greater while performing with the size six ball but with no substantial differences. At release, the shoulder angular velocity was significantly lower in shots with the size six ball (F = 3.089, $p \leq 0.01$, partial eta squared = 0.256). Similar angular velocities at ball release were observed for the elbow and knee joints.

Table 1. Descriptive statistics on anthropometry, biological maturation, and fitness tests of female adolescent basketball players (n = 27).

Variable	Unit	Mean		SD	Kolgomorov–Smirnov	
		Value	(95% CI of the Mean)		Value	p
Chronological age	years	12.1	(11.9 to 12.4)	0.7	0.20	≤0.01 **
Body mass	kg	48.8	(43.8 to 53.9)	12.8	0.14	0.20
Stature	cm	153.3	(150.1 to 156.5)	8.0	0.17	0.06
Sitting height	cm	69.8	(68.3 to 71.3)	3.8	0.14	0.17
Estimated leg length	cm	83.5	(81.0 to 85.9)	6.2	0.09	0.20
Predicted height	cm	166.3	(164.9 to 167.7)	3.5	0.09	0.20
CMJ height	cm	20.9	(19.2 to 22.5)	4.2	0.08	0.20
Handgrip	kg	21.3	(19.5 to 23.1)	4.5	0.12	0.20
Sit-ups	n	30.5	(26.7 to 34.3)	9.7	0.09	0.20
2 kg ball throw	m	4.4	(4.1 to 4.8)	0.9	0.07	0.20
Basketball experience	years	3.7	(3.0 to 4.4)	1.8	0.20	≤0.01 **

95% CI (95% confidence interval); SD (standard deviation); CMJ (countermovement jump); ** $p \leq 0.01$.

Table 2. Descriptive statistics and MANOVA results to examine mean differences for kinematic variables obtained in 5.75 m basketball shooting with ball size five and ball size six among female adolescent basketball players (n = 27).

Dependent Variable	Units	Descriptive Statistics According to Ball Size				Mean Comparisons		
		Ball Size 5		Ball Size 6				
		Mean (95% CI)	SD	Mean (95% CI)	SD	F	p	Partial Eta Squared
Shooting efficacy	points	1.7 (1.5 to 1.9)	0.6	1.7 (1.4 to 1.9)	0.5	0.184	0.67	0.004
Ball release angle	°	57.7 (56.5 to 58.8)	2.9	58.7 (57.4 to 59.9)	3.2	1.326	0.26	0.025
Ball release velocity	m/s	7.74 (7.57 to 7.91)	0.43	7.63 (7.54 to 7.72)	0.23	1.367	0.25	0.026
Ball release height	m	1.91 (1.86 to 1.96)	0.13	1.90 (1.85 to 1.94)	0.12	0.150	0.70	0.003
CoM horizontal displacement	m	0.23 (0.19 to 0.27)	0.10	0.23 (0.18 to 0.27)	0.11	0.005	0.95	0.000
CoM maximum height	m	1.14 (1.12 to 1.16)	0.06	1.14 (1.12 to 1.17)	0.06	0.034	0.85	0.001
Shoulder minimum angle	°	20.8 (16.5 to 25.0)	10.8	19.8 (14.8 to 24.7)	12.5	0.098	0.76	0.002
Shoulder maximum angle	°	133.9 (129.4 to 138.4)	11.3	168.1 (151.8 to 184.3)	41.0	2.782	≤0.01 **	0.210
Shoulder release angle	°	108.6 (104.6 to 112.6)	10.1	134.4 (129.2 to 139.6)	13.2	2.982	≤0.01 **	0.208
Elbow minimum angle	°	65.8 (57.1 to 74.5)	21.9	67.0 (57.6 to 76.4)	23.8	0.037	0.85	0.001
Elbow maximum angle	°	170.7 (168.3 to 173.2)	6.2	170.0 (167.4 to 172.5)	6.4	0.180	0.67	0.003
Elbow release angle	°	157.5 (153.7 to 161.3)	9.6	158.5 (154.5 to 162.4)	9.9	0.138	0.71	0.003
Knee minimum angle	°	113.0 (108.6 to 117.5)	11.2	111.0 (107.7 to 114.4)	8.5	0.541	0.47	0.010
Knee maximum angle	°	175.8 (174.3 to 177.2)	3.6	176.5 (174.8 to 178.1)	4.1	0.410	0.53	0.008
Shoulder peak angular velocity	°/s	1162 (1087 to 1237)	189	1175 (11094 to 1256)	204	0.056	0.81	0.001
Shoulder release angular velocity	°/s	716 (604 to 828)	277	637 (532 to 743)	267	3.089	≤0.01 **	0.256
Elbow peak angular velocity	°/s	833 (764 to 903)	166	860 (791 to 930)	192	0.304	0.58	0.006
Elbow release angular velocity	°/s	583 (529 to 637)	136	580 (526 to 634)	145	0.006	0.94	0.000
Knee peak angular velocity	°/s	561 (504 to 618)	139	608 (552 to 664)	152	1.413	0.24	0.026
Knee release angular velocity	°/s	155 (119 to 191)	81	165 (129 to 201)	103	0.161	0.69	0.003

