A COMPARATIVE STUDY OF BIOMECHANICAL VARIABLES FOR A FREE THROW SHOOT PERFORMANCE IN STANDARD RIM VS REDUCED RIM CONDITIONS

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ABSTRACT

Background. Basketball coaches often refer to their teams' success or failure as a product of their players' performances at the free-throw line. **Objectives.** The aim of the study was to investigate and compare the effects of reducing the diameter of the basketball rim on the kinematic variables of the free throw shoot. **Method.** The sample comprised of five number of male basketball players from the University of Kirkuk between the age of 20 to 25 years and a mean height of 1.92 $\pm$ 0.085 meters. Eight free throw attempts were made by each player for this investigation and the successful shots were taken into consideration. For the first four attempts a standard rim of 45 cm diameter was used while for the latter four shots a reduced rim of 35 cm diameter was used. The player performance was recorded using High speed video cameras to record the kinematic variables, including the release angle, the ball to hand angle, the maximum ball height and the ball to rim entry angle. A special motion analyses software Kinovea was used to analyze and measure these angles. **Results.** The study implied that a smaller rim with reduced diameter implied steeper and more controlled, mechanism adaptations by the players for all the studies variables. The players implemented a more precise release angle which increased from mean of 52 degrees to 57.38 degrees. The hand to ball angle also showed a similar result with an increase from mean of 94.71 degrees to 102 degrees. It was also observed that there was a much reduced variation and a substantial improvement in the ball to rim entrance angle (32.90^{o} $\pm$ 5.29^{o} to 35.78^{o} $\pm$ 1.37^{o}, $p<0.001$), which indicates a much better precision in the approach trajectory. **Conclusion.** The study indicated that due to the systematic changes in the free throw biomechanics to be successful in a reduced rim condition, the players repeatedly used sharper entrance trajectories, higher arcs and more accurate release mechanics.

Keywords; free-throw shooting, reduced rim, kinematic variables, release angle, ball to rim angle, performance accuracy.

INTRODUCTION

Basketball coaches often refer to their teams' success or failure as a product of their players' performances at the free-throw line (Kozar et al., 1994). According to Ammar et al. (2016), in basketball, free throws are very important because they give teams the opportunity to score points without being challenged and often determine the outcome of closely contested games. Free throws account for almost 20% of all points in competition (Abdullah & Abdullah, 2025; Custodio et al., 2024; Haïdara et al., 2023). According to (Trninic et al., 2002) from 1992 to 2000, winning teams outperformed losing teams in the European Club Championships final events, making more free throws. According to Zuzik, (2011), in competitive games, 80% of games were won by the side with the highest percentage of free throws and as a result, the free throw line determines the outcome of many games [4].Together, these findings emphasize the importance of optimizing free-throw mechanics to enhance performance.

A substantial body of research has investigated the biomechanical and physical factors influencing free-throw success. In a research conducted by Barzykina, (2017) a physical model of shot success using empirical free-throw trials and Monte Carlo simulations was created which produced an analytical formula for the minimum launch angle and finds an angle-velocity space where free throws have a higher chance of scoring the algorithm identified the best release circumstances that increase the likelihood of scoring through incorporating player shooting tendencies, offering a measurable means of enhancing individual player performance. Release height, release angle, and release speed are the primary variables affecting shot success. Hamilton & Reinschmidt (1997) used computer simulations to model the ideal path for a basketball free throw.

The investigators discovered that the optimal release angle is around 60 degrees to increase the likelihood of a successful free throw. In order to ascertain the ideal release circumstances for a successful free shot, Tran & Silverberg (2008) undertook a number of simulations. The optimal release angle, according to research, is 52 degrees, and the release height is around 2.134 meters above the ground. Aim the ball toward the rear of the hoop to improve your chances of winning.

In his study on the mechanics of free-throw shooting, Professor John Fontanella looked at the connection between player height and the ideal release angle. In this study the ideal angle of launching the ball for a standard diameter for a 7 foot player is 48.7 degrees and for a 6 foot player is 51 degrees. The differences are a result of changes in the release height and the distance from the basketball rim (Fontanella, 2006). The mentioned studies highlight a crucial aspects which influence the effectiveness of free throw shots i.e. the release angle. The studies indicate that the angle at which the player releases the ball from their hand and the ability of the player to shoot influence success of the shoot.

