

Effects of Shooting with A Reduced Hoop Diameter Rim on Kinematics of a Basketball Free-Throw

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ABSTRACT

The purpose of this study was to determine the effects of a reduced rim diameter (diameter 0.30 m) upon the kinematics of basketball free-throws. Ten male basketball players (mean $\pm$ s; age 17.1 ± 0.4 years, height 1.85 ± 1.43 m, mass 79.0 ± 5.3 kg) performed 8 direct successful free throws; 4 when using a standard 0.45 m diameter rim, and 4 with an 0.3 m diameter rim. Ball release parameters and joint angles at ball release were determined for each participant. The smaller rim was associated with significant increases ($p < 0.0001$) in ball release angle, ball release velocity, ball release height and shoulder joint angle at release. The reduced diameter rim can be advocated as a tactic for developing a higher ball release angle when training the shooting technique of young basketball players; this is likely to maximize the probability of a successful free-throw when attempted into a standard rim.

Keywords: Angle of release, height of release, joint angle, velocity of release.

INTRODUCTION

Shooting is the most frequent technical action in basketball, and is the principal source of points in games [1]. Accurate shooting is thus a key factor in high performance [2]. A free-throw is awarded after a single foul penalty (International Basketball Federation, 2010). In this type of shot, the shooter must throw an official-sized ball (mass 0.56 kg to 0.65 kg; diameter = 0.24 m) from the free-throw line (4.6 meters from the backboard), through a horizontal 0.45 m hoop 3.05 m above the ground [3]. The free-throw should be one of the easiest shots in basketball [4], since it is performed without opposition.

Many basketball teams lose games by one to five points, with victory within reach if players had achieved success with six or seven of ten or more missed free-throws. Several authors [5-8], underlined that successful free-throws could be the deciding factor in winning or losing basketball games. Hays and Krause [9] and Mersky. [10] noted that free-throws accounted for 20 to 25% of all points scored. Kozar et al [11] further pointed that opportunities to shoot free-throws increase near the end of close games and converting these opportunities into points is crucial for success.

The likelihood of a successful free-throw depends on the skill of the shooter and particularly on the choice of an optimal trajectory [12], defined as one that increases the probability of a successful shot [13]. Characteristics of a free-throw include the angle, velocity and height of ball release [1,3]. A highly skilled shooter consistently reproduces the optimal angle-velocity-height combination [13-15]. The swish aperture decreases with entry angle [13]; a greater angle offers a wider aperture and a greater possibility of success [1,14,16]. Generally, players attempt a trajectory where the ball touches neither the hoop nor the backboard [4].

Previous suggestions of optimal release angle-release height combinations for successful free throws are summarized in Table 1; the most effective angles and heights seem in the range of 49.2° to 60° and 1.52 m to 2.44 m respectively.

Table 1. Predictions for release angle-release height combinations for successful free throws.

	Release angle (°)	Release height (m)
Mortimer (1951)	58	1.52
Brancazio (1981)	49.2	2.44
Hay (1994)	52 - 55	2.13
Hamilton and Reinschmidt (1997)	60	2.05
Gablonsky and Lang (2005)	52.0 – 56.6	1.52 – 2.21
Tran and Silverberg (2008)	52	2.13

Free-throw ability is a critical skill for basketball players [13,17], and trainers often require players to spend many hours practicing shooting drills [7,18]. Gablonsky and Lang [14] suggested using an insert to narrow the ring and thus allow such practice to develop shots that passed through the centre of the hoop. Rendell, Farrow et al [19] advocated an adapted ring with an additional 0.3 m diameter metal barrier. Others [20-22], also, have developed various devices to narrow the standard rim. However, their effects upon the kinematics of shooting have yet to be analyzed.

The aim of the current study was thus to assess the effects of using a 0.3 m diameter rim upon the kinematics of basketball free-throws. We hypothesized that the reduction of rim diameter would modify ball release parameters and increase the minimum angle of ball entry.

METHODS

Participants

Ten male basketball players (mean $\pm$ s; age 17.1 ± 0.4 years, height 1.85 ± 1.43 m, mass 79.0 ± 5.3 kg), volunteered to participate in the study. All of the proposed procedures had been approved by the Institutional Review Committee for the ethical use of human participants, in accordance with current national and international laws and regulations. Subjects gave their written informed consent after receiving both a verbal and a written explanation of the experimental design and its potential risks. They were informed that they could withdraw from the study at any time without prejudice to their sport involvement.