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

The Pearson product correlation coefficient was used to assess the relationships between all analyzed kinematic parameters, anthropometry, and fitness variables. Tables 3 and 4 present only the significant results of the Pearson product correlation coefficient according to the ball size used. While shooting with the size five ball, ball release height was the kinematic parameter that showed the highest number of relationships with anthropometry and fitness tests. Strong and positive correlations were found between ball release height and stature (r = 0.71, $p \leq 0.01$), body mass (r = 0.77, $p \leq 0.01$), handgrip (r = 0.60, $p \leq 0.01$), and the 2 kg medicine ball throw (r = 0.67, $p \leq 0.01$). While shooting with the size six ball, ball release height also presented the highest number of relationships. Stature (r = 0.63, $p \leq 0.01$) and body mass (r = 0.71, $p \leq 0.01$) retained strong positive relationships with ball release height. In contrast, the CMJ displayed a significant and negative correlation with ball release height (r = −0.42, p = 0.03). Finally, both the handgrip (r = −0.46, p = 0.02) and the 2 kg ball throw (r = −0.43, p = 0.03) presented significant and negative relationships with the ball release angle.

Table 3. Significant results according to the Pearson product coefficient correlations between selected kinematic parameters while performing with ball size five, anthropometry, and fitness tests.

Kinematic Variable	CA		Basketball Experience		Stature		% Predicted Adult Stature		Body Mass		CMJ		Handgrip		2 kg Ball Throw	
	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*
Ball release																
angle																
height					0.71	≤0.01	0.50	≤0.01	0.77	≤0.01			0.60	≤0.01	0.67	≤0.01
Elbow																
peak angular velocity					−0.45	0.02	−0.39	0.05			0.41	0.04			−0.40	0.04
Knee																
peak angular velocity	−0.52	≤0.01			−0.65	≤0.01			−0.39	0.04			−0.48	≤0.01	−0.61	≤0.01

CA (chronological age); % (percentage) of predicted adult stature attained according to the Beunen–Malina method [25]; CMJ (countermovement jump); r (Pearson coefficient).

Table 4. Significant results according to Pearson-product coefficient correlations between selected kinematic parameters while performing with ball size 6, anthropometry, and fitness tests.

Kinematic Variable	CA		Basketball Experience		Stature		% Predicted Adult Stature		Body Mass		CMJ		Handgrip		2 kg Ball Throw	
	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*
Ball release																
angle													−0.46	0.02	−0.43	0.03
height					0.63	≤0.01	0.56	≤0.01	0.71	≤0.01	−0.42	0.03	0.45	0.02	0.45	0.02
Elbow																
peak angular velocity					−0.53	≤0.01	−0.46	0.02							−0.48	0.02
Knee																
peak angular velocity	−0.57	≤0.01	−0.44	0.02	−0.65	≤0.01							−0.43	0.03	−0.55	≤0.01

CA (chronological age); % (percentage) of predicted adult stature attained according to the Beunen–Malina method [25]; CMJ (countermovement jump); r (Pearson coefficient).

4. Discussion

This study aimed to investigate the variations in kinematic parameters for the BS performed with different ball sizes among adolescent female basketball players. Overall, slight differences were observed in the organization and behavior of several body segments. The ball release variables were not significantly different between shooting conditions, which contributed, contrary to what was expected, to similar efficacy levels between shots performed with different ball sizes. Thus, the current study results indicate that ball size variation does not represent a significant source of performance differences in the BS motor action at a mid-distance to the basket.

In this study, the mean ball release angle was one degree higher while shooting with the size six ball; consequently, the ball release velocity was slightly decreased in that shooting condition. The angular velocities of both shoulder and elbow joints were lower at the release point while performing with the size six ball, which should explain the lower ball release velocity. At ball release, as velocity decreases, the angle is expected to increase since both variables are characterized by an inverse behavior [5,15,17,31]. The ball release angle and velocity results align with previous research on free-throws performed by boys aged 12.8 ± 0.1 years with different ball sizes. Although they applied other procedures regarding basket heights and ball sizes used, the authors also reported a greater value for the ball release angle and a lower ball release velocity when shooting with a heavier ball compared to a smaller one [22].