In recent times many researches have also been conducted how the mobility patterns of players affect their shooting skills and mechanism. An anlysis of free throw and two-point jump shot mechanisms was conducted by Botsi (2024) which discovered biomechanical differences between the two. The study found that the entrance angle of the ball to the rim increases as the ball's angle increases. Hofer (1978), conducted a research in the past which used videography techniques to evaluate the path of the flifght of a basketball during a free throw attempt. The study established that the release angle and the ball to rim entrance angle is critical to the success of the free throw shot.

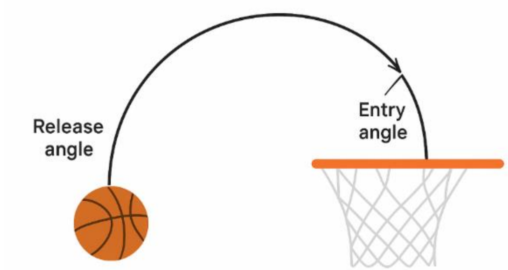

Fig. 1: A basketball shot's ball release angle and the angle at which the ball enters the basket are positively correlated. Generally speaking, an increase in release angle causes an increase in entrance angle.

Training studies have shown that performance can be enhanced through targeted practice. Since, the rate of success of free throw shoots are crucial for basketball players, a study was conducted by Olteanu et al. (2023) providing evidence that supports the implementation of specific training regimens to increase basketball professionals' free throw shooting proficiency. It backs up the notion that practice utilizing modern tools may lead to the establishment of sustainable shooting techniques, and are crucial for improving performance as a whole. Many Training aids that change task restrictions have been suggested as a way to enhance basketball shooting performance. Riepe & Riepe (1994) devised a practice rim that reduces the basket diameter compared to a standard basketball hoop such that its rim fits in perfectly with regular practice sessions.

Their research indicated regular practice with a smaller target can improve shooting accuracy when players return to a conventional hoop because the abilities developed under the more difficult conditions translate to the regular goal. Burkhardt (2009) Designed a new addition to basketball training equipment, rim attachment devices to reduce the effective diameter of the hoop and improve shooting accuracy. The device consisted of an insertion component that is fixed firmly to a standard rim and features many hooking holes that allow for a good fit and easy removal. They are often constructed from metals, rubber, polyurethanes, polyvinyl, and plastics. This provides a versatile way to adjust rim size, which is in line with previous research showing that altering the target's size may improve free-throw performance and impact shooting mechanics.

Quantitative framework is provided by a Kinetic analyses to understand the aspects related to mechanics of the performance. This form of the analysis optimizes the technique by identifying the critical kinematic variables (Manea et al., 2022). If we take a functional approach to the movement analysis focusing on the key motion elements which influence performance and it addresses the root cause of error rather than the visible effects 15. Manea & Uday (2024), in basketball, this approach can help coaches to refine shooting technique and the accuracy of the free throw shot.

The aforementioned researches lead us to believe that free-throw success is essential in basketball and that shooting accuracy may be enhanced by training aids that decrease rim diameter, suggesting that a smaller target may promote more optimal shooting mechanics. The purpose of this study is to examine how a reduced-diameter rim (0.35 m) affects free-

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throw kinematics—specifically release angle, hand–ball angle, maximum ball height, and ball-to-rim entry angle compared with a standard rim (0.45 m).

METHOD

Participants:

The samples consisted of five male basketball players from the University of Kirkuk with a range of age from 18 to 25 years old, who have obtained advanced ranks in interstate competitions in the country competition and the research sample was chosen by a deliberate method.

