Cíntia Raquel Nunes França

GROWTH, MATURATION AND SPORT-SPECIFIC MOTOR SKILLS IN YOUTH FEMALE BASKETBALL: IMPACT OF BALL SIZE AND DISTANCE TO THE BASKET

Thesis for the Doctor of Sport Sciences degree in the branch of Sports Training supervised by Prof. Dr. Manuel João Coelho-e-Silva, Prof. Dr. Élvio Rúbio Quintal Gouveia and Prof. Dr. Beatriz Branquinho Gomes submitted to the Faculty of Sports Sciences and Physical Education of the University of Coimbra.

December of 2021

Faculty of Sports Sciences and Physical Education

UNIVERSIDADE DE COIMBRA

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CENTRO DE INVESTIGAÇÃO
DO DESPORTO
E DA ACTIVIDADE FISICA
UNIVERSIDADE DE COIMBRA

Da minha aldeia vejo quanto da terra se pode ver do Universo...
Por isso a minha aldeia é tão grande como outra terra qualquer
Porque eu sou do tamanho do que vejo
E não do tamanho da minha altura...

Alberto Caeiro, no *Guardador de Rebanhos – Poema VII*

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Abstract

The present Thesis aimed to evaluate the basketball shot performance according to variation of the shooting distance and ball size manipulation through a kinematic analysis. The work was conducted in a sample of 27 adolescent female basketball players aged 12.1 ± 0.7 years (stature: 153.3 ± 8.0 cm; body mass: 48.8 ± 12.8 kg). The variation of the shooting distance was evaluated by comparing two shooting distances (4.75 m and 5.75 m). Participants performed ten attempts from each distance. Regarding ball size manipulation, the performance was compared between a smaller ball size (Wilson MVP Size 5, 480 g) and the standardized ball size for their age category (Wilson Evolution Size 6, 566 g). Participants performed ten attempts with each ball size. The kinematic analysis considered the ball release variables (angle, velocity, and height at ball release) and several parameters related to the shooters' body segments organization (centre of mass displacement – horizontal and vertical, hip height, joints angular positions, and respective velocities).

The ball size manipulation did not significantly influence the movement performance. Differences were observed in the joints' angular positions and velocities, mainly due to the elbow and knee joints' higher peaks of angular velocities while shooting with the ball size 6. Also, participants presented a significantly greater shoulder flexion and a greater angle at ball release while performing with the size 6.

On the other hand, the results suggest that several adjustment mechanisms emerge at longer shots on the basketball shot motor action. A significant movement variability was detected at longer shots, mainly due to the increase of the joints' angular velocities. Greater shoulder flexion and elbow extension were observed at ball release at longer shots. The ball release velocity also increased to compensate for the longer trajectory to the basket. Since velocity increased at ball release, the angle consequently decreased. Participants were less effective while performing at a longer shooting distance.

During the early stages of the basketball's long-term development, players should be incentivized to shoot from several ranges closer to the basket before increasing the distance from the basket. On the other hand, a more stable movement pattern was observed while performing with different ball sizes. Indeed, the variation of the ball weight and circumference may be used by coaches as a strategy for the acquisition and development of the shooting action, according to the youngsters' physical characteristics or experience level. Knowing the mechanisms that support the basketball shot performance is crucial for coaches' ability to give feedback and enhance the shooters' development. Additionally, a significant relationship was found between the upper-body strength (handgrip and 2 kg medicine ball throw) and the kinematic parameters, independently of the shooting conditions. Therefore, it is suggested that coaches should consider the strength development during the training sessions designed as part of the shooters' improvement.

Keywords: motor action, biomechanics, functional capacities, anthropometry, shooting conditions

Resumo

A presente Tese teve como principal objetivo a avaliação da performance do lançamento do basquetebol de acordo com a manipulação do tamanho da bola e com a variação da distância ao cesto. A amostra foi composta por 27 adolescentes do sexo feminino (idade: 12.1 ± 0.7 anos; altura: 153.3 ± 8.0 cm; peso: 48.8 ± 12.8 kg). A manipulação do tamanho da bola realizou-se através da comparação da performance com uma bola mais leve e pequena (Wilson MVP Size 5, 480 g) com o tamanho de bola estandardizado para este escalão etário (Wilson Evolution Size 6, 566 g). As participantes realizaram dez lançamentos com cada uma das bolas. A análise da influência da distância ao cesto foi realizada através da comparação da performance com o tamanho de bola estandardizado em duas distâncias de lançamento 4.75 m e 5.75 m. As participantes realizaram dez lançamentos em cada distância. A análise cinemática considerou as variáveis de saída da bola (ângulo, velocidade e altura), e vários parâmetros relacionados com a organização dos segmentos corporais da lançadora (deslocamento do centro de massa – horizontal e vertical, altura da anca, posições e velocidades angulares do ombro, cotovelo e joelho).

Os resultados sugerem a performance de uma ação motora mais estável perante a manipulação do tamanho da bola. Os lançamentos realizados com a bola de tamanho 6 apresentaram maiores ângulos de saída da bola e maior flexão do ombro no momento de saída. Contudo, as diferenças nos parâmetros cinemáticos não foram acentuadas e a eficácia manteve-se inalterada.

Em contraste, o aumento da distância ao cesto resultou no aumento das velocidades angulares das articulações em análise, e consequentemente, o aumento da velocidade de saída da bola. O aumento da velocidade de saída da bola justifica-se pelo aumento da trajetória até ao cesto. Sumariamente, existiu maior variabilidade da performance da ação motora perante o aumento da distância de lançamento. Por fim, a análise das correlações entre a idade cronológica, os anos de experiência, a antropometria, e as capacidades funcionais, indicam a força dos membros superiores como um fator relevante para a performance do lançamento independentemente das condições de execução. Os resultados provenientes dos estudos conduzidos no âmbito desta Tese são de grande importância para os treinadores de basquetebol, nomeadamente para os que atuam nos escalões de iniciação/formação. O tamanho da bola poderá ser manipulado pelo treinador no sentido de corresponder às características físicas do jogador e ao seu nível de experiência. Por outro lado, os jogadores devem ser incentivados a lançar de diferentes zonas do campo próximo do cesto até à aquisição de um padrão de movimento estável, antes de se proceder ao aumento da distância. Os resultados destes estudos sugerem uma relação significativa entre a força do trem superior e os parâmetros cinemáticos. Assim, os treinadores devem considerar o desenvolvimento força no processo de treino, particularmente para o desenvolvimento e melhoramento dos lançadores.

Palavras-chave: ação motora, biomecânica, aptidão física, antropometria, condições de execução

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List of Abbreviations

BS	basketball shot
CA	chronological age
CMJ	countermovement jump
CoM	centre of mass
CI	confidence interval
DLT	diret linear transformation
JS	jump shot
SD	standard deviation
2D	two dimensions
3D	three dimensions

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CHAPTER I: GENERAL INTRODUCTION

1. General Introduction

Sport is probably the primary form of physical activity among children and youth (Malina, Bouchard, & Bar-Or, 2004). In Portugal, participants increased from 265 588 in 1996 to 587 812 in 2020 (PORDATA, 2020). Basketball is among the most popular sports and registered a substantial increment of participants with more than 26 600 players according to the 2020 statistics. From the total of practitioners, the highest number of players is enrolled in youth basketball age categories.

The youth basketball literature has been mainly focused on the impact of growth and biological maturation in basketball game performance. Studies consistently suggested that mature advanced players characterized with large body sizes are more likely to be selected by coaches (Delorme, Chalabaev, & Raspaud, 2011; Gryko et al., 2019; te Wierike, Elferink-Gemser, Tromp, Vaeyens, & Visscher, 2015; J. Torres-Unda et al., 2013). Previous Portuguese studies among youth basketball players described the relationship between biological maturation, growth, and the selection of talented youngsters for the sport (Coelho e Silva, Figueiredo, Moreira Carvalho, & Malina, 2008; Guimarães, Baxter-Jones, et al., 2019; Sérgio Ramos et al., 2020; S. Ramos, Volossovitch, Ferreira, Fragoso, & Massuca, 2019). Elite players tend to be taller, heavier, had greater aerobic fitness and explosive strength due to their advanced mature state when compared with their peers (Guimarães, Baxter-Jones, et al., 2019; S. Ramos et al., 2019).

Meanwhile, youth basketball literature has also assessed the performance of sport-specific skills, mainly by evaluating a set of specific tasks such as dribble, passing, and shooting (Coelho e Silva et al., 2008; Guimarães, Baxter-Jones, et al., 2019; Guimarães, Ramos, Janeira, Baxter-Jones, & Maia, 2019). Indeed, the technical characteristics are crucial to distinguish youngsters by competitive level, instead of focusing almost exclusively on the players' physical attributes. Among the preceding skills, shooting is considered critical in the discriminant analysis between losing and winning teams (Csataljay, James, Hughes, & Dancs, 2013).

Among the preceding skills, shooting is considered crucial in the discriminant analysis between losing and winning teams (Csataljay et al., 2013). Although basketball shot (BS) is described as a central basketball-specific motor skill, the literature focused on efficacy instead of proficiency. Individual characteristics of the performer, such as anthropometry, functional capacities, and previous motor experiences, combined with contextual constraints, make the BS a highly complex motor action (V. H. Okazaki, Rodacki, & Satern, 2015). Briefly, although the existence of biomechanical principles for shooting the ball, each player has a unique style.

Therefore, the study of kinematic parameters emerged as relevant to understanding BS motor action (Knudson, 1993; Miller & Bartlett, 1993; Victor H.A. Okazaki et al., 2015). Knowing *what to look for* and *how to spot it* is crucial for teaching and learning (Satern, 1988), particularly among youngsters and more inexperienced players. Therefore, this study was designed to evaluate the BS performed at different conditions through a kinematic analysis.

1.1. Study object

Participation in youth sports is mainly based on chronological age (CA) with a two-year span. In Portugal, basketball players can be registered in competition according to the following stages: under-8, under-10, and under-12 (mini-basketball categories); under-14; under-16; and under-19 (FPB, 2019). Rules and game equipment (ball size and basket height) are adjusted considering the age group and gender to fit the participants' physical capacities and enhance motor learning (J. Arias, Argudo, & Alonso, 2011; Porter & Magill, 2010). Regarding the equipment, the basket height is manipulated to 2.60 m, and a smaller ball size is used in the mini-basketball (size 5, 480 g). Under-14 is the first competitive group playing in the official field, including the basket positioned 3.05-m height as standardized for adult basketball. Among girls, an intermediate ball size (size 6, 566 g) is officially adopted from the under-14 category and further. Males use the intermediate ball size (size 6) at the under-14 age group, modified to the heaviest size at the under-16 category (size 7, 624 g). The decisions about ball size and the basket height claim scientific evidence, including sex-specific adjustment.

Empirical studies reported the benefits of using a smaller ball size for the efficacy rates, particularly on shooting (J. L. Arias, Argudo, & Alonso, 2012). However, kinematic data on the BS using contrasting ball size and manipulation of the distance to the basket is lacking in the literature. The distance between the shooter and the basket is a prominent factor affecting shooting efficacy (Liu & Burton, 1999). Modern basketball values long-distance shooting as a critical tactical aspect. Longer distance demands a distinct trajectory of the projectile (the ball), and efficacy may be compromised by physical attributes such as the body size and strength of the upper limbs. Thus, previous research on kinematic analyses of the BS has been developed to describe long-distance attempts to the basket (Miller & Bartlett, 1996; Miller & Bartlett, 1993; V. H. A. Okazaki & Rodacki, 2012; Satern, 1993), particularly among experienced basketball players. Indeed, literature claims for details regarding the dynamics of the BS among youth basketball players, particularly the female.

1.2. Basketball shot

The inter-individual variation in the BS reference movement pattern interpretation has been illustrated by different shooting styles used by players with similar efficacy rates (Ibáñez et al., 2008). Literature has reported intra-individual differences associated with game-related conditions by comparing the motor action performed by the same player while shooting at several distances to the basket (Elliott & White, 1989). Empirical research using kinematic analyses also examined the BS, considering an opponent as an additional source of variability (Gorman & Maloney, 2016; Rojas, Cepero, Ona, & Gutierrez, 2000). Other studies focused on the effect of fatigue (Ardigò, Kuvacic, Iacono, Dascanio, & Padulo, 2018; Padulo et al., 2018), and manipulation of the distance to the basket (Miller & Bartlett, 1996; Miller & Bartlett, 1993; V. H. A. Okazaki & Rodacki, 2012).

Kinematic parameters are relevant for understanding the motor action, the ball trajectory, and the outcome (efficacy). This knowledge is crucial for teachers and coaches, particularly those involved in the early stages of basketball long-term development, which should privilege the sport-specific skills acquisition.

Ball trajectory

The ball trajectory is defined by the angle, velocity, and height at ball release (Miller & Bartlett, 1993). The angle and velocity are considered the most decisive factors for the shot's success (V. H. Okazaki et al., 2015). The release angle is related to the angle of entry of the ball through the rim, while the release velocity is directly related to accuracy (Miller

& Bartlett, 1996; V. H. Okazaki et al., 2015). Both variables present a direct relationship since a minor variation will change the other. This relationship is characterized by an inverse behavior, with previous studies reporting lower release angles associated with higher release velocities and vice-versa (Knudson, 1993; V. H. A. Okazaki & Rodacki, 2012).

Meantime, the ball release height is described as a more stable variable associated with individual characteristics, particularly with the players' stature and jumping ability (V. H. Okazaki et al., 2015). Body segmental alignment has a crucial influence on ball release height. Height at release is considered a relevant factor, with empirical studies reporting a consistent interrelationship among differences on ball release height and shooting conditions regarding the basket (V. H. A. Okazaki, Lamas, Okazaki, & Rodacki, 2013; V. H. A. Okazaki & Rodacki, 2012).

Parameters related to the shooter have also been studied, such as the position of the centre of mass (CoM) (Rojas et al., 2000; Vencurik, Knjaz, Rupcic, Sporis, & Li, 2021), jumping flight time (Gorman & Maloney, 2016; Rojas et al., 2000), and changes in the markers placed at joints to assess the respective position and time variation (Miller & Bartlett, 1996; Miller & Bartlett, 1993; V. H. A. Okazaki et al., 2013; V. H. A. Okazaki & Rodacki, 2012; Podmenik, Supej, Čoh, & Erčulj, 2017). Indeed, body segmental organization will determine the ball release variables and the shot's outcome.

Finally, the literature describes the ball trajectory as the result of a set of movements which are divided into three phases: (1) preparatory phase, defined by the start of the shooting motion to deepest knee flexion; (2) action phase, initiated with knee extension to ball release; and (3) follow-through phase, from ball release to landing (V. H. Okazaki et al., 2015; M. Satern, 1988) (Figure 1.1).