All participants had competed in the national basketball players' youth championship for at least 6 years; they were right-handed, free of injuries, and fell within the height range of 1.84 to 1.88 m.

Experimental Procedures

Standing height was measured using a wall stadiometer (Tanita, Ancona, Italy) and body mass was measured to the nearest 0.1 kg using an electronic scale (Seca, Hamburg, Germany). Other observations on a regulation indoor basketball court before pre-season training. The parameters examined were the angle, velocity, height at ball release and the corresponding angles at elbow, shoulder, trunk, knee and ankle joints. As with Miller and Bartlett [3] and Uygur et al [17], wrist angles were not examined.

In the first evaluative session, participants performed 15 minutes of warm-up exercises [8], and then practiced free-throw shooting for 5 minutes, using a standard [23]. Retro-reflective spherical markers of 5 mm diameter were attached by adhesive tape unilaterally on the right side of the body at the second distal phalangeal joint (right hand finger), styloid process of ulna (wrist) the lateral epicondyle of the humerus (elbow joint), the acromion process (shoulder) [24], pelvis (anterior superior iliac spine), the lateral epicondyle (knee), distal end of fibula (lateral malleolus), the heel of the shoe (calcaneus; at the same height above the plantar surface of the foot as the phalange marker) and at the 5th metatarsophalangeal joint [17]. Five 10 mm diameter markers were attached to the ball at the left and right medial-lateral axes, and at approximately 0.05 m from the right axis marker in three directions, thus forming a triangle [23]. Each participant performed free-throws using a standard rim until four successful shots had been accomplished where the ball did not touch either the hoop or the backboard [1,3,24].

Twenty-four hours later, a second evaluation was made, shooting into a 0.3 m diameter rim. Participants again performed a 15-min warm-up with standardised exercises [8] and then practiced free-throw shots until they were ready for data capture [23].

Determination of Minimum Entry Angle

We used the equation proposed by Hay [1]:

$$\sin \alpha = \frac{d^{ball}}{d^{rim}}$$

Where α = minimum angle of ball entry
 d^{ball} = diameter of ball (in meters)
 d^{rim} = diameter of rim (in meters)

Video Acquisition and Image Processing

Two fixed and synchronised cameras (Sony DVCAM DSR-300 PK, resolution PAL standard 720 x 576 pixels) were placed at 10 m, so that their optical axes were approximately horizontal, forming an angle of 90° with each other, and 45° with the horizontal plane axes of the calibration frame [3]. The cameras were started 3 s prior to each shot and the kinematics of placed markers were recorded at 50 Hz, until the ball had passed through the hoop [24]. A metal calibration frame with two vertical calibration poles formed a volume of approximately 7.0 m x 3.5 m x 1.5 m, sufficient to contain the shooter and the initial part of the ball trajectory. It was erected with its orthogonal axes parallel to and at right angles to the backboard. Trials were repeated until a successful attempt [3]. The total of 80 successful clean free-throws (4 free-throws to a standard rim plus 4 free-throws to a reduced rim x 10 participants) were analysed using data appropriate processing software (Regavi and Regressi, Mirelec, Coulommiers, France) [25]. The three-dimensional coordinate data were smoothed using a second-order low-pass filter with an 8-Hz cut-off frequency as determined from a residual analysis [27]. Ball release velocity was measured at the ball's centre of mass (midpoint between left and right axis markers). The instant of ball release was confirmed by the "breakpoint" where there was a rapid increase in the distance separating the second distal phalangeal joint from the right ball axis markers [23].

Statistical Analysis

Overall responses were analyzed using a one-way repeated measures analysis of variance. Statistical analysis was performed using SPSS (v.17.0 for Windows, SPSS, Chicago, IL, USA). Descriptive statistics are presented as means, standard deviations and ranges, the last being included to examine inter-individual differences in technique. Dependent variables at ball release were entry angle, velocity, height and joint angles at elbow, shoulder, trunk, knee and ankle joints. Intra-class correlation coefficients (ICC) for these selected test outcomes ranged from 0.88 to 0.96 [27]. Statistical significance was set at $p < 0.05$.

RESULTS

The 0.15 m reduction in rim diameter increased the minimum entry angle for a successful clean throw from 32.4° to 55.3°. This resulted in a 0.075 m decrease of the error margin in all directions when the ball passed through the center of the rim (Figure 1).