Table 1. Specifications of the research sample

Sr.	Player Name	Age (Years)	Height (cm)	Training age (Years)
1	Ammar Walid Mahmoud	24	185	10
2	Anas Ayad Muhammad	20	193	8
3	Sarmed Souad Hossam El-Din	22	202	9
4	Mustafa Farhad Hussein	25	180	8
5	Mustafa Azad Khurshid	22	194	11

Video Recording

The technical scientific observation was carried out using three cameras using the iPhone 16 Pro Max shoots video up to 4K at 120 fps (frames per second) for slow-motion, or 4K at 60 fps for regular video and 1080p at 240 fps. Two cameras were placed, for the purpose of recording the videos, one to record the ball entering the rim and another to record the players throwing the balls. The height of the player's camera (Camera 2 in the figure) from the side was 1.43 meters and the camera near the basketball rim is 3.05 meters high.

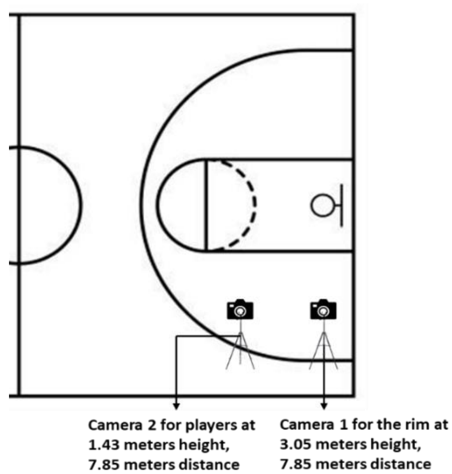

Figure 2. The scheme of the research experiment

RIM Description: A reduced basketball rim (35 cm diameter) was custom-fabricated by a local ironsmith from a standard hoop. The modified rim was securely mounted to the existing backboard, allowing controlled manipulation of target size while maintaining stability and safety during shooting trials.

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Data collection and analysis /Statistical analysis

Video recordings of the experimental trials were captured to document the motion of the basketball. Following this, the videos were analyzed using Kinovea motion analysis software to measure the movement and joint angles. Excel software was used for the statistical analysis using the applicable formulas.

Procedure

An outdoor basketball court was used for conducting the experiment with the objective of observing various biomechanical variables of the free throw shooting of under two conditions of a basketball rim of diameter 45 cm and reduced diameter rim of 35 cm. The variables that were analyzed were the ball release angle, hand – ball angle, maximum ball height and the ball to rim angle. These variables were selected based on previous studies conducted by Miller & Barlett (1996) & Uygur (2009) They emphasized on the relevance of these variables on the accuracy of the free throw shots. The experiment was divided into two sessions. In the first session, the participants performed five minutes of free throw practice under the standard rim conditions from the front.

Each participant was instructed to continue the free-throw attempts until four successful shots were obtained. The second session was conducted on the next day following the same warm-up, practice, and data collection methodology. In this session, the participants performed free throws using a reduced diameter rim (0.35 m). All recording procedures and camera configurations matched those of the first test conditions. The experimental set up included reduced rim (0.35 m), standard rim (0.45 m) and ten official size-basketball.

The data collected from the video recordings were used to measure the following angles using Kinovea motion-analysis software:

1. Release Angle: The release angle Amaro et al., (2025) represents the angular orientation of the ball's initial trajectory at the moment it leaves the shooter's hand. the exact frame in which the player's fingers lost contact with the basketball was identified as the release moment.
2. Hand to Ball Angle: The hand–ball angle describes the angular relationship between the shooter's hand/wrist orientation and the surface of the basketball at the moment of release. In Kinovea, anatomical landmarks on the wrist and hand were used to define the hand segment, while two visible contact points on the ball defined the ball segment.
3. Maximum Height: For measuring the maximum height, the highest vertical position achieved by the basketball during, its trajectory between the release angle and the rim contact (Caseiro et al., 2023). Using the Kinoveas' trajectory tracking feature, the ball's centroid was followed across the flight path. The Y-coordinate values were extracted, and the highest point was recorded as the ball's peak height.
4. Angle (degree) between Ball-to Rim: The ball to rim angle represents the angle of approach of the ball when it reaches the rim height – this is the angle at which the ball enters the basket at the point of score. Using Kinovea, the angle was measured between the tangent of the ball's downward trajectory and a horizontal reference line at the rim height.