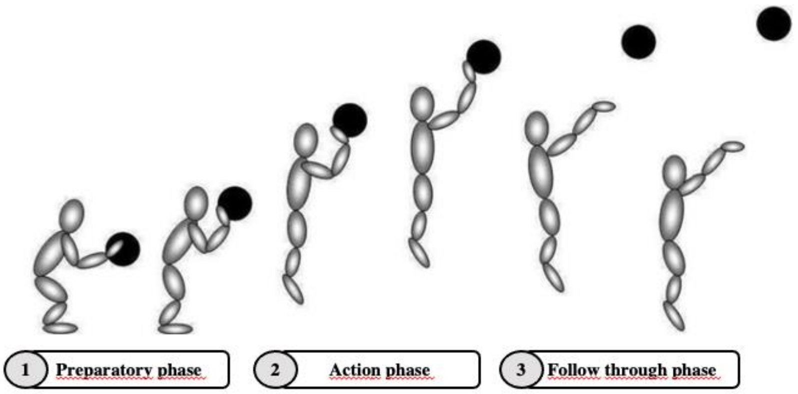

Figure 1.1. Representation of the BS movement phases (adapted from Okazaki et al., 2015).

1.3. Distance to the basket

As a highly dynamic game, players should be able to shoot at several positions and ranges (Ibáñez et al., 2008). Indeed, the 3-point shot has become popular worldwide. In the NBA (National Basketball Association) the number of 3-point attempts broke a record before the COVID-19 pandemic (season 2018-2019). Besides, some teams presented the highest shooting attempts from the 3-point than 2-point (Freitas, 2021). Thus, the basketball game is evolving and demanding the players' development as shooters.

Players and coaches have described the increase of the shooting distance as the more crucial factor that influences shooting efficacy and its form (Liu & Burton, 1999). As the distance from the basket increases, the players must generate greater ball velocity through adjustments in their body segmental organization (Miller & Bartlett, 1993; V. H. A. Okazaki & Rodacki, 2012). The increased velocity emerges from greater joints' angular velocities of the throwing arm (shoulder, elbow, and wrist) (Elliott & White, 1989; Miller & Bartlett, 1996; Miller & Bartlett, 1993; V. H. A. Okazaki & Rodacki, 2012). Consequently, the velocity will influence the angle, usually through an inverse relationship, as previously mentioned (Knudson, 1993). Past research focused on the effects of the shooting distance on the ball release parameters, particularly on the angle and velocity, are summarized in Table 1.1. Note that available data on the behavior of the kinematic parameters associated with distance from the basket is mainly concerned with adult and experienced basketball players, particularly males.

Table 1.1. Summary of the results obtained in the previous empirical studies focused on the BS assessment through a kinematic analysis with the variation of the shooting distance.

Author, year	Participants	Shooting conditions	Kinematic variables assessed	Ball release	
				Angle (º)	Velocity (m/s)
Hudson, 1985	22 college F	Free throw	12 variables: 5 variables related to the ball release; 5 variables related to the shooter's body organization; and 2 variables related to the efficacy rates.	~52	7.04 – 7.10
Elliot & White, 1989	10 elite F basketball players (~22.0 years)	Variation of the shooting distance (4 m and 6.25 m from the basket)	12 variables: 2 variables related to the ball release; 7 variables related to the ankle, knee, hip, shoulder, elbow, and wrist angular displacement and angular velocities, and trunk inclination; and 3 variables concerned the jump phase.	4 m: 52.8 ± 4.1 6.25 m: 52.1 ± 3.7	4 m: 6.60 ± 0.40 6.25 m: 7.90 ± 0.30
Miller & Bartlett, 1993	15 M basketball players (> 21 years)	Variation of the shooting distance (<3.7 m, >3.7<5.5 m, and >5.5 m from the basket)	2 variables associated with the ball release; 13 variables related to the shoulder, elbow, wrist, and hip angular displacement and angular velocities; 5 variables related to the jump phase; and 3 variables with the time from release until maximum joint velocity.	<3.7 m: 48.8 ± 10.1 >3.7<5.5 m: 47.8 ± 5.8 >5.5 m: 51.9 ± 5.5	<3.7 m: 3.04 ± 0.65 >3.7<5.5 m: 4.71 ± 0.74 >5.5 m: 6.24 ± 0.80
Satern, 1993	8 Division I basketball players - 4 M and 4 F (~21.0 years)	Variation of the shooting distance (3 m, 4.6 m, 5.2 m, 6.4 m, 7.0 m, 7.6 m, and 8.2 m)	8 variables: 2 variables related to ball release; 3 variables associated with CoM's displacement; 2 variables related to the shoulder and elbow's angular velocity; and 1 variable concerned with the trunk inclination.	3 m: F 54.9 ± 3.1, M 53.5 ± 6.1 4.6 m: F 53.2 ± 3.5, M 52.7 ± 8.8 5.2 m: F 51.4 ± 3.3, M 51.3 ± 5.2 6.4 m: F 51.5 ± 1.9, M 49.2 ± 3.0 7.0 m: F 51.7 ± 2.5, M 50.7 ± 4.7 7.6 m: F 50.2 ± 5.3, M 46.7 ± 5.0 8.2 m: F 53.8 ± 1.1, M 48.4 ± 3.7	3 m: F 5.43 ± 0.18, M 4.82 ± 0.72 4.6 m: F 6.35 ± 0.53, M 6.06 ± 6.73 5.2 m: F 6.51 ± 0.49, M 6.73 ± 0.21 6.4 m: F 6.69 ± 0.52, M 6.87 ± 0.45 7.0 m: F 7.70 ± 0.23, M 7.15 ± 0.47 7.6 m: F 7.97 ± 0.31, M 7.57 ± 0.31 8.2 m: F 8.74 ± 4.40, M 7.19 ± 1.88

F – females; M – males; CoM – centre of mass

Table 1.1. Cont.

Author, year	Participants	Shooting conditions	Kinematic variables assessed	Ball release	
				Angle (º)	Velocity (m/s)
Miller & Bartlett, 1996	15 M basketball players (> 21 years)	Variation of the shooting distance (2.74 m, 4.57 m, 6.40 m)	3 variables associated with the ball release; 5 variables related to the upper limb joint angular displacements at release; 2 variables related to the movement times.	2.74 m: 52.0 ± 6.0 to 55.0 ± 3.0 4.57 m: 52.0 ± 6.0 to 54.0 ± 3.0 6.40 m: 48.0 ± 7.0 to 50.0 ± 7.0	2.74 m: 5.27 ± 0.52 to 5.71 ± 0.29 4.57 m: 6.27 ± 1.25 to 6.41 ± 0.67 6.40 m: 7.36 ± 1.28 to 8.39 ± 0.49
Okazaki & Rodacki, 2012	10 M basketball players (~25 years)	Variation of the shooting distance (2.8 m, 4.6 m, and 6.4 m)	21 variables: 5 variables related to ball release; 8 variables associated to CoM's displacement; 7 variables related to the ankle, knee, hip, trunk, shoulder, elbow, and wrist angular displacement and velocity; 1 variable related to efficacy rate.	2.8 m: 78.9 ± 8.8 4.6 m: 65.6 ± 12.5 6.4 m: 69.3 ± 10.6	2.4 m: 4.39 ± 0.36 4.6 m: 5.75 ± 0.50 6.4 m: 6.89 ± 0.62
Okazaki et al., 2013	15 M youth basketball players (12.1 ± 1.4 years)	Variation of the shooting distance (2.8 m, 4.6 m, and 6.4 m)	21 variables: 5 variables related to ball release; 8 variables associated to CoM's displacement; 7 variables related to the ankle, knee, hip, trunk, shoulder, elbow, and wrist angular displacement and velocity; 1 variable related to efficacy rate.	2.8 m: 68.7 ± 3.3 4.6 m: 63.3 ± 3.5 6.4 m: 57.9 ± 3.4	2.4 m: 5.43 ± 0.16 4.6 m: 6.30 ± 0.20 6.4 m: 7.37 ± 0.20

F – females; M – males; CoM – centre of mass

Meanwhile, the ball release height is theoretically considered as a more stable variable. It is directly related to the shooter's stature and the jump phase (V. H. Okazaki et al., 2015). However, empirical studies have concluded that the ball release height tends to decrease when the distance to the basket is increased. At longer shots, the jump height until ball release decreases, since players' throw the ball before reaching the peak of the jump phase (Elliott & White, 1989; V. H. A. Okazaki et al., 2013; V. H. A. Okazaki & Rodacki, 2012).

The increase of the distance from the basket also influences the centre of mass (CoM) displacement. The horizontal displacement increases at longer shooting ranges, compromising efficacy (V. H. A. Okazaki & Rodacki, 2012). The literature points out that top-level shooters presented less horizontal shift during the BS performance when compared to less skilled shooters (Knudson, 1993). The preceding author concluded that efficacy was improved with a more stable base. For that reason, players should minimize the horizontal motion by jumping as close to vertical as possible.

In literature, only four studies evaluated the shooting performance among youth basketball players (González-Fimbres, López, & Valdez-Melchor, 2015; V. H. A. Okazaki et al., 2013; Podmenik et al., 2017; Vencurik et al., 2021). Only one has reported results on the ball release variables (V. H. A. Okazaki et al., 2013), while the others focused on assessing parameters related to the shooters' body organization. Also, note that two studies considered female basketball players as participants (González-Fimbres et al., 2015; Vencurik et al., 2021).

1.4. Ball size

The game equipment and rules are commonly adjusted in youth sports to fit the participants' physical capacities (J. Arias et al., 2011). Regarding manipulative skills, early sports experiences are crucial in developing motor proficiency. Indeed, it is implicitly assumed that motor learning and refinement are affected by the dynamic interactions with the contextual constraints (Molenaar, Lerner, & Newell, 2013; Porter & Magill, 2010). Besides, contextual conditions enhance enjoyment and prevent premature dropout (Buszard, Farrow, Reid, & Masters, 2014).

The ball size is adapted according to players' age and sex. The ball gets heavier as players get older. On the other hand, the physical differences between sexes justify the heavier ball size used by males than female players. Previous research among youth basketball regarding the effects of ball size on shooting efficacy, concluded higher success rates while using a smaller ball size (J. L. Arias et al., 2012). However, data on the relationship between the ball size and the percentage of efficacy is not consensual. Among adolescent female basketball players, authors reported that performance with a smaller ball size was not associated with higher efficacy rates (Podmenik, Leskošek, & Erčulj, 2014). In children aged 10.9 years, results indicated that equipment modification (basket height and ball size) did not produce differences in static and dynamic shooting efficacy rates (Milovanovic, Pazin, Mrdakovic, Erculj, & Jakovljevic, 2020).

Regarding the shooting motor action analysis when performing with different ball sizes, only three studies were found in past literature (V. H. A. Okazaki & Rodacki, 2005; Satern, Messier, & Kellermcnulty, 1989; M. N. Satern, 1988). Besides the ball size manipulation during the free-throw performance, these studies also manipulated the basket height (2.60 m and 3.05 m). Data concerning the ball release variables are lacking and presented in Table 1.2. Overall, the authors did not report substantial changes in the shooting action due to the ball size used. However, modified game actions should be expected when an element of the system, such as the ball, is adapted. Thus, it is crucial to conduct future research on this topic.

Table 1.2. Summary of the results obtained in studies focused on the BS assessment with the ball size manipulation through a kinematic analysis.

Author, year	Participants	Shooting conditions	Kinematic variables assessed	Ball release	
				Angle (º)	Velocity (º)
Satern, 1988	Adolescents recruited from PE classes (~13.0 years), F (18.8 - 21.0 years), and M (19.0 - 21.4 years)	Free throw with ball size manipulation	6 variables: 2 variables related to the ball release; and 4 variables concerning the timing and coordination of the knee, shoulder, elbow, and wrist joints during the shooting motion.	n/s	n/s
Satern, et al., 1989	13 boys recruited from PE classes (12.9 ± 0.1 years)	Free throw with BS manipulation (regulation – BML10, and intermediate size – BML119) and with BH manipulation (2.45 m and 3.05 m)	6 variables: 2 variables related to the ball release; and 4 variables concerning the timing and coordination of the knee, shoulder, elbow, and wrist joints during the shooting motion.	BH 2.45 m, BML10: ~45.2 BH 3.05 m, BML10: ~50.5 BH 2.45 m, BML119: ~44.6 BH 3.05 m, BML119: ~51.5	BH 2.45 m, BML10: ~7.07 BH 3.05 m, BML10: ~7.00 BH 2.45 m, BML119: ~6.98 BH 3.05 m, BML119: ~7.02
Okazaki & Rodacki, 2005	8 M youth basketball players (10.0 ± 0.5 years)	Ball size manipulation (BS1, BS2, BS3)	Shoulder, elbow, and wrist joints angular displacement and velocity.	n/s	n/s

PE – physical education; F – females; M – males; BS – ball size; BH – basket height; n/s – not specific

1.5. Rationale and objectives

Available studies in youth basketball have been focused on assessing functional capacities, maturity status, and game performance (Coelho e Silva et al., 2008; Delorme et al., 2011; Silva et al., 2010; Jon Torres-Unda et al., 2016). On the other hand, the study of the BS motor action and ball trajectory at longer distances from the basket has already attracted empirical research, mainly on experienced basketball players, particularly males (Miller & Bartlett, 1996; Miller & Bartlett, 1993; Nakano, Fukashiro, & Yoshioka, 2020; V. H. A. Okazaki & Rodacki, 2012).

The experiences at the early stages of basketball long-term development are crucial for the specific-skills acquisition. Indeed, contextual constraints such as the shooting distance and the ball size used are expected to influence motor learning and refinement (Molenaar et al., 2013). The percentage of efficacy does not provide suitable feedback for the shooters' improvement regarding the shooting action. Therefore, knowledge of the adjustment mechanisms that support the BS motor action is critical for the coaches’ intervention. The acquisition of adequate movement patterns will promote the shooters' development and enhance efficacy.

Meanwhile, the anthropometric and physical differences between males and females demand proper research for each group. The basketball literature has privileged male players and fails to provide details on the motor skills performance among female players.

Therefore, the overall purpose of this Thesis is to examine the BS performance among adolescent female basketball players, particularly considering variation in distance from the basket and the manipulation of ball size. The current Thesis is presented in a format composed of several manuscripts and is organized in sections: the first ones consider a general introduction to the problem (Chapter 1) and methods (Chapter 2). Chapter 2 provides a detailed description of the participants, procedures, instruments, and variables. The subsequent section comprises chapter 3, which corresponds to a systematic review of the literature on the BS performance among youth basketball players (study 1). The following sections refer to two cross-sectional studies: chapter 4 (study 2) and chapter 5 (study 3). Both studies evaluated BS performance through a kinematic analysis. Study 2 was focused on the effects of ball size manipulation in the BS performance, and study 3 assessed the influence of the distance variation to the basket in the BS performance. The final section corresponds to chapter 6, which presents a general discussion and conclusions. The studies' findings are summarized, and practical implications are discussed.

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CHAPTER II: METHODS

This Chapter provides a detailed description of the methods and instruments used for data collection and analysis.

2.1. Study design

The present research proposal 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 (Harriss, MacSween, & Atkinson, 2019).