The mean of ball release height was very similar between shooting conditions. Since the literature mentions that ball release height is a more predictable parameter due to its direct relationship to the shooter's stature, the jump phase, and body segment organization [5,31], these results were expected. Greater shoulder flexion, which is a significant influencer of ball release height, was observed at ball release in shots performed with the size six ball. Previous research in boys aged 10.0 ± 0.5 years shooting free throws also reported greater shoulder flexion while shooting with a heavier ball size [21]. However, in our study, the elbow extension at release remained the same, and the CoM variables indicate no differences in the shot's jump phase between shooting conditions, which justifies the values observed for ball release height.

Regarding the angular velocities of the joints, no statistically significant variations were observed except for the shoulder at ball release. Due to greater shoulder flexion, the angular velocity at release was lower while shooting with the size six ball. Although with no substantial differences, the peaks of the angular velocities of the joints were higher in shots performed with the size six ball. This behavior was also observed in boys [21]. It could be assumed that participants adapted the impulse generated to shoot according to the ball's size and weight. At the same distance to the basket, a greater impulse may be needed to propel a heavier ball when compared to a smaller one. This theory is also supported by the greater knee flexion observed when shooting with the size six ball. Indeed, the minimum angle reached by the knee joint reflects the squat movement performed before the shooting jumping phase. Consequently, it allows us to better understand the type of impulse produced to shoot. However, past data on joint behavior during the BS motor action are still lacking, making it difficult to compare to previous results.

Meanwhile, strength has been described as a crucial capacity for generating the impulse needed to throw the ball. Players who are less able to generate force, such as females and children, have a more challenging time while shooting [2]. Therefore, it is essential to understand the relationship between the shooting motor action and the shooter's anthropometric and fitness characteristics. To the best of our knowledge, this is the first study to consider this type of analysis. According to our results, the ball release height showed the highest number of relationships independently of the ball size. Past literature suggests that a strong and positive correlation exists between ball release height and stature [31]. Body mass also displayed a strong and positive relationship with ball release height ($r = > 0.71 < 0.77$), which is likely related to strength. Indeed, both the handgrip and the 2 kg ball throw presented strong correlations with ball release height (positive), ball release angle (negative), and the peak angular velocities of joints. Strength likely contributes to generating ball velocity, and if velocity increases, the angle at ball release should decrease, which would justify the negative correlation between the 2 kg ball throw and the ball release angle. Thus, upper-body strength appears to be an important predictor of ball trajectory. In contrast, the CMJ was significantly and negatively related to the ball release height. A linear and positive correlation between both variables would be expected; however, this result must be interpreted together with the other variables in the analysis. In fact, the literature has described the positive relationship between body mass and strength during the adolescent years and the detrimental effect of body mass in jumping tasks [3]. Overall, our results underline upper-body strength as a crucial variable for the performance of the shooting motor action, as previously suggested in the literature [1,2]. In addition, it may contribute to raising awareness among sports agents and coaches regarding promoting strength development in the basketball training process as part of supporting a shooter's improvement.

The overall assessment of the kinematic parameters shows a slight variation in the performance of the shooting motor action according to the ball size used, which is insignificant in affecting shooting efficacy. Indeed, efficacy is a product of the ball's trajectory, and the ball's trajectory is defined by the angle, velocity, and height at release [15]. Note that the ball release variables did not significantly vary between shooting conditions. Thus, our results suggest that the movement pattern used was consistent and not immediately affected by short-term changes in ball characteristics. This is also reflected by the ratio between scored and missed attempts.

The results of the current study have important practical implications for those working with young people at the early stages of basketball-specific skills development. Although the sample size and the 2D analysis represent limitations in this study, the results showed that the manipulation of ball size did not significantly affect shooting performance. Therefore, the BS teaching process may not be limited to the standardized rules regarding ball size and weight for a specific age group, and adaptations could be made according to participants' anthropometric features or basketball experience level. This strategy could be helpful in the acquisition of optimal shooting patterns, enhancing efficacy and enjoyment among youth basketball players. Moreover, the relationships between the handgrip and the 2 kg ball throw with the selected kinematic parameters indicate the crucial contribution of upper-body strength to motor action performance. Sports agents and coaches should consider strength development as part of basketball training, particularly for shooting improvement among female youth players. Nevertheless, future research is still needed to profoundly understand the relationships between player characteristics (anthropometry and functional capacities) and the basketball shooting motor action. In addition, future work investigating the long-term effect of ball size variation on the shooting action of young people may prove to be more informative.