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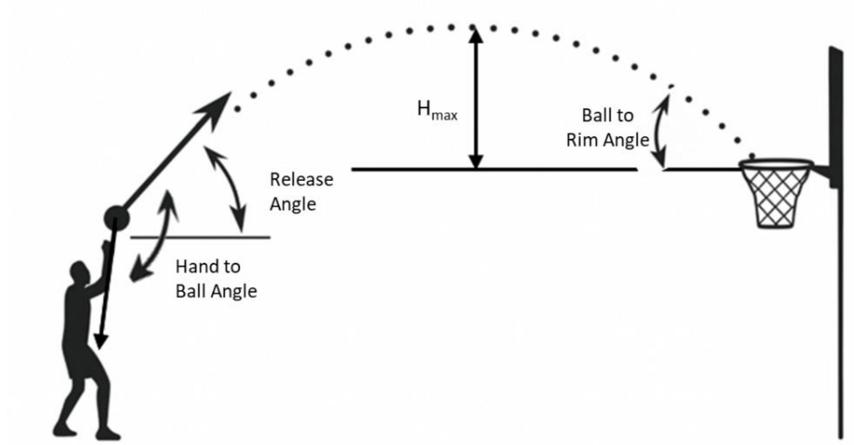

Figure 3. Minimum Entry Angles of a Successful "Clean" Free Throw in a Standard and in a Reduced Diameter Rim.

RESULTS AND DISCUSSION

Table 2. summarizes the descriptive statistical analysis of all kinematic variables under the Standard and Reduced rim condition across all four variables i.e. release angle, hand and ball angle, maximum height and ball to rim entry angle. The analysis showed that the reduced rim condition consistently yielded higher mean values than the standard rim condition.

Table 2. Data Analyses for Release Angle, hand to ball angle, Maximum height and ball to Rim Angle for free throws performed for a standard rim and in a reduced diameter rim

Sr. no.	Statistical Analysis	Standard Rim	Reduced Rim	T value	P Value
Release angle (deg.)	Mean	52.00	57.38	-23.98	p< 0.001.
	Standard Deviation	1.18	1.39		
	Variance	1.39	1.92		
	CV %age	2.27	2.42		
Hand and ball Angle	Mean	94.71	102.00	-14.53	p < 0.001
	Standard Deviation	5.30	7.65		
	Variance	28.07	58.56		
	CV %age	5.59	7.50		
Maximum height	Mean	3.27	3.62	–11.37	p < 0.001
	Standard Deviation	0.12	0.12		
	Variance	0.01	0.01		
	CV %age	3.61	3.20		
Ball to Rim Angle	Mean	32.90	35.78	-10.21	p < 0.001
	Standard Deviation	5.29	1.37		
	Variance	27.96	1.87		
	CV %age	16.07	3.83		

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Release Angle

The mean release angle increased from 52.00° (SD= 1.18) under the standard rim to 57.38° (SD=1.39) in the reduced rim condition. The increase in the mean angle was substantial even when the coefficient of variation was small (CV=2-2.4%). This indicates that the participants systematically adopted a higher release angle when shooting towards the reduced rim. The difference between the two variables was statistically significant, t (19) = -23.98, p<0.001. This indicates a highly consistent adjustment towards a higher release posture under the constraint i.e., the reduction of the rim size.

Hand–Ball Angle

The hand – ball angle also increased from 94.71° with SD = 5.30 to 102 ° with SD = 7.65 between standard and reduced rim conditions. The variability was higher under the reduced rim condition (CV = 7.50%), which suggests that the players made individual adjustments in the hand or the wrist orientation to achieve the required trajectory. The t-test results showed (t9190 = -14.53, p<0.001), suggesting that the players adjusted their hand positioning and the ball alignment to produce a more controlled and precise release.

Maximum Height

The maximum height increased from 3.27 meters with a standard deviation of 0.12 to 3.62 meters with a standard deviation of 0.12 as well. The CV was very low between 3- 3.6% in both the condition which indicates that the variable was consistent and the players produced a higher ball arc or trajectory with a reduced rim.