The sample was composed of twenty-seven female adolescent basketball players aged 12.4 ± 0.9 years (height: 153.4 ± 8.1 cm; body mass: 48.8 ± 12.8 kg) from clubs of Madeira Island. All participants had at least two years of basketball training experience and were not injured at the time of data collection. Participants and respective legal guardians were informed about the nature of the studies, including objectives, protocols, and related risks, and signed informed consent. All participants were volunteers and could withdraw from data collection at any time.

All procedures for data collection were applied by a research team composed of four elements. The research team members were experienced and familiarized with the data collection methods.

Due to the number of participants, data collection was divided into three different moments with two days apart. All data were collected in an official basketball court, including the anthropometry. The Department of Physical Education and Sports of the University of Madeira made available all the equipment used.

2.2. Procedures and instruments

Chronological age (CA)

CA was determined to the nearest 0.01 year by subtracting the birth date from the data collection date.

Anthropometry

Height and sitting height were measured using a portable stadiometer (SECA 213, Hamburg, Germany) to the nearest 0.1 cm. For the measurements, participants were barefoot. The *Frankfort Plane* was considered the reference for the positioning of the head. Participants stood erect with their feet together against the stadiometer and arms relaxed at their sides. The heels, buttocks, upper back, and skull touched the stadiometer. The measurer slides the headboard of the stadiometer down to the vertex, and the indicated measurement is recorded. Body mass was measured using a portable scale (SECA 760, Hamburg, Germany) to the nearest 0.1 kg. Participants were weighed barefoot. Leg length was estimated as height minus sitting height.

Skinfold thickness was measured to the nearest 0.1 mm at six sites (triceps, subscapular, suprailiac, abdominal, thigh, and calf) using a skinfold calliper (Harpenden Skinfold Caliper, West Sussex, England). A single investigator took all measurements following the ISAK (International Society for the Advancement of Kinanthropometry) guidelines (Olds, Carter, & Marfell-Jones, 2006).

The percentage of adult stature was calculated to indicate the maturity status using the Beunen-Malina-Freitas method (Beunen et al., 2011). The information regarding menarche was collected through a proper questionnaire.

Fitness tests

Two tests were applied to assess lower limb explosive strength and power: (1) countermovement jump (CMJ) and (2) squat jump (SJ) (Bosco, Luhtanen, & Komi, 1983). Both protocols included four data collection trials and were performed in the Optojump Next (Microgate, Bolzano, Italy) system of analysis and measurement. Participants rest 45 seconds between each trial and five minutes between each test. In both tests, participants were encouraged to jump for maximum height. In the CMJ protocol, 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. The SJ protocol testing began with the participant in a squat position at a self-selected depth of approximately 90º of knee flexion, holding this position for researchers' count of three before jumping. If a dipping movement of the hips was evident, then the trial was repeated.

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 alternated data collection trials for each arm performed using a hand dynamometer (Jamar Plus+, Illinois, USA). Participants were instructed to hold a dynamometer in one hand, laterally to the trunk with the elbow on a 90º position (Gerodimos, 2012). From this position, participants were instructed to squeeze as hardest as possible and progressively and continuously the hand dynamometer for about two seconds. At no time, the dynamometer could contact the participant's body. The recovery time between trials was set at 45 seconds. The best score was retained for analysis.

A sit-ups protocol consisted in performing the most significant number of repetitions for 60 seconds (Silva et al., 2010). Participants were instructed to start in a sitting position, torso vertical, hands behind their neck, bent knees (90º), and feet on the floor. From this position, participants were instructed to stretch out on their back, shoulders in contact with the floor, then 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. The absence of counting meant that the repetition had not been correctly performed.

The 2 kg medicine ball throw is based on three trials with 30 seconds of rest between tests (Palao & Valdes, 2013). In the throws, participants could not vary their throwing position. The best score was retained for analysis.

Shooting procedures

Participants completed a 15-minute warm-up that included jogging, dribbling, shooting, and dynamic stretching exercises. After the warm-up, nine anatomical reflective markers (1.5 cm of diameter) were placed over the participant's skin and clothes in the following segments (Okazaki & Rodacki, 2012): 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 represent 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. The same investigator positioned all markers on the participants' dominant side.

Afterwards, participants performed two sets of 10 BS attempts from a frontal position to the basket: the first at 4.75 m, and the second at 5.75 m. All shots were made with the standardized ball size for their age category (Wilson Evolution Size 6, 566 g). Then, participants performed two more sets of 10 BS from a frontal position at 5.75 m from the basket: the first with a smaller and lighter ball (Wilson MVP Size 5, 480 g), and the second with the standardized ball size for their age category (Wilson Evolution Size 6, 566 g). The shooting order was not randomized, and all participants shot following the previous guidelines. Each participant performed a total of 40 BS.

One investigator captured rebounds, and the ball was passed back to the shooter through a direct pass. A second investigator filmed each BS trial with a digital camera (Sony Cyber-Shot RX100, 120Hz) placed in the sagittal plane at 7 m from the participant's dominant side and at 1.20 m from the floor. 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. All BS were filmed and kept for analysis.

The camera's positioning did not allow recording the BS outcome through filming. Therefore, a third investigator registered the outcome using an efficacy rating system composed of five levels (Satern, 1988) : (4 points) successful attempts that did not hit the rim; (3 points) successful shots 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").

Kinematic analysis

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 (Two Dimension-Direct Linear Transformation) (Brewin & Kerwin, 2003; Pourcelot, Audigié, Degueurce, Geiger, & Denoix, 2000), considering the vertical and horizontal dimensions of the reference object. The 2D-DLT has been used in kinematic analyses of human movement, allowing the definition of 2D coordinates based on the virtual coordinates of each point (Pourcelot et al., 2000).

The following kinematic parameters were retained for analysis: ball release variables (angle, velocity, and height); the 2D position of the centre of mass - CoM (total horizontal displacement and maximum height attained); the position of the hip (maximum height and height at ball release); shoulder, elbow, and knee joints angular position (minimum angle, maximum angle, and at ball release) for the sagittal plane of movement (flexion-extension); angular velocities of the shoulder, elbow and knee joints (maximum angular velocity and 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 change in the absolute angle, formed by the centre of the ball, between the frame of release and the immediately following frame corresponded to the ball release angle. The ball release velocity was defined by the value of the velocity at ball release. The ball release height was expressed by the distance between the centre of the ball and the floor at ball release. The ball trajectory was studied partially after the moment of release due to the camera's position. Since filming was made at 120 Hz it was not possible to determine with all precision the ball's limits. The ball was marked with a circumference and its center was marked at least five frames before and after the release (Okazaki & Rodacki, 2012; Uygur, Goktepe, Ak, Karabörk, & Korkusuz, 2010) (Figure 2.1).

Figure 2.1. Representation of the digitalization process used to define the ball's trajectory in Tracker software.

The 2D CoM's assessment was made through a segmental model using the coordinates of the anatomical markers, considering specific equations (Winter, 2009). The joints' angular position and angular velocities were automatically calculated by Tracker software. The kinematic analysis started in the first frame, where knee flexion was perceptible, and ended two frames after the participant's feet touched the floor.

A single investigator performed all kinematic analyses. A previous pilot study developed with 10 participants was conducted to check the established procedures, particularly regarding to the assessment of the ball trajectory. Additionally, the Cronbach alpha coefficient was calculated to evaluate the intra-individual reliability in analyzing selected kinematic variables. The results showed good consistency, with the Cronbach alpha coefficient varying between 0.87 and 0.99 (Pallant, 2013).

Statistical analyses

Descriptive statistics included mean and standard deviation. Paired t-test was used to compare the kinematic parameters according to shooting conditions. Effect size was interpreted using d-Cohen as follows (Cohen, 2013): $d<0.2$ (small), $0.2\leq d<0.6$ (moderate), $0.6\leq d<1.2$ (large), $1.2\leq d<2.0$ (very large). The Pearson-product correlation coefficient was used to study the relationship between selected variables in each study. All analyses were performed using the Statistical Package for Social Sciences (IBM SPSS software, version 26). The level of statistical significance was set at 5%.

2.3. References

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CHAPTER III: STUDY 1

The jump shot performance in youth basketball: a systematic review

Reference: França, C., Gomes, B. B., Gouveia, É. R., Ihle, A. & Coelho e Silva, M. J. (2021) The jump shot performance in youth basketball: a systematic review. *International Journal of Environmental Research and Public Health. 18*(6). 3283

3.1. Abstract

Background: The basketball jump shot (JS) is consensually considered as a high-complexity specific motor skill, with a complex teaching and learning processes involved. The aim of this paper was to conduct a systematic review of the literature on the JS performance among youth basketball players. Methods: The data search was made according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) in the Institute for Scientific Information (ISI) Web of Knowledge, PubMed, Scopus and Sportdiscus databases until March 2021. Results: The results suggest that JS performance of youth basketball players is influenced by (i) distance to the basket, (ii) fatigue, (iii) presence of a defender and (iv) visual information available. Conclusion: This research emphasizes the crucial need for players and coaches to promote training situations matching the game reality to develop successful shooting performance of youth basketball players.

Keywords: youth players; game-related conditions; motor action; kinematics

3.2. Introduction

In basketball, shooting efficacy is consensually considered by athletes and coaches as an essential component to achieve a successful performance (Ibáñez et al., 2008; Struzik, Pietraszewski, & Zawadzki, 2014) The basketball shooting literature supports a reference movement pattern for the jump shot (JS) performance (Liu & Burton, 1999), which has emerged from biomechanics' fundamental principles. However, even in experienced players, it is possible to observe different shooting styles with a similar efficacy percentage (Ibáñez et al., 2008). Therefore, inter-individual differences in the motor action's performance could be found not only due to individual characteristics, such as anthropometry and physical capacities (V. H. Okazaki, Rodacki, & Satern, 2015), but also due to game-related conditions (Elliott & White, 1989; Knudson, 1993; Rojas, Cepero, Ona, & Gutierrez, 2000).

Meanwhile, intra-individual differences have also been pointed out, mainly through comparing the motor action used by the same player across several shooting conditions (Elliott & White, 1989). Literature suggests that players are able to adapt their performance according to game-related conditions, such as distance variation to the basket or the presence of a defender (Miller & Bartlett, 1996; V. H. Okazaki et al., 2015; Rojas et al., 2000). If even in expert players, these inter- and intra-individual differences could be easily observed, it seems crucial to understand what happens in youth basketball. Being recognized as a complex specific motor skill (Knudson, 1993; Miller & Bartlett, 1996; V. H. Okazaki et al., 2015), the teaching and learning process involved in JS are also complex, particularly among the more inexperienced players such as youngsters.

Overall, basketball shooting has already attracted empirical research, mainly focused on the final product: percentage of efficacy (Gorman & Maloney, 2016; Nakano, Fukashiro, & Yoshioka, 2020; V. H. A. Okazaki & Rodacki, 2012; Oudejans, Van De Langenberg, & Hutter, 2002). Indeed, efficacy could be considered the best single dependent variable of the shooting action, since it represents the game's scoring system. However, the ratio obtained from the scored points and the total number of attempts during a game or training session fails to provide adequate feedback about the process for the shooter's improvement, especially for the more inexperienced players. The literature claims details regarding the dynamics of motor action. For that reason, the use of a kinematic analysis emerged as crucially relevant for understanding the movement pattern, the ball trajectory and the final outcome (Hudson, 1985; Miller & Bartlett, 1996; Miller & Bartlett, 1993).

The ball trajectory, defined by the angle, velocity and height at the moment of ball release (Miller & Bartlett, 1996), intermediates the players' muscle action and the final outcome. Additionally, parameters of the shooter have also been studied, such as the position of the center of mass (CoM) (Hudson, 1985; Rojas et al., 2000; Slawinski et al., 2018); trunk inclination (Hudson, 1985; Rojas et al., 2000); jumping flight time (Gorman & Maloney, 2016; Podmenik, Supej, Čoh, & Erčulj, 2017; Rojas et al., 2000; Struzik et al., 2014); changes in land- marks placed at joints to assess the respective position and time variations (Nakano et al., 2020; V. H. A. Okazaki & Rodacki, 2012; Podmenik et al., 2017). The kinematic parameters have been previously used to evaluate the game-related conditions as a source of inter and intra-individual variability among basketball shooters (Miller & Bartlett, 1996; Miller & Bartlett, 1993; Nakano et al., 2020; Rojas et al., 2000; Supej, 2009). However, most of the data available are concerned with adult and experienced players.

Therefore, this paper aims to review the existent literature for the basketball JS performance, exclusively among youth basketball players. Of particular interest was to (1) determine which game-related conditions are relevant for the jump-shooting performance; (2) to understand the influence of those game-related conditions on the shooting motor action.

3.3. Methods

Search strategy

A systematic review of the literature on the basketball JS was conducted according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021) for relevant publications from the last 20 years. This research was not registered on PROSPERO platform. To ensure the quality of the articles selected, the data search was conducted in the Institute for Scientific Information (ISI) Web of Knowledge, PubMed, Scopus and Sportdiscus databases until March 2021. The main term used in the research process was "basketball shot", associated with the following keywords: “performance”, “ball trajectory” and “young players”. The Boolean phrase used in the search was—AND—to identify the largest number of documents possible that complied with the established conditions. The Boolean phrase OR has not been used, since it was intended to achieve exclusive information in the search process. For the documents to be included and analyzed, they had to fulfil the defined inclusion and exclusion criteria. Two authors individually performed the search using the strategy previously mentioned. The same authors screened the citations and abstracts to identify documents that could be included in the review. In case of potential doubt about the selection of one particular article, both authors analyzed the full article to determine whether the inclusion criteria were met. In the case of disagreements between the two authors in terms of the inclusion criteria, a third author analyzed the full article and made the final decision.

Eligibility criteria

The inclusion criteria for these articles were (i) data including one or more variables that affect the JS performance; (ii) sample uniquely composed by basketball players; (iii) participants (boys and/or girls) aged between 10 and 19 years; (iv) presented quantitative or theoretical data; (v) written in English, Spanish or Portuguese languages; (vi) published in the past 20 years (2000–2020). Manuscripts were excluded if they did not refer to the JS performance; were only focused on the free-throw motor action; were developed in Paralympic basketball or school samples not engaged in competitive and organized youth basketball; papers developed in high-level competitions such as Euroleague, National Basketball Association (NBA) or Olympic games; conference papers or other material that cannot be referenced.

3.4. Results

A total of 929 studies were selected, as presented in Figure 1. References were ade- quately managed (Zotero 5.0.94), and duplicates were automatically deleted (n = 308). The 621 articles remaining were examined for relevance based on title and keywords. Addition- ally, conference papers, items that could not be referenced and documents classified as not scientific relevant were also eliminated (n = 593). Articles that did not perform some type of analysis of the JS performance were considered not relevant (e.g., papers developed on Paralympic basketball; in high-level competitions such as Euroleague, NBA or Olympic games; injuries assessment or prevention; physical fitness; game-analysis performance; nutritional aspects; coaching). Thus, 28 articles have remained for full-text assessment remaining. From those, papers developed with elite players older than 19 years (n = 12) and papers focused on the free-throw analysis (n = 4) were also excluded. Thus, a final selection of 12 papers has been used for this review.