5. Conclusions

In this study, some kinematic adjustments emerged in the performance of the BS while shooting with two different ball sizes. Shoulder extension and angular velocity at ball release significantly decreased when performing with a size six ball, contributing to lower mean ball velocity at release. However, the ball release variables did not differ significantly between conditions, suggesting a similar ball trajectory and efficacy level. On the other hand, stature and upper-body strength strongly correlated with ball release variables (angle and height) and the peaks of joint angular velocities (elbow and knee). In the early stages of long-term basketball skill development, manipulation of the ball size may be a helpful strategy for sports agents and coaches to promote optimal shooting patterns, enhancing effectiveness and enjoyment among young people.

Author Contributions: Conceptualization, C.F., M.J.C.-e.-S., and B.B.G.; methodology, C.F., É.R.G., M.J.C.-e.-S., and B.B.G.; validation, É.R.G., M.J.C.-e.-S., and B.B.G.; formal analysis, C.F., É.R.G., M.J.C.-e.-S., and B.B.G.; investigation, C.F., É.R.G., M.J.C.-e.-S., and B.B.G.; resources, É.R.G., M.J.C.-e.-S., and B.B.G.; data curation, C.F.; writing—original draft preparation, C.F.; writing—review and editing, É.R.G., M.J.C.-e.-S., and B.B.G.; visualization, É.R.G., M.J.C.-e.-S., and B.B.G.; supervision, É.R.G., M.J.C.-e.-S., and B.B.G.; project administration, É.R.G., M.J.C.-e.-S., and B.B.G.; funding acquisition, C.F. and É.R.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the University of Coimbra (CE/FCDEF-UC/00482019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