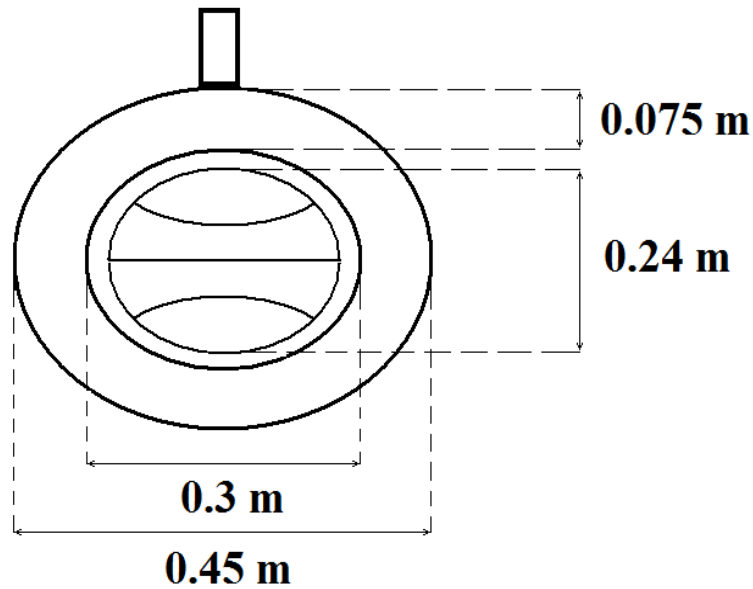


Figure 1: Drawing illustrating the diameters of the standard rim, the reduced rim and the basketball.

0.075 m = Decrease of ball error margin in all directions

0.24 m = Diameter of the ball

0.3 m = Diameter of the reduced rim

0.45 m = Diameter of the standard rim

Release parameters are summarized in Table 2. The release angle, the release velocity and the release height all increased significantly ($p < 0.0001$), from $51.8 \pm 2.7^\circ$ to $62.8 \pm 0.71^\circ$, from 6.76 ± 0.14 m/s to 7.39 ± 0.02 m/s and from 2.21 ± 0.03 m to 2.26 ± 0.02 m, respectively.

Table 2. Release parameters for clean successful free-throws performed in standard and reduced rims (mean $\pm$ s, min to max).

	Standard rim	Reduced rim
Release angle ($^\circ$)		
Mean	51.8 ± 2.7	$62.6 \pm 0.9^{***}$
Min	47.1	58.8
Max	56.3	63.9
Release velocity (m/s)		
Mean	6.76 ± 0.14	$7.39 \pm 0.02^{***}$
Min	6.54	7.31
Max	7.02	7.44
Release height (m)		
Mean	2.21 ± 0.03	$2.26 \pm 0.02^{***}$
Min	2.15	2.21
Max	2.26	2.31

*** Statistically significant difference between values of free-throws performed in standard and reduced rims at $p < 0.0001$.

There were no significant changes in angles at release for the elbow, trunk, knee or ankle joints (Table 3.), but the shoulder joint angle at release was increased from $137.1 \pm 3.0^\circ$ to $144.8 \pm 4.1^\circ$ ($p < 0.0001$).

Table 3. Joint angles at ball release for clean successful free throws performed in standard and reduced rims (mean $\pm$ s, min to max).

	Standard rim	Reduced rim
Elbow ($^\circ$)		
Mean	125.8 ± 7.8	128.1 ± 7.7
Min	119.1	120.7
Max	145.2	146.1
Shoulder ($^\circ$)		
Mean	137.1 ± 3.02	$144.8 \pm 4.1^{***}$
Min	133.2	138.1
Max	147.7	151.3
Trunk ($^\circ$)		
Mean	172.0 ± 2.9	172.6 ± 2.8
Min	164.9	167.3
Max	177.6	178.4
Knee ($^\circ$)		
Mean	165.8 ± 4.4	167.3 ± 4.6
Min	161.2	162.2
Max	176.7	178.3
Ankle ($^\circ$)		
Mean	71.5 ± 3.2	72.6 ± 3.7
Min	67.3	66.7
Max	77.6	78.6

*** Statistically significant difference between values of free-throws performed in standard and reduced rim at $p < 0.0001$

DISCUSSION AND IMPLICATIONS

The main findings in this study were an increased ball release angle, release velocity, release height and shoulder angle when practising free-throws with a narrowed rim.