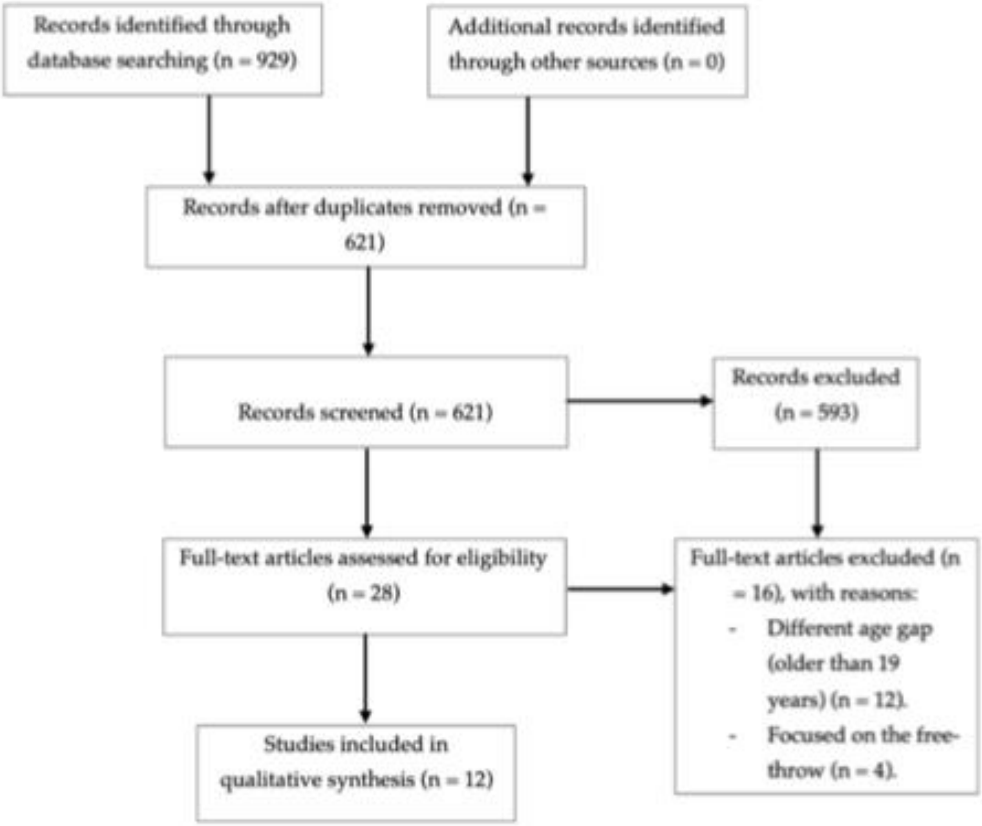

Figure 3.1. Flow chart of the document's selection process.

3.4.1. Evidence synthesis

Twelve documents were selected for this analysis (Table 1). Evidence was synthesized according to the following variables: (i) distance variation to the basket (four studies) (González-Fimbres, López, & Valdez-Melchor, 2015; V. H. A. Okazaki, Lamas, Okazaki, & Rodacki, 2013; Podmenik et al., 2017; Vencurik, Knjaz, Rupcic, Sporis, & Li, 2021); (ii) fatigue (four studies) (Ardigò, Kuvacic, Iacono, Dascanio, & Padulo, 2018; Padulo et al., 2018; Rupčić et al., 2020; Slawinski et al., 2018); (iii) presence of a defender (two studies) (Gorman & Maloney, 2016; Van Maarseveen & Oudejans, 2018); (iv) visual information available (two studies) (Klostermann, Panchuk, & Farrow, 2018; Oudejans et al., 2002). One of the documents has reported data on the JS performance both on a defender's presence and on the players' gaze behavior (visual information) (Van Maarseveen & Oudejans, 2018). Besides, only two studies have used exclusively female participants, eight studies used male participants, and two studies used participants both boys and girls. In nine studies, participants were adolescent players. From the total sample, seven papers have presented results of the kinematic parameters.

Table 3.1. Studies description and identification of the variables considered.

Author	Aim(s) of the study	Participants	Game-related conditions considered	Main results
Vencurik et al. (2021)	To compare the kinematic variables of 2- and 3-point shot.	48 male and female basketball players U16 and U18	Distance variation to the basket	- 2-point shots showed lower entry angles of the ball and were performed faster than the 3-point shots.
Rupcic et al. (2020)	To evaluate the effect of fatigue on the kinematic parameters of the 2- and 3-point JS.	1 male basketball player aged 17 years	Fatigue	- Height of ball release decreased and angular velocities of joints on the upper extremity decreased in fatigued conditions.
Van Maarseveen & Oudejans (2018)	Effects of a defender contesting the JS on the performance and gaze behavior of basketball players	13 female basketball players aged 16.8 ± 1.8 years	Presence of a defender and visual information	- Shorter final fixation in the contested than in the uncontested condition; - Contested shots were performed faster and had a long jump phase and ball flight than uncontested shots.
Slawinski et al. (2018)	Impact of physical fatigue (repeated sprints protocol) on upper and lower limb joint kinematics and in ball release parameters	10 elite basketball players, six male and four female, aged 16.3 ± 1.2 years	Fatigue	- No effect of fatigue on the angles formed by the body's joints; - No differences were found for ball release variables (height, angle and velocity), CoM's vertical displacement and jump height between fatigue and non-fatigued conditions.
Ardigo et al. (2018)	Effects of a fatigue protocol on the 3-point shooting efficacy.	24 male basketball players aged 16.3 ± 0.6 years	Fatigue	- Results showed that 50%HRMax does not significantly decrease on 3-point accuracy, while 80%HRMax significantly does when compared to rest (0%HR).
Padulo et al. (2018)	Effects of a fatigue protocol on the 2-point shooting efficacy.	22 male basketball players aged 15.7 ± 0.9 years	Fatigue	- Results showed that 50%HRax does not significantly decrease the 2-point jump shot accuracy while 80%HRMax significantly does when compared to rest (0%HR).
Podmenik et al. (2017)	To describe joint angular velocities during the JS performance with the increase of the shooting distance.	14 top-level male basketball players aged 15.4 ± 0.5 years	Distance variation to the basket	- The maximum angular velocities of the elbow and shoulder joint increased when the distance of the throw was increased; - The maximum angular velocities were generally similar for the first and second distances (3.75 m and 5.2 5m) but were higher for the third distance (6.7 5m).
Klostermann et al. (2017)	To explore the quiet eye (QE) functionality in a defended and undefended condition, in highly vs. intermediately skilled basketball players executing JS.	17 male basketball players aged 18.8 ± 0.6 years	Visual information	- Successful shots were associated with longer QE durations, both in highly-skilled as in intermediate-skilled players; - The percentage of efficacy was significantly higher in the uncontested (M = 65.6 %) than in the contested condition (M = 44.5%).
Gorman & Maloney (2016)	Examine the influence of a defender on the performance of a basketball shot using five different shot types.	12 male basketball players aged 17.8 ± 1.1 years	Presence of a defender	- The presence of a defender led to faster shot execution times, longer jump times, and an increase of the ball flight time; - The percentage of efficacy was higher in uncontested (M = 63.9%) than in contested conditions (M = 41.1%).

Okazaki et al. (2013)	Analyze the effect of the increase of the shooting distance on the JS performed by boys.	15 boys aged 12.1 ± 1.4.	Distance variation to the basket	- Significant differences were found on the ball release variables (height, angle and velocity) when the shooting distance was increased; - The maximum angular velocities of the shoulder and elbow joints were greater at longer distances to the basket.
González-Fimbres, et al. (2015)	Impact of the increase of the shooting distance on the JS kinematics performed by girls.	6 girls aged between 10-11 years.	Distance variation to the basket	- Angles formed by the shoulder, elbow, knee and trunk, had increased when the shooting distance was increased.
Oudejans (2005)	Effects of perceptual training on basketball JS percentage of efficacy.	10 adolescent male basketball players aged 17 years	Visual information	- Participants submitted to visual training have increased their ability to pick up relevant information during the final instance before ball release; - Additionally, participants also improved their game percentage of efficacy.

3.4.2. Main findings

Distance to the basket

Regarding distance to the basket, the first study among six girls aged between 10 and 11 years considered a two-dimension kinematic analysis used to analyze the effects of five shooting distances to the basket (2, 3, 4, 5 and 6 m) on the JS performance (González-Fimbres et al., 2015). Authors have focused their attention on the angles formed by the shoulder, elbow and knee joint. Results showed lower values for all the variables previously mentioned with the increase in the shooting distance. The ball release variables were not assessed. However, the authors pointed out a high variability of the movement pattern as the distance to the basket was increased (González-Fimbres et al., 2015).

In another study, using a two-dimensional kinematic analysis, authors have examined the JS performed by boys aged 12.1 ± 1.4 years among three distances to the basket (2.8, 4.6 and 6.4 m) (V. H. A. Okazaki et al., 2013). Significant differences were found when the performance at 2.8 m was compared with the performance at 6.4 m for the ball release parameters: height of release (M = 1.93 ± 0.07 m; M = 1.79 ± 0.05 m) ($p < 0.01$); angle of release (M = 68.7 ± 3.2◦; M = 57.8 ± 3.4◦) ($p < 0.05$); velocity of release (M = 5.43 ± 0.1 m/s; M = 7.37 ± 0.2 m/s) ($p < 0.01$). The maximum angular velocities of the elbow and the shoulder joints have progressively increased, with a statistically significant value ($p < 0.05$), due to the distance increase. The mean value for the elbow joint angular velocity was 637.2 ± 39.7◦/s at 2.8 m condition and 855.3 ± 40.4◦/s at 6.4 m condition. On the other hand, the mean value for the shoulder joint angular velocity was 422.3 ± 38.7◦/s at 2.8 m condition and 576.5 ± 50.2◦/s at 6.4 m condition. Meanwhile, at ball release, the mean value for the elbow joint angular velocity was superior at 4.6 m (M = 599.6 ± 42.6◦/s) when compared to the 2.8 m condition (M = 509.0 ± 48.6◦/s), but lower when compared to the 6.4 m condition (M = 593.6 ± 64.9◦/s). Simultaneously, the mean values for the shoulder joint angular velocity at ball release have increased from the shorter to the longer shooting distance, although with no significant statistical impact. Additionally, significant differences were detected in the body's horizontal displacement ($p < 0.05$) when the shots at 2.8 m were compared with the shots at 6.4 m condition, 0.35 ± 0.02 m and 0.49 ± 0.03 m, respectively (V. H. A. Okazaki et al., 2013).

In a three-dimensional kinematic analysis, the joints' angular velocities were assessed during the JS performance in a group of 14 top-level male players aged 15.4 ± 0.5 years (Podmenik et al., 2017). The authors aimed to describe the joint angular velocities during the JS performed three distances to the basket (3.75, 5.75 and 6.75 m). The elbow joint's maximum angular velocities increased significantly (p < 0.05) when the shooting range was longer, with mean values of 923.4 ± 86.4◦/s and 1212.4 ± 158.8◦/s, at 3.75 and 6.75 m, respectively. The mean values for the shoulder joint were 444.2 ± 78.9◦/s at 3.75 m condition and 718.6 ± 174.2◦/s at 6.75 m condition, illustrating significant differences in the maximum angular velocities for this joint as well. The angular velocity of the elbow and the shoulder joint at ball release was also higher at longer shooting distances. On the contrary, no significant differences were reported on the wrist joint's maximum angular velocities, with mean values of 1528 ± 383.2◦/s at 3.75 m and 1731 ± 658.5◦/s at 6.75 m (Podmenik et al., 2017).

In another study, through a three-dimensional kinematic analysis, the CoM's behavior, the player's shooting speed, the entry angle of the ball when approaching the rim and the shoulder angle at release were observed in 2 and 3-point shots performed by 48 players U16 and U18 male and female categories who participated on the European Championship in 2017 (Vencurik et al., 2021). In all categories (male and female), significant differences were found between 2- and 3-point shot on the entry angle of the ball (p < 0.01) and on the player's shooting speed (p < 0.01). In general, the 2-point shots presented lower entry angles of the ball and were performed faster in comparison to the 3-point shots. Across the same shooting conditions, results also showed that males shot with a higher CoM's difference in the vertical direction, with a higher release shoulder angle and with a higher entry angle of the ball, when compared to female players. Finally, the efficacy was lower in the 3-point shot and females showed lower shooting percentages of efficacy than male, except the 2-point shot at U18 category (Vencurik et al., 2021).

Fatigue

Three studies have examined fatigue through specific protocols and used maximal heart rate (HR) percentages as an indicator of physical fatigue (Ardigò et al., 2018; Padulo et al., 2018; Slawinski et al., 2018). Significant differences were found on the 3-point percentage of efficacy in a group of 24 young male basketball players aged 16.3 ± 0.6, at higher rates of maximal HR. When comparing three conditions of HR measurements, respectively 0, 50 and 80%HR, the authors observed a progressive decrease in efficacy as a response to fatigue increase (Ardigò et al., 2018). Although with no significant differences ($p = 0.25$), a 15% reduction in shooting efficacy rate at 50%HR was observed when compared to the rest condition (0%HR). On the other hand, 3-point efficacy has decreased significantly 28% when shooting at 80%HR was compared to the rest condition (0%HR) ($p < 0.05$) (Ardigò et al., 2018). Another study applied a similar protocol of maximal HR measurement in 22 young male basketball players aged 15.7 ± 0.9 years to evaluate the effect of fatigue on the 2-point shot efficacy (Padulo et al., 2018). Results showed lower percentages of efficacy at 80%HR when compared to 50%HR (−21%) and to 0%HR (−29%) ($p < 0.01$). No differences in shooting efficacy were found when the performance at 50%HR was compared to the rest condition (0%HR) ($p = 0.34$) (Padulo et al., 2018).

Meanwhile, a kinematic analysis aimed to investigate fatigue's effects on the 3-point shot performed by ten elite male basketball players aged 16.3 ± 1.2 years (Slawinski et al., 2018). At 88%HR, no significant differences were found in the ball release parameters (release velocity $p = 0.80$, release angle $p = 0.14$ and release height $p = 0.51$) when the non-fatigued was compared to the fatigued condition. In addition, the angles formed by the shoulder, elbow, wrist, hip, knee and ankle joint did not show significant statistical differences between shooting conditions (Slawinski et al., 2018).

Another study has evaluated several kinematic parameters in fatiguing conditions. Instead of the HR measurement, the level of blood lactate concentration was used as a fatigue indicator (Rupčić et al., 2020). The maximum angular velocities of the shoulder and wrist joint were significantly scaling down with the greater manifestation of fatigue. In the first shooting series, the shoulder's mean maximum angular velocity was 510.89 ± 22.10◦/s and in the final series was 484.46 ± 18.56◦/s ($p = 0.02$). The wrist's mean maximum angular velocity has also decreased significantly ($p < 0.01$) from the first (1227.02 ± 143.73◦/s) to the last series (950.04 ± 53.23◦/s). Moreover, the height of ball release was also significantly lower ($p < 0.01$) in the fatigued condition (2.47 ± 0.02 m) when compared with the first shooting series (2.58 ± 0.02 m). No differences were reported on the angle and velocity at the moment of ball release.