Acknowledgments: The authors would like to thank all the participants who volunteered to participate in this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Arias, J.; Argudo, F.M.; Alonso, J.I. Review of rule modification in sport. *J. Sports Sci. Med.* **2011**, *10*, 1. [PubMed]
2. Porter, J.M.; Magill, R.A. Systematically increasing contextual interference is beneficial for learning sport skills. *J. Sports Sci.* **2010**, *28*, 1277–1285. [CrossRef] [PubMed]
3. Buszard, T.; Reid, M.; Masters, R.; Farrow, D. Scaling the Equipment and Play Area in Children's Sport to improve Motor Skill Acquisition: A Systematic Review. *Sports Med.* **2016**, *46*, 829–843. [CrossRef] [PubMed]
4. Chase, M.A.; Ewing, M.E.; Lirgg, C.D.; George, T.R. The effects of equipment modification on children's self-efficacy and basketball shooting performance. *Res. Q. Exerc. Sport* **1994**, *65*, 159–168. [CrossRef]
5. Okazaki, V.H.; Rodacki, A.L.; Satern, M.N. A review on the basketball jump shot. *Sports Biomech.* **2015**, *14*, 190–205. [CrossRef]
6. Satern, M. Performance EXCELLENCE: Basketball: Shooting the Jump Shot. *Strategies* **1988**, *1*, 9–11. [CrossRef]
7. Liu, S.; Burton, A.W. Changes in basketball shooting patterns as a function of distance. *Percept. Mot. Ski.* **1999**, *89*, 831–845. [CrossRef]
8. Milovanovic, M.Z.; Pazin, N.R.; Mrdakovic, V.D.; Erculj, F.F.; Jakovljevic, S.T. Shooting accuracy in children's basketball: Do equipment dimensions influence static and dynamic performances? *J. Sports Sci.* **2020**, *38*, 2740–2749. [CrossRef]
9. Arias, J. Influence of ball weight on shot accuracy and efficacy among 9–11-year-old male basketball players. *Kinesiology* **2012**, *44*, 52–59.
10. Podmenik, N.; Leskošek, B.; Erčulj, F. The impact of introducing a lighter and reduced-diameter basketball on shot performance in young female basketball players. *Kinesiology* **2014**, *46*, 61–68.
11. Arias, J.L.; Argudo, F.M.; Alonso, J.I. Effect of basketball mass on shot performance among 9–11 year-old male players. *Int. J. Sports Sci. Coach.* **2012**, *7*, 69–79. [CrossRef]
12. França, C.; Gomes, B.B.; Gouveia, É.R.; Ihle, A.; Coelho e Silva, M.J. The jump shot performance in youth basketball: A systematic review. *Int. J. Environ. Res. Public Health* **2021**, *18*, 3283. [CrossRef]
13. Elliott, B.; White, E. A kinematic and kinetic analysis of the female two point and three point jump shots in basketball. *Aus. J. Sci. Med. Sport* **1989**, *21*, 7–11.
14. Miller, S.; Bartlett, R. The relationship between basketball shooting kinematics, distance and playing position. *J. Sports Sci.* **1996**, *14*, 243–253. [CrossRef]
15. Miller, S.; Bartlett, R.M. The effects of increased shooting distance in the basketball jump shot. *J. Sports Sci.* **1993**, *11*, 285–293. [CrossRef]
16. Vencurik, T.; Knjaz, D.; Rupcic, T.; Sporis, G.; Li, F. Kinematic Analysis of 2-Point and 3-Point Jump Shot of Elite Young Male and Female Basketball Players. *Int. J. Environ. Res. Public Health* **2021**, *18*, 934. [CrossRef]
17. Okazaki, V.H.A.; Rodacki, A.L.F. Increased distance of shooting on basketball jump shot. *J. Sports Sci. Med.* **2012**, *11*, 231.
18. Gorman, A.D.; Maloney, M.A. Representative design: Does the addition of a defender change the execution of a basketball shot? *Psychol. Sport Exerc.* **2016**, *27*, 112–119. [CrossRef]
19. Rojas, F.J.; Cepero, M.; Ona, A.; Gutierrez, M. Kinematic adjustments in the basketball jump shot against an opponent. *Ergonomics* **2000**, *43*, 1651–1660. [CrossRef]
20. Slawinski, J.P.; Louis, J.; Poli, J.; Tiollier, E.; Khazoom, C.; Dinu, D. The Effects of Repeated Sprints on the Kinematics of 3-Point Shooting in Basketball. *J. Hum. Kinet.* **2018**, *62*, 5–14. [CrossRef]
21. Okazaki, V.H.A.; Rodacki, A.L.F. Changes in basketball shooting coordination in children performing with different balls. *Fédération Int. D'éducation Phys.* **2005**, *75*, 368–371.
22. Satern, M.; Messier, S.; Kellermcnulty, S. The effect of ball size and basket height on the mechanics of the basketball free throw. *J. Hum. Mov. Stud.* **1989**, *16*, 123–137.
23. Harriss, D.; MacSween, A.; Atkinson, G. Ethical standards in sport and exercise science research: 2020 update. *Int. J. Sports Med.* **2019**, *40*, 813–817. [CrossRef]
24. Stewart, A.; Marfell-Jones, M.; Olds, T.; De Ridder, H. *International Standards for Anthropometric Assessment*; International Society for the Advancement of Kinanthropometry: Lower Hutt, New Zealand, 2011.
25. Beunen, G.P.; Malina, R.M.; Freitas, D.L.; Thomis, M.A.; Maia, J.A.; Claessens, A.L.; Gouveia, E.R.; Maes, H.H.; Lefevre, J. Prediction of adult height in girls: The Beunen-Malina-Freitas method. *J. Sports Sci.* **2011**, *29*, 1683–1691. [CrossRef]
26. Pourcelot, P.; Audigié, F.; Degueurce, C.; Geiger, D.; Denoix, J.M. A method to synchronise cameras using the direct linear transformation technique. *J. Biomech.* **2000**, *33*, 1751–1754. [CrossRef]
27. Brewin, M.A.; Kerwin, D.G. Accuracy of scaling and DLT reconstruction techniques for planar motion analyses. *J. Appl. Biomech.* **2003**, *19*, 79–88. [CrossRef]
28. Uygur, M.; Goktepe, A.; Ak, E.; Karabörk, H.; Korkusuz, F. The Effect of Fatigue on the Kinematics of Free Throw Shooting in Basketball. *J. Hum. Kinet.* **2010**, *24*, 51–56. [CrossRef]
29. Grimshaw, P.; Fowler, N.; Lees, A.; Burden, A. *BIOS Instant Notes in Sport and Exercise Biomechanics*; Routledge: Oxfordshire, UK, 2007.
30. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*; Academic Press: Cambridge, MA, USA, 2013.
31. Knudson, D. Biomechanics of the Basketball Jump Shot—Six Key Teaching Points. *J. Phys. Educ. Recreat. Dance* **1993**, *64*, 67–73. [CrossRef]