Hay [1] investigated the relationship between the ball entry angle (incoming angle) and the surface of the ball passage through the rim (swish aperture), when performing a successful and clean free-throw. He concluded that the error margin decreased as the entry angle decreased, with a minimum entry angle of 32.4° for a standard rim. With the narrowed rim, the minimum entry angle was increased to 55.3° , and participants adopting release angles in the range 32.4° to 55.3° were thus advised to modify their shooting technique to give entry angles greater than 55.3° . When performing a clean shot, the ball release angle and the ball entry angle are positively related [16,28]; thus, participants who normally adopted release angles that gave entry angles of less than 55.3° were required to increase their release angles and consequently their release velocities.

The mean ball release angles observed when using the standard rim fell within the range seen by others [1,16,29] (Table 1). Hudson [30] compared release angles for players differing in skill,

finding values for poor, good and elite players of 52.9°; 52.5° and 52.7° respectively. Mullineaux and Uhl [23] investigated the kinematics and coordination-variability between missed and successful free-throws; the mean release angle was 49.8° for both successful and missed free-throws. Others have observed mean release angles with the standard rim that differ from the 51.8° that we observed [23,30]. This may reflect differences in ball release height.

The considerable increase in release angle seen with the reduced rim size could also be due to extraneous factors. Rojas et al [24] saw the ball release angle increase from 44.7° to 47.0° when performing jump shots in the presence of an opponent. They argued that this change reflected the reactions of participants to avoid interception of the ball by the opponents' hands.

In the current study, ball release velocity increased in parallel with ball release angle when using the narrowed rim. This is in accord with laws governing projectile motion. Indeed, as confirmed by several authors [1,14,16], the increase in release velocity is a direct result of the increase in release angle.

Ball release height also increased with the narrower rim. This increase may be due to changes in joint position, or it could result from the greater ball release angle, as several authors [31-34] have postulated a positive relationship between the two variables, reflecting a more vertical orientation of the arm at release. Hudson [30] was able to predict the skill of basketball players, based upon an analysis of free-throw biomechanics; he concluded that a greater height of ball release was related to a higher level of skill. Tran and Silverberg [12] also argued that basketball players should release the ball as high above the ground as possible, provided that this did not worsen launch consistency. Based upon these findings, we suggest that the increase of the ball release height developed when practising with the narrowed rim could enhance shooting technique.

Joint shoulder angles at release increased when performing successful free-throws with the narrowed rim. This could be related to the increased release angle. Miller and Bartlett [3] studied the relationship between basketball shooting kinematics, distance and playing position, commenting upon a parallel increase in ball release angle and in joint shoulder angle at release. Simultaneous increases of these two variables were also observed by Rojas et al [24], when studying kinematic adjustments to jump-shots performed against an opponent. It would seem that this same positive relationship applies to free-throws as well as to jump-shots [3,24].

Shooting at the reduced rim diameter resulted in higher release angles and velocities and consequently higher entry angles. This suggests that regular training with a narrowed rim could help in developing a higher release angle during normal play. Maintaining the kinematics learnt for a reduced diameter rim when throwing into a standard rim would allow a greater margin of error and a wider ball passing surface, determinant factors for a successful clean free-throw [1,16]. Moreover, the narrow rim would offer valuable training for inaccurate players whose principal cause of error is a low release angle [4].

Based upon the findings of the current study, we can conclude that training with a narrowed rim diameter typically increases the minimum angle of ball entry and often causes players to perform free-throws at greater release angles and velocities, likely with an improved accuracy. The ability to shoot with a greater release angle would also be beneficial in situations when

avoiding an opponent [24]. These observations point the need for controlled trials to determine, firstly the optimal extent of rim narrowing during training, and secondly how far the apparent benefits of such training actually enhance match performance.

CONCLUSIONS

A reduction in the size of the basketball rim leads to a considerable increase in the minimum ball entry angle for a clean free throw. Players practising with a narrowed rim are forced to modify their shooting technique by increasing ball release angle, ball release velocity, ball release height and shoulder joint angle at release. The reduced diameter rim may facilitate the free-throw training of young basketball players, and help those individuals who make inaccurate free-shots due to a low release angle. Further research is recommended to determine optimal narrowing of the practise rim and the impact upon match performance.

Limit of the study

The results of this current study are limited to a restraint number of participants. A further investigation would be preferable.

Acknowledgements

The authors appreciate all the athletes and coaches for their collaboration in this study.

Disclosure Statement

No potential conflict of interest was reported by the authors.

Funding

This research received no external funding.

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