Presence of a defender

Two studies have assessed the influence of a defender on the JS (Gorman & Maloney, 2016; Van Maarseveen & Oudejans, 2018). In 12 highly skilled male basketball players aged 17.8 ± 1.1 years, the influence of a defender was examined on the performance of several types of shooting (Gorman & Maloney, 2016). Results showed that contested shots (M = 0.99 s) were performed significantly faster ($p < 0.01$) than uncontested shots (M = 1.08 s). Besides, the jump time was significantly longer ($p < 0.01$) in defended conditions (M = 0.43 s) compared to that observed in the undefended conditions (M = 0.40 s). The ball flight time was also longer in defended conditions (M = 0.96 s) than in undefended conditions (M = 0.83 s). Regarding efficacy, the percentage was significantly lower ($p < 0.01$) in defended conditions (M = 41.1%) compared to undefended conditions (M = 63.9%) (Gorman & Maloney, 2016).

In the second study, the effect of the presence of a defender on jump-shooting was evaluated among 13 talented young female basketball players aged 16.8 ± 1.8 years. Authors have assessed the percentage of efficacy, the ball's trajectory, the total time of shot execution and the gaze behavior during the shot performance as well (Van Maarseveen & Oudejans, 2018). Results showed that the ball trajectory was longer in contested (M = 1027 ± 69 ms) than in uncontested shots (M = 994 ± 55 ms) ($p < 0.01$). Contested shots were also performed faster (M = 817 ± 82 ms) than uncontested shots (M = 896 ± 100 ms) ($p < 0.01$). Moreover, the percentage of efficacy was almost similar between both conditions, with 52.2% efficacy in the contested shots and 51.3% of efficacy in the uncontested ones ($p = 0.85$) (Van Maarseveen & Oudejans, 2018). On the other hand, the gaze behavior was studied using eye-tracking glasses and video recording to compare the duration and the onset of the final fixation on the rim before the ball release. In this particular study, a "fixation" was defined as a gaze maintained on a specified location (e.g., the rim) for a period equal or superior to 100 ms or three sequential frames. Overall, the final fixation on the rim was shorter and occurred later on contested (M = 364 ± 191 ms) than in uncontested condition (M = 443 ± 221 ms) ($p = 0.39$). Furthermore, the authors also reported differences in the gaze behavior between the highly skilled players and their counterparts. While the highly skilled players' gaze behavior was not affected by the defender's presence, players who shot with less efficacy with a defender also presented shorter final fixations on the rim than their highly skilled peers (Van Maarseveen & Oudejans, 2018).

Visual information

Regarding visual information available, the first study in 17 male participants aged 18.8 ± 0.6 years composed of ten intermediately skilled and seven highly skilled basket- ball players, the "quiet-eye" (QE) functionality was compared between a defended and undefended condition (Klostermann et al., 2018). Authors reported that successful shots performed by highly skilled players in defended game situations were associated with longer QE durations (M = 452 ± 43.3 ms). In comparison, unsuccessful shots were related to shorter quiet eye duration (M = 349 ± 54.4 ms). The same results were found for the intermediate-skilled players, with longer QE durations being found for scored shots (M = 431.9 ± 36.8 ms) compared with missed shots (322.8 ± 47.3 ms) in defended condition. As expected, the shooting performance was significantly higher in the undefended (M = 65.6 ± 16.1%) than in defended situations (M = 44.5 ± 14.2%) ($p < 0.01$) (Klostermann et al., 2018).

The second study was based on an intervention with goggle training between six adolescent male basketball players aged 17 years. Participants were submitted to 8 weeks of visual control training where they only had a vision during the final 350 ms before the moment of ball release (Oudejans et al., 2002). Besides, players had screen training sessions, where they had to shoot behind a screen where they could barely see the top of the small rectangle on the backboard. This intervention aimed to manipulate the vision so that participants could only see the basket during the final instances before ball release. Results showed that participants submitted to the training sessions had extended the last fixation duration when shooting with late vision. This suggests an increase in their ability to pick up relevant information during the final instance before ball release. Moreover, the shooting percentages were compared between the pre-intervention period (M = 46.1 ± 10.2%) and post-intervention period (M = 60.6 ± 12.1%), showing an improvement of almost 15% of the game percentage of efficacy after the intervention ($p < 0.05$). On the contrary, the control group's efficacy was maintained practically constant, with 42.5 ± 3.7% on the pre-intervention period and 42.2 ± 3.6% on the post-intervention ($p < 0.10$) (Oudejans et al., 2002).

3.5. Discussion

This paper aimed to identify which game-related conditions could influence the JS performed by youth basketball players and describe their effect on the motor action used. Our detailed analysis of the empirical research suggests that the JS is influenced by (i) distance to the basket, (ii) fatigue, (iii) presence of a defender and (iv) visual information available.

Shooting efficiency and efficacy have been considered by coaches and basketball players, substantially affected by distance to the basket (Liu & Burton, 1999). Several authors have investigated the influence of the shooting distance on the JS performance by experienced players through two- and three-dimensional kinematic analyses (Miller & Bartlett, 1996; Miller & Bartlett, 1993; Nakano et al., 2020; V. H. A. Okazaki & Rodacki, 2012). Consensually, literature mentions lower angles and higher velocities at the moment of ball release when the distance to the basket is increased (Knudson, 1993). In our research, only one study evaluated the ball release variables when the shooting distance was increased (V. H. A. Okazaki et al., 2013). The inverse relationship between the angle and velocity mentioned on literature was also reported in boys aged 12.1 ± 1.4 years (V. H. A. Okazaki et al., 2013). However, it seems essential to develop more studies related to the ball release variables (height, angle and velocity) mainly to compare the variation of those variables between adults and youngsters. Due to their accumulated experience, adult players should be more able to coordinate the motor action and to accomplish a successful shot.

Additionally, basketball-shooting literature mentions higher maximum angular velocities of the shoulder and elbow joints in longer shots (Miller & Bartlett, 1996; Miller & Bartlett, 1993; V. H. A. Okazaki & Rodacki, 2012). This conclusion is in line with the results reported on youth basketball players, both in top-level male players aged 15.4 ± 0.5 years (Podmenik et al., 2017) and intermediate-skilled boys aged 12.1 ± 1.4 years (V. H. A. Okazaki et al., 2013). For the elbow and the shoulder joints, an increase of almost 300°/s in the maximum angular velocities was found in a group of 14 top-level U16 male players when the JS performance at 3.75 m was compared to 6.75 m (Podmenik et al., 2017). There was also an increase in the elbow's and shoulder's angular velocity in a younger population when the performance at a shorter distance (2.8 m) was compared with the performance at a longer distance (6.4 m). Indeed, at longer distances to the basket, players need to adapt their body segments to generate a greater impulse to shoot, since the ball's trajectory will be longer (V. H. Okazaki et al., 2015). Thus, joints' angular velocities tend to increase, and the angles formed by the body's segments tend to decrease as a way to create an appropriate impulse to shoot (González-Fimbres et al., 2015; Miller & Bartlett, 1993; V. H. Okazaki et al., 2015).

Meanwhile, in boys, significant differences were also detected in the body's horizontal displacement when the performance at a shorter distance (M = 0.35 ± 0.02 m) was compared with the longer distance (M = 0.49 ± 0.03 m) (V. H. A. Okazaki et al., 2013). The horizontal displacement seems to be accentuated by the increased distance to the basket. However, highly skilled shooters have been observed to have a less horizontal shift in their CoM than their less-skilled peers (Knudson, 1993). Thus, it should be expected that a more significant horizontal displacement may be observed in inexperienced performers as youngsters, mainly due to the higher impulse created to shoot when the distance to the basket is increased.

The angles formed by the joints have also been used on the assessment of the shooting motor action. In girls aged 10–11 years, authors reported the decrease in the mean values of the angles formed by the elbow, shoulder and knee joint when the performance at a shorter distance (2 m) was compared with the performance at a longer distance (6 m) (González-Fimbres et al., 2015). In fact, in the knee joint's particular case, the minimum knee flexion value is a good indicator of the squat movement performed during the shot's preparatory phase, which will have a significant repercussion on the jump phase. Therefore, it is expected that lower values of knee flexion should be observed when players' aim to jump more to achieve longer ball trajectories.

In another study with U16 and U18 male and female players, differences between 2- and 3-point shots were reported on the entry angle of the ball when approaching the rim and on player's shooting speed (Vencurik et al., 2021). The 2-point shots presented lower entry angles of the ball and were performed faster. The entry angle of the ball represents a main criterion for successful performance, since as the entry angle increases, the width of the basket increases as well (Miller & Bartlett, 1993; V. H. Okazaki et al., 2015). In this study, the authors did not report data concerning the ball release parameters (angle, velocity and height). However, previous studies have shown that the ball release angle tends to decrease at longer shooting distances (Elliott & White, 1989; Miller & Bartlett, 1996; Miller & Bartlett, 1993; V. H. A. Okazaki & Rodacki, 2012). For that reason, it would be expected that lower entry angles of the ball in the rim were reported in 3-point shots when compared with the 2-point shot, since greater values of the angle of release should generate greater values of the entry angle as well (V. H. Okazaki et al., 2015). Players showed lower shoulder angles at ball release in the 2-point shot performance, which should explain the lower entry angles of the ball. On the other hand, the need to create a higher impulse to shoot from longer distances justifies the faster performance of the 2-points shots when compared with the 3-point shots.

In sports literature, fatigue has been recognized as an adverse variable for game performance (Supej, 2009). In youth basketball, the 2-point and the 3-point performance in fatigued and non-fatigued conditions were examined through the percentage of efficacy (Ardigò et al., 2018; Padulo et al., 2018). The maximal HR measurement was used as a fatigue indicator. In both situations, the most significant decrease in the shot's success was reported at 80%HR when compared with a rest condition (0%HR). Although there was a decrease in the efficacy rate at 50%HR when compared to the rest condition (0%HR), it did not significantly impact the performance. Considering these results, it seems that efficacy is only seriously compromised at higher fatigued conditions. However, the percentage of efficacy is still not enough to comprehend the motor action, since it only represents the shot's output.

Certainly, fatigue is widely considered a modifier of the kinematic of various sports- related movements (Slawinski et al., 2018; Supej, 2009). Only two studies on the JS were found on young basketball players on the JS performance's kinematic assessment in fatigued conditions. A case-study developed with a member of the Croatian U18 Men's National Team showed a significant decrease in the mean values of the maximum angular velocities of the shoulder and wrist joints in fatigued conditions in 3-point shots performance (Rupčić et al., 2020). On the other hand, the maximum angular velocities of the lower extremities increased in a fatigued state. The height of ball release was the only release parameter that showed significant differences across conditions, with lower values being observed in a fatigued state (Rupčić et al., 2020). Although these data are concerned to only one individual, it could be assumed that even with the reorganization of the body's behavior in response to accumulated fatigue, the ball release parameters stayed mostly unaffected.

Meanwhile, after a protocol of repeated sprints and jumps, the 3-point shot was evaluated in a group of ten elite male basketball players aged 16.3 ± 1.2 years (Slawinski et al., 2018). At 88% of the maximal HR, no significant differences were detected in the joint angle's movements or the ball release parameters when the non-fatigued condition was compared to the fatigued state. Unfortunately, no percentages of efficacy were reported in both situations. However, it could be assumed that efficacy was not seriously compromised by fatigue, since the performance of the motor action did not differ significantly. It must be referenced that only elite youth players were involved in this study, who seem to be able to cope with physical fatigue while performing coordinated movements such as the 3-point shot (Slawinski et al., 2018). The lack of studies and the different backgrounds of the players and methods used to assess fatigue demand additional research on the topic, since some of the results founds are contrary. Once fatigue has been recognized as an adverse variable for game performance, more information on the subject brings greater input for the organization of training sessions.

Indeed, elite players should be more capable of performing a coherent motor action even through several game-related conditions, including the presence of a defender or restricted visual information available. The players' field of view is often affected by defenders' and teammates' positioning, representing a dynamic system (Klostermann et al., 2018). In precision tasks, such as basketball shooting, a gaze behavior labelled QE has been found to explain differences in motor expertise. The QE is defined as a fixation or tracking gaze located on a specific object or location in the environment (de Oliveira, Oudejans, & Beek, 2008; Klostermann et al., 2018; Oudejans, Koedijker, Bleijendaal, & Bakker, 2005; Vickers, Vandervies, Kohut, & Ryley, 2017). The presence of a defender while shooting represents a severe constraint for the JS performance, mostly constituting an obstacle for the target (basket) visualization. In youngsters, authors described the contested shots as faster, with long jump phases and longer ball trajectories (Gorman & Maloney, 2016; Van Maarseveen & Oudejans, 2018). This behavior has also been observed in adult expert players (Rojas et al., 2000) and should be related to the shooter's strategy to avoid the defender's interception (Gorman & Maloney, 2016; Rojas et al., 2000).

On the other hand, other studies have mentioned that expert players are able to extract relevant information earlier than their less-skilled peers (de Oliveira et al., 2008). This allows them to select and execute appropriate motor responses more accurately (Klostermann et al., 2018; Vickers et al., 2017). In fact, successful jump- shooting performance has been associated with the players' ability to pick up relevant information during the final instance before ball release (de Oliveira et al., 2008; Oudejans et al., 2002; Vickers et al., 2017). After being submitted to eight weeks of shooting with late vision training, six adolescent male basketball players aged 17 years have extended the final fixation duration during the jump-shooting (Oudejans et al., 2002). In addition, an improvement of efficacy percentages during the competition was also observed in comparison to the control group. Authors have found that visual control training can change the temporal pattern of shooting and improve performance by enhancing information detection timing (Oudejans et al., 2005).

Similar results were reported in highly-skilled youth players, who did not show significant differences in the gaze behavior or the percentage of efficacy when shooting against a defender. On the contrary, intermediate-skilled players shot worst with a defender (less efficacy) and presented shorter final fixations on the rim than their highly skilled counterparts (Van Maarseveen & Oudejans, 2018). This result all together brings important practical implication on the training process, since the position on the court of the teammates and defenders during gameplay is extremely dynamic, which will impact the shooter's field of view.

To the best of our knowledge, this is the first study developed to explore the JS motor action's performance in the early stages of basketball's long-term development. Most of the previous studies have so far been focused on expert or adolescent highly skilled participants. Moreover, the percentage of efficacy has been widely used as the primary indicator of shooting success, which fails to provide adequate feedback for the shooter's improvement. Thus, the kinematic variables' analysis emerges as fundamentally relevant to understand the performance adjustments needed according to game-related conditions. The few studies eligible for this review represent a limitation. However, aggregating all available empirical work on this topic represents a strength of this paper. It emphasizes the need for future investigations on this topic. Since the early stages of basketball's long-term development are crucial to the specific motor skills acquisition and, consequently, for players to achieve successful performance at elite levels, it is fundamental to understand the best strategies for skill improvement already at younger ages. Therefore, future research should be developed in youth, particularly with a focus on the comprehension of the motor action, which could be achieved through the assessment of the kinematic parameters.