Ball-to-Rim Angle

The angle of the entry of the increased from 32.90° with a standard deviation of 5.29 to 35.78° with SD = 1.37. The variance decreased from 27.96 to 1.87, which indicates that under reduced rim condition, the players demonstrated much more consistent angles of approach. The variability under standard rim condition is much higher which implies more flexibility when the target is larger. Ball entry angle is significantly steeper with the reduced rim. The paired t-test showed a strong effect (t (19) =-10.21, p < 0.001), which indicates that players produced higher arcing trajectories to improve the likelihood of successful shots through a reduced size rim target.

Discussion

The results give a very clear indication that the players alter their biomechanics when they are performing in a restricted reduced rim condition. It was observed that all the kinematic variables were increased under a reduced rim condition, which indicates that the players adopt a more controller, steeper and higher trajectory when they have to shoot in a reduced basketball rim target. The players produce a higher arc on purpose which is due to the fact that there is an increase in the release angle and maximum height. This in turn increases the ball's vertical approach to the rim. This adaptation is a classic example of projectile motion theory. The subsequent ball to rim angle increase and reduced variation implies that the players aimed to improve the entry angle by making the shot trajectory steeper and more accurate (Khlifa et al., 2012).

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The hand and ball angle increase indicates that the wrist of the shooters and hand positioning was adjusted at the time the ball was released to generate a steeper arc. The higher CV in this measurement is suggesting that this approach was adjusted by each player in their own individualized manner, while still attaining a similar outcome which is in the release trajectory and ball trajectory.

In general, the findings exhibit that by reducing the rim diameter, the players have to make significant biomechanical adaptations. The players responded by increasing the angle at which the ball is released, making changes to the orientation of their hand and wrist and shooting the ball at a higher trajectory. Due to all these adjustments, a more controlled and precise ball entry angle, which asserts the theoretical needs for accuracy when the scoring area is reduced due to the reduction in the size of the rim.

CONCLUSION AND RECOMMENDATIONS

In this study it was proven that there is systematic and consistent biomechanical adaptations displayed by players shooting under a reduced rim conditions. When the players aim for a reduced rim target, they significantly adopt a more controlled and steeper shooting technique and with an observation that the release angle increased from $52.00^{o} \pm 1.18^{o}$ to $57.38^{o} \pm 1.39^{o}$ and the hand to ball angle rising from $94.71^{o} \pm 5.30$ to $102.00^{o} \pm 7.65^{o}$. The maximum trajectory height and ball to rim entry angles also display that there is a consistent upwards adjustment, which reflects that there was an adaptation of a refined release mechanism and the flight path to maintain accuracy. The above mentioned findings emphasized on the relation between the biomechanics of shooting to a reduction in the rim and support that using a modified rim size is a good training strategy. The reduced rim condition encourages higher arcs and more accurate ball entry angles which in turn enhances the shooting form and consistency of the players. Further studies should be conducted which would be focused on examining whether these biomechanical adaptations can be transferred to a game like scenario and whether long term training using a reduced rom can produce a more measurable improvement in a competition based shooting performance. The investigation offers many practical applications for sports players, practitioners and coaches. Training techniques can be optimized by understanding the differences in the release angle and hand-ball kinematics which can improve the player free throw shoot accuracy and performance. Coaches can use these observations to tailor individualized training programs which are focused on factors like the writ and hand position for grip mechanisms, timing and angle of the ball release and the positioning of the body to get steeper and higher ball trajectories. Additionally, modifications to the equipment i.e. standard vs. reduces rims can be evaluated for the impact they have on the performance and enabling more informed decisions during the training and competitive games. Overall, the study provides and actionable guideline to improve the skills, reduce injury risk and improve overall player performance.

Even though the study provides valuable insights, it also has several limitations. The size of the sample was relatively small, which affects the validity of the result to a broader set of population. The ball size and rim configuration limits the application to other equipment and sport settings. Also, the environmental factors like player psychology, fatigue and varying surfaces of the courts were not included in this research. The research should include a more diverse participant group, explore additional equipment variations and examine in depth long term adaptations to the training intervention. Further integration of motion capture with muscle activation techniques or biomechanical modelling can also provide a much deeper understanding on the underlying mechanism and how it influences the performance.

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