3.6. Conclusion

Our detailed analysis of the body of empirical evidence suggests that in youth basket- ball, the JS performance is influenced by distance to the basket, accumulated fatigue, presence of a defender and visual information available. There are intra- and inter-individual differences in the motor action performance due to players' characteristics, such as previous sports experience and as a response to game-related conditions. Critical practical implications for players and coaches have emerged from this review, in particular the need to promote dynamic shooting training situations that should be matching the game reality.

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CHAPTER IV: STUDY 2

A kinematic analysis of the basketball shot performed with different ball sizes

Reference: França, C., Gouveia, É. R., Coelho-e-Silva, M. J., & Gomes, B. B. (2022). A Kinematic Analysis of the Basketball Shot Performed with Different Ball Sizes. *Applied Sciences*, *12*(13), 6471.

4.1. 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 in 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 each ball size: a smaller and lighter ball (Size 5, 480 g); and the standardized ball size for their age (Size 6, 566 g). No statistically significant differences were observed for ball release variables and efficacy levels. A significantly greater shoulder flexion was detected at release while shooting with ball size 6 ($F = 2.982$, $p \leq 0.01$). The shoulder’s angular velocity at release was significantly lower while performing with ball size 6 ($F = 3.089$, $p \leq 0.01$). No significant differences were found for the elbow and knee angles or angular velocities. Stature and upper-body strength were significantly correlated with selected kinematic parameters. Ball’s size manipulation might be a helpful strategy for coaches to promote optimal shooting patterns, enhancing effectiveness and enjoyment, particularly among youngsters and more inexperienced players.

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

4.2. 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 (Jose Arias, Argudo, & Alonso, 2011). 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 (Jose Arias et al., 2011; Porter & Magill, 2010). Moreover, the quality of the contextual conditions enhances the enjoyment and prevents premature dropout (Buszard, Reid, Masters, & Farrow, 2016; Chase, Ewing, Lirgg, & George, 1994).

The basketball shot (BS) is considered a fundamental sport-specific skill (V. H. Okazaki, Rodacki, & Satern, 2015; Miriam Satern, 1988). 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" (V. H. Okazaki et al., 2015). The technique is supposed to be taught by coaches and learned by youth players based on fundamental principles from biomechanics (Liu & Burton, 1999; Miriam Satern, 1988). 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 (V. H. Okazaki et al., 2015).

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 (José Arias, 2012; Chase et al., 1994; Milovanovic, Pazin, Mrdakovic, Erculj, & Jakovljevic, 2020). 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 (Jose Arias et al., 2011). In parallel, one study did not provide evidence of any benefit for shooting performance when youth participants were exposed to manipulated equipment (Milovanovic et al., 2020). 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 (Podmenik, Leskošek, & Erčulj, 2014). 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 (José Arias, 2012; Chase et al., 1994; Milovanovic et al., 2020; Podmenik et al., 2014).

Although efficacy is the central aspect of basketball games, it is crucial to understand the mechanisms that underlie performance (França, Gomes, Gouveia, Ihle, & Coelho e Silva, 2021). The analysis of kinematic parameters may be relevant, particularly for youth players and coaches (França et al., 2021; Miriam Satern, 1988). Several studies used kinematic parameters to evaluate BS performance, considering variations associated with distance from the basket (Elliott & White, 1989; Miller & Bartlett, 1996; Miller & Bartlett, 1993; V. H. A. Okazaki & Rodacki, 2012; Vencurik, Knjaz, Rupcic, Sporis, & Li, 2021), presence of opposition (Gorman & Maloney, 2016; Rojas, Cepero, Ona, & Gutierrez, 2000), and induced fatigue (Slawinski et al., 2018). 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 (V. H. A. Okazaki & Rodacki, 2005; MN Satern, Messier, & Kellermcnulty, 1989). 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 (Podmenik et al., 2014). 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 (Jose Arias et al., 2011; Porter & Magill, 2010). 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 (Jose Arias et al., 2011). 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.

4.3. Methods

Participants

The current sample comprises twenty-seven female adolescent basketball players aged 12.1± 0.9 years (height: 153.3 ± 8.0 cm; body mass: 48.8 ± 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.

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 (Harriss, MacSween, & Atkinson, 2019). 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.

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 (Olds, Carter, & Marfell-Jones, 2006).

The percentage of predicted adult stature attained was calculated as an indicator of the maturity status using the Beunen–Malina–Freitas method (Beunen et al., 2011). Information regarding menarche was collected through an appropriate questionnaire.

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.

Shooting

Participants completed a 15-minute 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 segments: 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; on the head of the fifth metatarsal to define the foot (V. H. A. Okazaki & Rodacki, 2012). A single investigator placed all landmarks on the participant's dominant side.

Each participant performed 10 BS trials from a frontal position at 5.75 m from the basket with each ball size: a smaller and lighter ball (Wilson MVP Size 5, 480 g); and 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. A second investigator was responsible for filming each BS attempt with a digital camera (Sony Cyber-Shot RX100, 120Hz) 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 (Miriam Satern, 1988): (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").

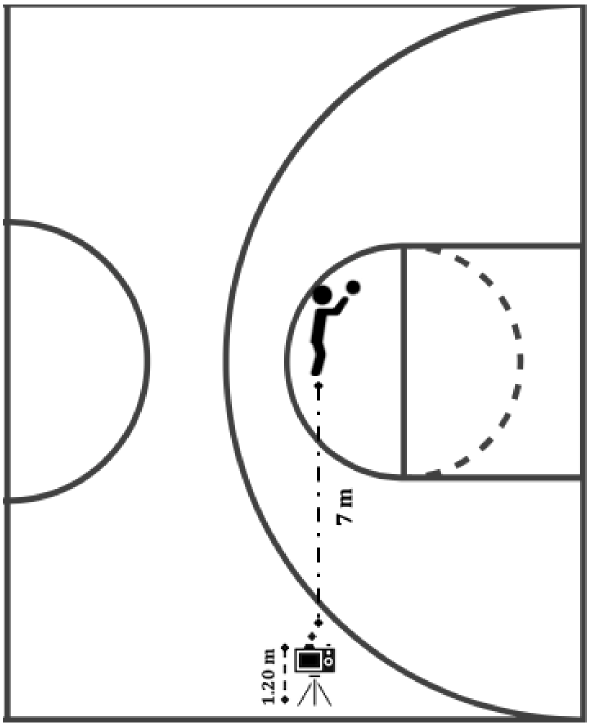

Figure 1. Schematic representation of data collection.

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. 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) (Brewin & Kerwin, 2003; Pourcelot, Audigié, Degueurce, Geiger, & Denoix, 2000), 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 among ten female basketball players aged 14.7 ± 0.6 years. From 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), 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 center 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 angles 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 (Uygur, Goktepe, Ak, Karabörk, & Korkusuz, 2010). 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. For the ball release angle, it was considered a line between ball release and the ball 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. 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. After, the CoM of the several 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 (Grimshaw, Fowler, Lees, & Burden, 2007).

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 (Cohen, 2013): $d<0.2$ (small), $0.2\leq d<0.6$ (moderate), $0.6\leq d<1.2$ (large), $1.2\leq d<2.0$ (very large). The Pearson product-moment correlation coefficient was used to assess the relationship between the kinematic variables, CA and basketball experience, anthropometry (stature, percentage of predicted stature, 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%.

4.4. 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 4.1. 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 4.2 summarizes descriptive statistics and MANOVA results. The efficacy level was very similar between shooting conditions (ball size 5: 1.7 ± 0.6 points; ball size 6 (1.7 ± 0.5 points). No significant statistical differences were observed for ball release variables (angle, velocity, and height). However, the mean ball release velocity was greater, and the mean ball release angle was lower in shots performed with the ball size 5. The CoM's 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 ball size 6, the differences were not statistically significant ($F = 0.541$, $p = 0.47$, partial eta squared = 0.010). Overall, the peak of joints' angular velocities was greater while performing with ball size 6, but with no substantial differences. At release, the shoulder angular velocity was significantly lower in shots with ball size 6 ($F = 3.089$, $p \leq 0.01$, partial eta squared = 0.256). Similar angular velocities at ball release were observed for the elbow and knee joints.

Table 4.2. Descriptive statistics and MANOVA results to examine mean differences for kinematic variables obtained in the 5.75 m basketball shooting with ball size 5 and ball size 6 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	º	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	º	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	º	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	º	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	º	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	º	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	º	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	º	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	º	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	º/s	1162 (1087 to 1237)	189	1175 (11094 to 1256)	204	0.056	0.81	0.001
Shoulder release angular velocity	º/s	716 (604 to 828)	277	637 (532 to 743)	267	3.089	≤ 0.01**	0.256
Elbow peak angular velocity	º/s	833 (764 to 903)	166	860 (791 to 930)	192	0.304	0.58	0.006
Elbow release angular velocity	º/s	583 (529 to 637)	136	580 (526 to 634)	145	0.006	0.94	0.000
Knee peak angular velocity	º/s	561 (504 to 618)	139	608 (552 to 664)	152	1.413	0.24	0.026
Knee release angular velocity	º/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 kinematic parameters analyzed, anthropometry and fitness variable. In Tables 4.3 and 4.4 are presented only the significant results of the Pearson-product correlation coefficient according to the ball size used. While shooting with ball size 5, the 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 the 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 ball size 6, the ball release height also presented the highest number of relationships. Stature ($r = 0.63$, $p \leq 0.01$) and body mass ($r = 0.71$, $p \leq 0.01$) remained with the stronger and positive relationship with ball release height. In contrast, the CMJ emerge with 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 a significant and negative relationship with the ball release angle.

Table 4.3. Significant results according to Pearson-product coefficient correlations between selected kinematic parameters while performing with ball size 5, 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; CMJ (countermovement jump); r (Pearson coefficient).

Table 4.4. 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; CMJ (countermovement jump); r (Pearson coefficient).

4.5. Discussion

This study aimed to investigate the variation in kinematic parameters in the BS performed with different ball sizes among adolescent female basketball players. Overall, slight differences were observed in the body segments' organization and behavior. The ball release variables were not significantly different between shooting conditions, which contributed, contrary to what was expected, to a similar efficacy level 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 ball size 6; consequently, the ball release velocity had slightly decreased in that shooting condition. Both shoulder and elbow joints' angular velocities were lower at the release point while performing with ball size 6, which should explain the lower ball release velocity. At ball release, as velocity decreases, the angle is expected to increase since both variables have been characterized by an inverse behavior (Knudson, 1993; Miller & Bartlett, 1993; V. H. Okazaki et al., 2015; V. H. A. Okazaki & Rodacki, 2012). 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 applying other procedures in basket height and ball sizes used, the authors also reported a greater value of ball release angle and lower ball release velocity when shooting with a heavier ball was compared to a smaller one (MN Satern et al., 1989).

The mean of ball release height was very similar between shooting conditions. Since the literature mentions 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 (Knudson, 1993; V. H. Okazaki et al., 2015), these results would be expected. Greater shoulder flexion was observed at ball release in shots performed with ball size 6, which is a significant influencer of ball release height. Previous research in boys aged 10.0 ± 0.5 years shooting free throws also reported greater shoulder flexion while shooting with the heavier ball size (V. H. A. Okazaki & Rodacki, 2005). However, in our study, the elbow extension at release remained alike, and the CoM’s variables indicate no differences in the shot’s jump phase between shooting conditions, which should justify the values of ball release height.

Regarding joints' angular velocities, no statistically significant variation was observed except for the shoulder at ball release. Due to greater shoulder flexion, the angular velocity at release was lower while shooting with ball size 6. Although with no substantial differences, the peak of joints' angular velocities was higher in shots performed with ball size 6. This behavior was also observed in boys (V. H. A. Okazaki & Rodacki, 2005). It could be assumed that participants adapted the impulse created to shoot according to the ball's size and weight. At the same distance to the basket, a greater impulse could 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 ball size 6. Indeed, the minimum angle reached by the knee joint reflects the squat movement performed before the shooting jumping phase. Consequently, it allows us to understand better the type of impulse produced to shoot. However, past data on joints' behavior during the BS motor action is still lacking, making it difficult to compare to previous results.

Meanwhile, strength has been described as a crucial capacity to generate 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 (V. H. Okazaki et al., 2015). 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 considering 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 was found between ball release height and stature (Knudson, 1993). Body mass also emerged with a strong and positive relationship with ball release height ($r = > 0.71 < 0.77$), which should be 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 joints' peak angular velocities. Strength should contribute to generating ball velocity, and if velocity increases, the angle at ball release should decrease, which should justify the negative correlation between the 2 kg ball throw and the ball release angle. Thus, upper-body strength appears as an important predictor of ball trajectory. In contrast, the CMJ was significantly and negatively related to the ball release height. It would be expected a linear and positive correlation between both variables; 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 (Malina, Bouchard, & Bar-Or, 2004). Overall, our results underline upper-body strength as a crucial variable for the shooting motor action performance, as previously suggested in the literature (Elliott & White, 1989; V. H. Okazaki et al., 2015). Also, it might contribute to raising awareness among sports agents and coaches for promoting the strength development in the basketball training process as part of the shooter's improvement.

The overall assessment of the kinematic parameters shows a slight variation of the shooting motor action performance 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 (Miller & Bartlett, 1993). 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.

Results of the current study have important practical implications for those working with youngsters 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 the shooting performance. Therefore, the BS teaching process may not be limited to the standardized rules regarding ball size and weight for the 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. Besides, the relationship between the handgrip and the 2 kg ball throw with the selected kinematic parameters indicates a crucial contribution of upper-body strength to the motor action performance. Sports agents and coaches should consider strength development as part of the basketball training, particularly for shooting improvement among female youth players. Nevertheless, future research is still needed to profoundly the relationship between the players' characteristics (anthropometry and functional capacities). Besides, future work investigating the long-term effect of ball size variation on the shooting action of youngsters may prove to be more informative.

5.6. Conclusion

In this study, some kinematic adjustments emerged in the BS performance while shooting with two different ball sizes. The shoulder extension and angular velocity at ball release have significantly decreased when performing with ball size 6, 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 joints' peak of angular velocities (elbow and knee). In the early stages of basketball long-term development, the ball's size manipulation may be a helpful strategy for sports agents and coaches to promote optimal shooting patterns, enhancing effectiveness and enjoyment among youngsters.

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CHAPTER V: STUDY 3

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

Reference: Franca, C., Gouveia, É. R., Coelho-e-Silva, M. J., Gomes, B. B., & França, C. (2021). A kinematic analysis of the basketball shot performance: impact of distance variation to the basket. *Acta of Bioengineering and Biomechanics*, *24*(1).

5.1. Abstract

Purpose: The current study aimed 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.

Keywords: youth, motor action, female, biomechanics, strength.

5.2. Introduction

The basketball shot (BS) is considered a fundamental motor skill and the most used shooting technique in the basketball game (V. H. Okazaki, Rodacki, & Satern, 2015; Satern, 1988; Vencurik, Knjaz, Rupcic, Sporis, & Li, 2021). The BS learning and teaching processes are supported by a reference movement pattern, which emerged from basic biomechanics principles (Knudson, 1993; V. H. Okazaki et al., 2015). 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 (V. H. Okazaki et al., 2015). 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 (Ibáñez et al., 2008).

Meantime, 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 (Elliott & White, 1989). 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 (Liu & Burton, 1999). Indeed, efficacy is consensually assumed as the main discriminant between winning and losing teams (Csataljay, James, Hughes, & Dancs, 2013; Ibáñez et al., 2008). However, the ratio between scored and missed attempts limits the feedback needed for the shooter's improvement, particularly among youngsters and more inexperienced 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 (Miller & Bartlett, 1993).

Motor abilities play an important role in determining the players’ long-term development (Buśko, Pastuszak, Lipińska, & Gryko, 2017). 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 (Miller & Bartlett, 1996; Miller & Bartlett, 1993; Podmenik, Supej, Čoh, & Erčulj, 2017). The study of the ball trajectory is defined by the angle, velocity, and height at ball release (Miller & Bartlett, 1996; V. H. Okazaki et al., 2015) 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 ±3.4º and 68.7 ± 3.3º, 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 (V. H. A. Okazaki, Lamas, Okazaki, & Rodacki, 2013). 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 ± 10.6º and 78.9 ± 8.8º, and velocity ranged between 4.39 ± 0.36 m/s and 6.89 ± 0.62 m/s (V. H. A. Okazaki & Rodacki, 2012). In females, lower mean angle and velocity at release was observed (angle: 52.8 ± 4.1º to 52.1 ± 3.7º; velocity: 6.60 ± 0.40 m/s to 7.90 ± 0.30 m/s) (Elliott & White, 1989).

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 (V. H. A. Okazaki & Rodacki, 2012; Podmenik et al., 2017; Vencurik et al., 2021). 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 (França, Gomes, Gouveia, Ihle, & Coelho e Silva, 2021). 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 should present less strength and power than their male counterparts (Susman et al., 2010), 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 where to look for (Satern, 1988) and to encourage consistency on the acquisition of the shooting action (Elliott & White, 1989).
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.

5.3. Methods

Participants

Participated in the study 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. 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 (Harriss, MacSween, & Atkinson, 2019). 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, 120Hz) positioned in the sagittal plane at 7 m from the participant's dominant side, 1.20 m from the floor (Figure 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.

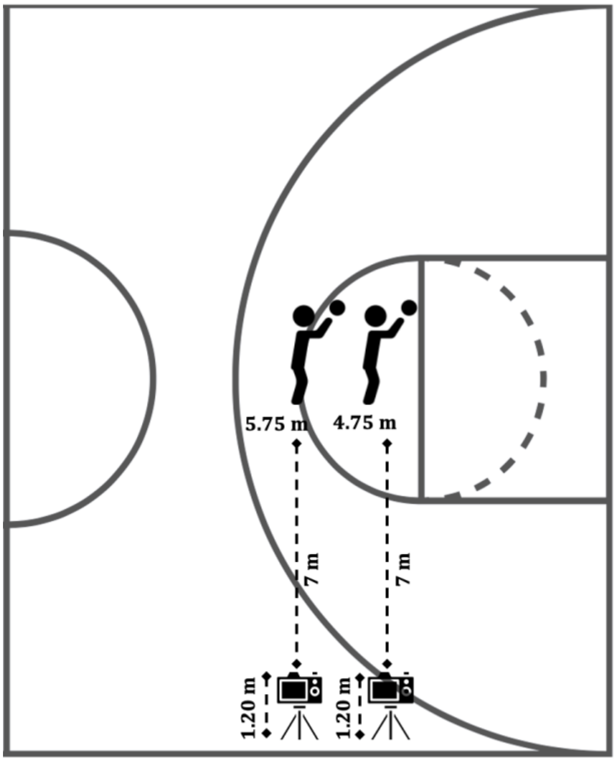

Figure 5.1. Schematic representation of data collection with variation of the shooting distance.

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 (V. H. A. Okazaki & Rodacki, 2012). 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) (Brewin & Kerwin, 2003; Pourcelot, Audigié, Degueurce, Geiger, & Denoix, 2000), 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 among 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 (Uygur, Goktepe, Ak, Karabörk, & Korkusuz, 2010). 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 in 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 (Grimshaw, Fowler, Lees, & Burden, 2007).

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 if needed, were corrected.

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; and 3) the follow-through phase, identified immediately after ball release to landing (Satern, 1988). 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 d-Cohen as follows (Cohen, 2013): $d<0.2$ (small), $0.2\leq d<0.6$ (moderate), $0.6\leq d<1.2$ (large), $1.2\leq d<2.0$ (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 (Pallant, 2013).

5.4. Results

Descriptive statistics on chronological age (CA) and anthropometry are presented in Table 5.1. Except for CA, all variables fit the assumption of normal distribution.

Table 5.1. Descriptive statistics of female adolescent basketball players (n=27).

Variable	unit	Mean value	Mean (95% CI)	SD	Shapiro-Wilk value	Shapiro-Wilk *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); $**p \leq 0.01$

Table 5.2 summarizes descriptive statistics and paired t-test results for the shooting efficacy, movement duration, and ball release variables. 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, $p \leq 0.01$, d = 0.46), and in the velocity (t = -115.437, $p \leq 0.01$, d = -1.70). The ball release angle decreased at longer shots, and the ball release velocity increased. The mean of ball release height was comparable between shooting distances, with no significant differences observed.

Table 5.3 presents the descriptive statistics and paired t-test results for the kinematic parameters related to the shooter. 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).

Table 5.2. 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).

	Descriptive statistics				Mean comparisons		
Variables	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 (º)	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* ≤ 0.01

Table 5.3. 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 (º)	111 (107 to 115)	10	109 (105 to 113)	11	-11.060	≤0.01**	0.24
Elbow							
release angular position (º)	159 (155 to 162)	10	158 (154 to 162)	11	-0.447	0.66	-0.04
Knee							
minimum angular position (º)	114 (110 to 119)	11	111 (108 to 114)	9	3.364	≤0.01**	0.34
release angular position (º)	170 (168 to 172)	6	170 (167 to 172)	7	0.774	0.45	0.08
Shoulder							
peak angular velocity (m/sº)	1114 (1029 to 1199)	214	1175 (1094 to 1256)	204	-2.958	≤0.01**	-0.52
release ang velocity (m/sº)	470 (420 to 520)	127	637 (532 to 743)	267	-5.164	≤0.01**	-0.81
Elbow							
peak angular velocity (m/sº)	795 (712 to 877)	209	860 (784 to 936)	192	-3.333	≤0.01**	1.42
release angular velocity (m/sº)	611 (550 to674)	157	580 (523 to 637)	145	2.783	≤0.01**	0.22
Knee							
peak angular velocity (m/sº)	532 (474 to 590)	146	608 (548 to 669)	152	-6.097	≤0.01**	-0.62
release angular velocity (m/sº)	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* ≤ 0.01

5.5. 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 would 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) (Miller & Bartlett, 1996; V. H. Okazaki et al., 2015). As velocity increases, the ball release angle decreases since the relationship between both variables is characterized by an inverse behavior (Knudson, 1993; V. H. Okazaki et al., 2015). 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 (V. H. A. Okazaki & Rodacki, 2012) and female (Elliott & White, 1989) basketball players, as well as in boys (V. H. A. Okazaki et al., 2013). 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 (Elliott & White, 1989). 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 3º lower compared to 4.75 m. In experienced basketball players, females showed variation in the deepest knee flexion of 1º, and males presented a variation of 2º (Elliott & White, 1989; V. H. A. Okazaki & Rodacki, 2012). In boys, differences in the deepest knee flexion derived from the increase of the shooting distance were approximately 10º (V. H. A. Okazaki et al., 2013). The data suggest the contribution of the lower body on the BS performance, particularly to produce velocity at ball release.

Meantime, 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 (Elliott & White, 1989). 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 (Alexander & Hayward-Ellis, 2016). For that reason, this movement has been related to the ball release height (V. H. Okazaki et al., 2015). In our study, the shoulder angular position at the point of release ranged between 109 and 111º, while in boys, results varied between 101 and 111º (V. H. A. Okazaki et al., 2013). Both male (128–137º (Miller & Bartlett, 1993); 118 –122º (V. H. A. Okazaki & Rodacki, 2012)); and female experienced basketball players (107.3-113.8º (Elliott & White, 1989)) 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 (Elliott & White, 1989; Miller & Bartlett, 1993; V. H. A. Okazaki & Rodacki, 2012). In contrast, boys presented more significant elbow extension when performing at increased distances from the basket (V. H. A. Okazaki et al., 2013). 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 (Alexander & Hayward-Ellis, 2016).

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 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 (Knudson, 1993). 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 (Alexander & Hayward-Ellis, 2016). Indeed, efficacy should be improved with a more stable base (Knudson, 1993). 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 (Elliott & White, 1989).

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.

5.6. Conclusion

The slight increase of 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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CHAPTER VI: GENERAL DISCUSSION AND CONCLUSIONS

This section summarizes the main findings and contributions of the studies conducted. Additionally, a reflection on the consequent practical applications and future research suggestions is presented.

6.1. Ball release variables

The study of the ball trajectory is defined by the angle, velocity, and height at ball release. Thus, the analysis of the ball release variables was a crucial point in our research.

Distance from the basket

Previous literature has mentioned a direct and inverse relationship between the angle and velocity at ball release (Knudson, 1993). Lower velocities have been associated with higher angles at ball release and vice-versa (Miller & Bartlett, 1993; V. H. A. Okazaki & Rodacki, 2012). The angle-velocity relationship is crucial for efficacy. The ball release angle is related to the angle of entry of the ball through the rim of the basket (Miller & Bartlett, 1996). Increasing the angle of entry of the ball into the basket increases the width of the basket, and consequently, the possibility of success (V. H. Okazaki et al., 2015). A study conducted among male and female players from the under-16 and under-18 age categories compared the angle of entry of the ball into the basket between successful and unsuccessful 2-point and 3-point BS. The authors observed that successful attempts presented a higher mean of entry angle than unsuccessful attempts (Vencurik et al., 2021).

The angle of entry of the ball is associated with the ball's vertical and horizontal displacement. A greater ball release angle will allow a more significant ball vertical displacement. On the other hand, the ball's horizontal displacement is determined by the distance between the shooter and the basket (Miller & Bartlett, 1996; V. H. Okazaki et al., 2015). Therefore, longer shooting distances demands a greater velocity to overcome the greater horizontal displacement, which has been reported in previous empirical studies (Elliott & White, 1989; Miller & Bartlett, 1996; Miller & Bartlett, 1993; V. H. A. Okazaki et al., 2013; V. H. A. Okazaki & Rodacki, 2012; Satern, 1993).

However, the percentage of efficacy may be improved through lower ball release velocity (Knudson, 1993). Decreasing the velocity allows greater movement stability. The less variability of the body segments increases the consistency of the motor action performance. In experienced male basketball players, the percentage of efficacy was nearly 22% lower when shooting at 2.8 m distance than at 6.4 m distance (V. H. A. Okazaki & Rodacki, 2012). Besides, the authors reported the increase of ball release velocity from 4.39 ± 0.36 m/s to 6.89 ± 0.62 m/s. The comparison of the BS performance between 2.8 m and 6.4 m distances was also made among youth male basketball players aged 12.1 ± 1.4 years (V. H. A. Okazaki et al., 2013). Efficacy was evaluated using a point rating system and decreased significantly from the closer to the longer shooting distance. As expected, the ball release angle decreased (68.7 ± 3.3º to 57.9 ± 3.4º) while velocity increased (5.43 ± 0.16 m/s to 5.43 ± 0.16 m/s) from 2.8 m to 6.4 m.

Meantime, the literature points out the ball release height as a more stable variable since it is related to the shooter's stature and with the jump phase (Knudson, 1993; V. H. Okazaki et al., 2015). However, the effects of the increase of the shooting distance have also been observed at the ball release height. Both in experienced male basketball players and youngsters, authors described a significant decrease of the ball release height when shooting at 2.8 m was compared to 6.4 m (V. H. A. Okazaki et al., 2013; V. H. A. Okazaki & Rodacki, 2012).

Overall, our results corroborate previous findings on the effects of the shooting distance on motor action performance. The slight increase of 1 m in the shooting distance (4.75 m compared to 5.75 m) was enough to observe a substantial decrease in the ball release angle (60.4 ± 4.3º to 58.7 ± 3.2º) and a significant increase of the ball releasee velocity (6.98 ± 0.50 m/s to 7.63 ± 0.23 m/s). The difference in the ball release height between shooting distances was not statistically significant (1.92 ± 0.15 m to 1.90 ± 0.12 m). The percentage of efficacy decreased about 5% from the shorter to the longer shooting distance.

Ball size

The study of the ball trajectory associated with ball size manipulation is lacking. Only one previous study presented data concerning the angle and the velocity at ball release in free throws performed by boys aged 12.9 ± 0.1 years with two ball sizes (smaller and regulated size) (Satern et al., 1989). At ball release, both the mean angle (smaller ball size: 51.5º, regulate ball size: 50.5º) and the mean velocity lower (smaller ball size: 7.02 m/s and 7.00 m/s) were greater when performing with a smaller ball size. The differences between shooting conditions were not significant. However, in this case, the relationship angle-velocity did not follow the inverse behavior observed while shooting with the same ball size from several ranges. No data was reported in previous literature regarding the ball release height and the percentage of efficacy.

In our study, the results corroborate a greater ball release angle while shooting with the heavier ball size (smaller ball size: 57.7 ± 2.9º, standardized ball size: 58.7 ± 3.2º) followed by a decrease in the ball release velocity (smaller ball size: 7.74 m/s, standardized ball size: 7.63 m/s). The difference in the ball release angle was significant. On the other hand, the ball release height was slightly lower while shooting with the heavier ball size, and the percentage of efficacy did not differ between shooting conditions.

6.2. Body segments organization

Distance from the basket

The analysis of the joints' angular position and velocity allows understanding the body segments' organization and movement during performance. Indeed, the body movement defines the ball release variables and, consequently, the ball's trajectory to the basket (V. H. Okazaki et al., 2015).

At longer shooting distances, greater shoulder and elbow flexion during the ball release has been consistently reported in experienced basketball players (Elliott & White, 1989; Miller & Bartlett, 1993; V. H. A. Okazaki & Rodacki, 2012). However, in boys, greater elbow extension was observed when shooting at 2.8 m was compared to 6.4 m (141.8 ± 4.1º and 144.2 ± 5.2º). Our data among adolescent female basketball players also suggested greater elbow extension when the distance to the basket is increased. Indeed, the elbow extension has been defined as the beginning of the release phase (V. H. Okazaki et al., 2015). Besides, literature has pointed out the elbow extension as a crucial contributor to the ball release velocity (Knudson, 1993; Miller & Bartlett, 1993). The differences in the elbow positioning at ball release between experienced and youth basketball players, may be justified by the youngsters' physical characteristics, particularly their lack of strength. With the increase of the distance from the basket, youngsters must generate enough velocity to throw the ball to compensate for the longer trajectory.

Due to greater joints' flexion, the shoulders and elbow's angular velocity at ball release increases at longer shots (Elliott & White, 1989; Miller & Bartlett, 1993; V. H. A. Okazaki & Rodacki, 2012). However, our results showed a decrease of the elbow's angular velocity at the longer distance, probably since the elbow joint was near the full extension. Indeed, the coaching literature has advocated using full elbow extension at ball release to increase the ball release height and the ball release angle (M. Satern, 1988). Moreover, the ending of the BS motor action is characterized by the shooting elbow extended, the hand parallel to the floor, and the fingers pointing towards the basket (V. H. Okazaki et al., 2015).

Meantime, the analysis of the deepest knee flexion (transition from the first to the second phases of the movement) suggests a greater contribution of lower body strength to shoot at increased distances from the basket. Our results are supported by previous findings in experienced (V. H. A. Okazaki & Rodacki, 2012) and youth basketball players (V. H. A. Okazaki et al., 2013). The greater knee flexion observed resulted in higher knee angular velocity at ball release and increased the ball release velocity at longer distances. Due to their physical characteristics, youngsters are less able to generate the impulse needed to shoot. Therefore, the greater joints' angular velocity is required to compensate for the ball trajectory.

The literature also mentions a significant increase in CoM horizontal displacement at longer shots among experienced (Miller & Bartlett, 1996) and youth basketball players (V. H. A. Okazaki et al., 2013). Our results are in line with previous studies. Indeed, some horizontal motion is needed to shoot from longer distances. However, highly skilled shooters presented a minor CoM horizontal shift during the BS performance than their less skilled peers (Brancazio, 1981; Knudson, 1993). Therefore, it is intuitively assumed that the youngsters' inexperience and lack of strength to produce the impulse to shoot from longer distances justifies the substantial increase of the CoM horizontal displacement. The combined analysis of the joints' positions and the CoM displacement suggests a high movement variability during the shooting action of adolescent female basketball players at longer distances from the basket. The movement variability is common in novice players or children (V. H. Okazaki et al., 2015) and has a negative effect on efficacy (Knudson, 1993).

Finally, the maximum height attained by the hip confirms a greater vertical component of the jump phase at longer shots. The comparison of the hip height during release between shooting distances shows two key points: (a) despite the shooting distance, players tended to throw the ball at a similar point of the jump phase; and (b) the ball release not occurred before the peak of the jump phase. Indeed, previous research has suggested that the ball is released before the peak of the jump phase (Elliott & White, 1989; Miller & Bartlett, 1993; V. H. A. Okazaki & Rodacki, 2012). Probably, this strategy indicates the use of the vertical velocity of the body during the upward phase of the jump to increase the ball release velocity due to the lack of upper body strength (Elliott & White, 1989).

Ball size

The differences in the ball size, in terms of weight and circumference, were reflected in the joints' angular position and velocity. Greater shoulder and elbow flexion at ball release were observed while shooting with the smaller ball size. Consequently, both shoulder and elbow angular velocities were higher at ball release. In contrast, the deepest knee flexion and knee angular velocity during release were accentuated while shooting with the heavier ball size. Thus, the ball release velocity increase when shooting with the smaller ball size is mainly justified by the joints' movement of the shooting arm than by the contribution of the lower body.

The analysis of the CoM displacement showed a jump phase similar between shooting conditions. Overall, few movement variabilities were observed in the motor action performed, suggesting a more stable movement pattern. Also, the percentage of efficacy did not differ between shooting conditions.

Players' characteristics

The study of the relationships between CA, years of basketball experience, biological maturation, anthropometry, and the fitness tests, concluded that stature and the % of predicted adult stature attained are strongly correlated to the ball release height in all shooting conditions. These results corroborate the theory described in the past literature that stature is directly related to the height achieved by the ball during release (Knudson, 1993). Besides, the upper-body strength tests presented the highest number of relationships with the kinematic parameters independently of the shooting condition. Thus, it is believed that the development of strength during training sessions is crucial for the shooters' improvement, particularly among youngsters. Note that these were the first studies exploring correlations between the players' characteristics and the shooting action, limiting comparisons with previous research. Future work should address the detailed interrelationship between anthropometry, functional capacities, and motor performance, providing guidelines for designing the training process. Moreover, the role of biological maturation on the performance of basketball-specific skills based on the kinematic assessment is still unclear.

6.3. Limitations

The current Thesis presents limitations, such as the sample size, the lack of randomization on the shooting order, and the assessment of the kinematic parameters through a 2D analysis. The increase of the sample size would be more representative of the studied population. Moreover, a 3D analysis would be far more informative and precise on the data collection. However, considering that the data available on the BS performance among youth basketball players are lacking, it is believed that our results bring crucial practical implications for the ones involved in the early stages of basketball long-term development.

6.4. Conclusions and Practical Implications

Greater shoulder flexion and elbow extension at ball release were observed at longer shooting distances. The deepest knee flexion was accentuated, and the CoM horizontal displacement was substantially greater when the distance to the basket was increased. The joints' angular velocities at ball release were greater at longer shots, except for the elbow near the full extension. There was a substantial increase in the CoM horizontal motion during the jump phase. Besides, the ball release occurred before the peak of the jump phase. The kinematic adjustments previously mentioned emerged as a strategy to increase the ball release velocity to compensate for the more extended ball displacement to the basket. It is intuitively assumed that youngsters lack the strength to produce the impulse needed to shoot from longer distances. Consequently, the movement variability was higher and negatively affected the percentage of efficacy.

Regarding the ball size manipulation, greater shoulder and elbow flexion were observed while performing with the smaller ball size. Due to greater flexion, the shoulders and elbow's angular velocities were higher during the release. The increased angular velocities in the joints of the shooting arm contribute to a greater ball release velocity and lower ball release angle. No significant differences were observed in the jump phase due to the ball size variation, suggesting the performance of a more stable movement pattern. The percentage of efficacy was not affected.

Overall, our results bring crucial practical implications for the ones involved in youth basketball. The current game evolution demands the players' ability to shoot from long ranges with effectiveness. However, the percentage of efficacy limits the feedback needed for the shooters' development. Therefore, the knowledge of the dynamics that support motor action performance is decisive for coaches' feedback, particularly among youngsters. Besides, the early stages of basketball's long-term development are critical for learning and refining game-specific skills. In these stages, coaches should incentivize players to shoot from several close and mid-distance to the basket with a consistent movement pattern before increasing the shooting distance. On the other hand, it seems that the shooting action is not immediately affected by short-term changes in the ball size. Our results suggest a more stable movement pattern performance despite the differences in the weight and circumference of the ball used. Thus, the teaching and learning processes of the BS may not be limited to the standardized rules in terms of the ball size defined for a specific age group. Coaches may use the ball size manipulation according to the youngsters' physical features or level of basketball experience. This strategy could be helpful to promote optimal shooting patterns, enhancing efficacy and enjoyment among youth basketball players. Besides, the upper-body strength was pointed out as a critical factor for the shooting motor action. Coaches should consider strength development as part of the basketball training process, particularly to shooting improvement.

The contents of this Thesis bring new insights into the BS performance among adolescent female basketball players. However, the limitations previously mentioned should be considered in future research. The manipulation of the contextual constraints during the learning process of such a complex motor skill as the BS should be evaluated long-term. Besides, the interrelationship between the youngsters' anthropometry, functional capacities, and motor actions performance sill claims for future research. Youth basketball coaching would benefit from future work focused on the pathways for motor skill development.

6.5. References

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Appendix A: Informed consent

Folha de Informação ao Participante

Título do estudo: "Habilidades específicas no basquetebol jovem feminino: impacto da variação da distância ao cesto e do peso da bola na eficácia do lançamento em suspensão".

Investigadores responsáveis: Professor Doutor Manuel João Coelho-e-Silva, Professora Doutora Beatriz Branquinho Gomes, Professor Doutor Élvio Rúbio Gouveia e Professora Cíntia França.

Instituições responsáveis: Universidade da Madeira (Departamento de Educação Física e Desporto) e Universidade de Coimbra (Faculdade de Ciências do Desporto e Educação Física).

Finalidade do estudo: O presente projeto tem como finalidade a avaliação da eficácia do lançamento em suspensão através da avaliação dos parâmetros cinemáticos. O lançamento será realizado por jovens basquetebolistas, do sexo feminino, perante diferentes condições de execução.

Objetivos do estudo: (1) analisar, através dos indicadores cinemáticos, o padrão de movimento do lançamento em suspensão do basquetebol utilizado por raparigas com idades compreendidas entre os 11 e os 13 anos perante duas condições distintas: a) aumento da distância ao cesto; e b) variação do tamanho e peso da bola; (2) comparar, quantitativamente, os parâmetros cinemáticos que caracterizam a variabilidade intra-individual e inter-individual, utilizando como preditores a caracterização antropométrica e a avaliação das capacidades funcionais. Os dados gerados considerarão como variáveis dependentes a análise do produto (eficácia) e os parâmetros qualitativos do processo (ação do centro de gravidade do lançador; e a altura, ângulo e velocidade de saída da bola).

Procedimentos: Será aplicado a cada participante um questionário, entregue e preenchido em papel, de caracterização individual e da prática desportiva. A avaliação das capacidades físicas será realizada em contexto laboratorial (laboratório de Desporto e Educação Física da Universidade da Madeira) e/ou de pavilhão, sendo aplicados os seguintes testes: (1) lançamento da bola medicinal de 2kg e preensão manual no dinamómetro, para a avaliação da força dos membros superiores; (2) *squat jump* e *countermovement jump*, para a avaliação da força dos membros inferiores; (3) Teste T, para a avaliação da agilidade; (4) número de abdominais realizados em 60s, para a avaliação da força e resistência abdominal. Para completar o perfil individual do participante serão avaliados os seguintes parâmetros antropométricos: (1) altura; (2) altura sentado; (3) índice de massa corporal; (4) comprimentos e circunferências dos membros superiores e inferiores; (5) pregas de adiposidade. Todos os procedimentos são não-invasivos.

A recolha de informação para a avaliação dos indicadores cinemáticos procede-se através da recolha de imagens, sendo utilizada a filmagem em vídeo. Cada participante realizará, na totalidade, 40 lançamentos com variação da distância ao cesto e com variação do tamanho e peso da bola. As filmagens serão realizadas no contexto do pavilhão.

A recolha de dados decorrerá entre fevereiro e março de 2020. Todos os dados recolhidos nos questionários, observações e filmagens, serão processados de forma a preservar sempre o anonimato da sua educanda.

Requerimentos para a participação: A participação da sua educanda é voluntária. Caso a sua autorização seja concedida, importa referir que a sua educanda poderá desistir a qualquer momento sem qualquer tipo de consequência. A sua educanda é considerada elegível a participar neste estudo se cumprir com os seguintes requisitos: (1) idade compreendida entre os 11 e 13 anos; (2) sem lesões graves reportadas no último ano de prática desportiva; (3) ter, pelo menos, um ano de prática do basquetebol; (4) frequentar, pelo menos, quatro sessões de treino por semana; (5) estar inscrita como atleta federada na presente época desportiva.

Riscos: O risco associado à participação neste estudo é idêntico ao encontrado habitualmente nas sessões de treino semanais. Nenhum dos procedimentos propostos representa qualquer risco acrescido para a saúde.

Benefícios: A análise da informação recolhida permitirá o desenvolvimento de novas metodologias e estratégias de ensino do lançamento, derivadas do conhecimento do padrão motor utilizado por jovens atletas. A participação da sua educanda permitirá a elaboração de um perfil, com base nos registos dos testes físicos e antropométricos que será, posteriormente, facultado a cada participante. A análise das filmagens permitirá ainda, a caracterização do padrão motor utilizado pela sua educanda e uma melhor perceção sobre os aspetos que devem ser melhorados para uma maior consistência e eficácia do gesto técnico.

Confidencialidade: Esta investigação cumpre com as normas em vigor previstas para a proteção de dados. A confidencialidade dos dados da sua educanda será mantida da seguinte forma: (1) cada participante terá um número de identificação pessoal que permitirá manter o anonimato; (2) as informações pessoais dos participantes serão destruídas depois de finalizadas todas as análises previstas nesta investigação; (3) os dados recolhidos durante este estudo serão utilizados pelo grupo de investigação apenas para fins de investigação e publicados e/ou divulgados à comunidade científica. As informações pessoais da sua educanda nunca serão reveladas em qualquer publicação ou divulgação dos resultados da pesquisa. A recolha, gestão, organização de todos os dados recolhidos, será da responsabilidade dos investigadores: Professor Doutor Manuel João Coelho-e-Silva, Professora Doutora Beatriz Branquinho Gomes, Professor Doutor Élvio Rúbio Gouveia e Professora Cíntia França.

Ao autorizar a participação da sua educanda neste estudo, compreende e concorda que o grupo de investigação possa ser obrigado a divulgar o formulário de consentimento informado, dados e outras informações pessoalmente identificáveis, apenas se exigido por lei, regulação, intimação ou ordem judicial.

Direitos: A equipa de investigadores assume a responsabilidade pelo desenvolvimento do estudo e compromete-se a responder a qualquer dúvida existente. Para qualquer questão relacionada com a participação da sua educanda neste estudo, por favor, contacte a professora Cíntia França através de um dos seguintes meios: a) correio eletrónico - cintiarnf@gmail.com; e/ou b) telemóvel – 968517978.

CONSENTIMENTO INFORMADO, ESCLARECIDO E LIVRE PARA A PARTICIPAÇÃO EM ESTUDOS DE INVESTIGAÇÃO (de acordo com a Declaração de Helsínquia e a Convenção de Oviedo)

Manuel João Coelho-e-Silva, Beatriz Branquinho Gomes, Élvio Rúbio Gouveia e Cíntia França, investigadores principais do projeto intitulado "Habilidades específicas no basquetebol jovem feminino: impacto da variação da distância ao cesto e do peso da bola na eficácia do lançamento em suspensão" informaram, através da documentação anexa, os encarregados de educação da basquetebolista ____, sobre o procedimento geral do presente estudo, nomeadamente os seus objetivos, duração, finalidade, os requerimentos de participação e os riscos e benefícios associados. A possibilidade de desistência do estudo a qualquer momento e sem consequências para a participante, bem como as medidas que serão adotadas para a proteção dos seus dados pessoais de acordo com os regulamentos atuais, constam da informação em anexo.

Outorga(m) o seu consentimento para a participação do menor no referido projeto:

Senhor(a):____
Nº Identificação:____________________Validade: ______________ Assinatura: ____________________
Grau de parentesco (ou tipo de representação): ____________________ Data: ______________________

Senhor(a):____
Nº Identificação:____________________Validade: ______________ Assinatura: ____________________
Grau de parentesco (ou tipo de representação): ____________________ Data: ______________________

Participante: ____ Assinatura: _______________________
Nº Identificação:____________________Validade: ________________ Data:______________________

Professor responsável: Data: 05/02/2020