

# KINEMATIC DIFFERENCES BETWEEN PROFICIENT AND NON-PROFICIENT FREE THROW SHOOTERS – VIDEO ANALYSIS

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## ABSTRACT

*Despite its importance and significant contribution to the final game outcome, the free throw shooting motion is greatly understudied. The purpose of this study was to examine kinematic differences between proficient and non-proficient free throw shooters and to determine which variables have the greatest impact on successful free throw shooting performance. Thirteen healthy recreationally active males volunteered to participate in this study. Each participant shot three sets of ten consecutive free throws from the regulation distance from the basket. Each set was performed under 3 minutes with 1-2-minute rest between each set. A high-definition camera recording at 30 fps captured the free throw shooting motion from a sagittal point of view. Video analysis software was used to analyze the following kinematic variables: knee angle, elbow angle, hip flexion, ankle flexion, release angle, shoulder angle, hand release height, and elbow height. The findings of this study suggest that lower elbow positioning influenced by greater knee, ankle, and hip flexion during the preparatory phase of the shooting motion may lead to improvements in free throw shooting accuracy. Moreover, greater ball release height and release angle, as previously suggested, could decrease the margin of error and enhance free throw shooting performance. By using these kinematic variables to create the discriminant function projection model, it is plausible that proficient free throw shooters can be accurately classified in 94% of cases.*

**Key words:** basketball, sport, shooting technique, coaching

## INTRODUCTION

Basketball is one of the most popular sports worldwide. Quick pace of play, rapid changes in score, and high-skill movements make this game very attractive to a large audience. While scoring opportunities can emerge from various sources, free throw shooting has been an elementary contributor for over a century. Previous research found that free throw contributions to the overall number of scored points can range between 20-25% (Hays & Krause, 1987; Kozar et al., 1994, Merskey, 1987). Besides defensive rebounds and field goal percentage, successful free throw shooting performance is capable of distinguishing

between winning and losing teams (Csataljay et al., 2009; Trninić et al., 2002). It has been shown that free throw performance can be one of the major determinants for a regular season winning profile (Sampaio & Janeira, 2003). While offering further support to the previously mentioned findings, Kozar et al. (1994) indicate that successful free throw shooting performance might be even more critical during the last five minutes of game play. In a study analyzing the discriminating power of various aspects of basketball playing statistics within a cohort of professional basketball players, Sampaio & Janeira (2003) found that optimal free throw shooting performance for the away

games and number of committed fouls for the home games were major determinants for a successful game outcome. Considering that a large number of foul calls result in free throw shooting opportunities, especially during the end of each regulation period, we can realize how critical it is for each player to develop and maintain peak free throw shooting capabilities.

Despite its importance, the free throw shooting motion is greatly understudied. Previous research has mainly focused on estimating kinetic and kinematic requirements necessary for achieving optimal ball trajectory and release conditions that ultimately lead to successful free throw outcomes (Brancazio, 1981; Hamilton & Reinschmidt, 1997; Huston & Grau, 2003; Okubo & Hubbard, 2006; Tran & Silverberg, 2008). However, to date, there is little scientific literature addressing key kinematic characteristics during the preparatory phase of the free throw shooting motion that allows basketball players to achieve and satisfy some of the previously mentioned requirements. By using video analysis software, Nakai et al. (2018) examined free throw shooting kinematics and found that probability of a successful free throw shooting outcome is positively correlated with greater flexion in the knee joint. The researchers also found that inexperienced players tend to push the basketball from the chest area, while more experienced players manage to achieve greater release heights by positioning the ball in the front of the head (Nakai et al., 2018). These findings are similar to the findings of Tran & Silverberg (2008) who estimated a 5% increase in free throw shooting accuracy with every 0.152 m increase in release height above 1.981 m. In a study focused on examining kinematic differences between made and missed shots within a cohort of novice basketball players, Ammar et al. (2016) found that less flexion of

the knee during the preparatory phase of the shooting motion and greater extension at the time of ball release is associated with better free throw performance. The researchers also found that in relation to the total movement hand velocity was highly correlated with knee flexion, while the shoulder and hip angles had moderate contributions (Ammar et al., 2016). Mullineaux & Uhl (2010) conducted a similar study on a cohort of experienced collegiate basketball players. While no differences in wrist linear velocity were observed between missed and made free throws, the results revealed that elbow positioning had a significant impact on wrist shooting mechanics which could eventually impact optimal shooting performance (Mullineaux & Uhl, 2010). Hayes's (1987) findings reveal that the forearm, upper arm, and trunk have major contributions to ball velocity during the preparatory phase of the free throw shooting motion, although the majority of force during the propulsion phase necessary to push the ball towards the basket is attributed to the lower body. It has been estimated that hand contribution to ball velocity is the greatest at the time point of ball release, and rapidly increases during the last 0.15 seconds of the free throw shooting motion (Hayes, 1987).

While joint mechanics play an important role in proper execution of various sport specific motions, we need to be aware of individual differences during the preparatory phase of the free throw shooting motion. Many basketball players have their own shooting routines that might include, but are not limited to, a couple of stationary dribbles, ball movements, or certain body motions. Regardless of the routine type, in order for each player to achieve a successful shooting outcome, their free throw shooting movements need to satisfy the previously mentioned kinetic and kinematic requirements. Southard et al.

(1993) found that the actual rhythmicity of the routine movement is more important than the overall duration of the movement in determining a successful free throw shooting outcome. Behaviors that the players chose to incorporate as a part of a preparatory shooting technique need to be controllable and unchanged through different playing conditions (Southard et al., 1993). Moreover, findings by Gayton et al. (1989) reveal impairment in free throw shooting performance when subjects were prohibited from using their own preparatory routine. When implemented within a competitive environment, the shooting performance impairment seems to reach a greater magnitude (Gayton et al., 1989). Considering that the free throw shot is an uncontested scoring opportunity performed under no time constraints, it has been suggested that players should be allowed to perform their preparatory routine as long as it does not harm their shooting mechanics and impair the shooting percentage (Wrisberg et al., 1992).

Based on the previously mentioned findings, we can conclude that optimal free throw shooting technique requires full body contribution and is highly contingent on the summation of forces and appropriate sequential action of joints to provide the desired motion. Thus, being solely focused on analyzing kinetic and kinematic properties of certain body parts, even though they may seem to provide a greater kinetic or kinematic contribution, might not be an optimal approach to determine proper preparatory techniques necessary for optimal free throw shooting performance. Hence, the purpose of this study was to examine the difference in kinematic variables between proficient and non-proficient free throw shooters regardless of their preparatory shooting routines, and to determine which kinematic variables have the greatest impact on successful free throw shooting performance.

## METHODS

### *Subjects*

Thirteen healthy recreationally active male subjects (height =  $187.1 \pm 8.2$  cm, weight =  $89.3 \pm 6.7$  kg, age =  $27.5 \pm 6.4$  years) volunteered to participate in this research study. The participants were separated into proficient ( $\geq 70\%$ ;  $n=8$ ) and non-proficient ( $<70\%$ ;  $n=5$ ) groups based on their free throw shooting capability. Before the start of any testing procedures, subjects signed an informed consent form. Subjects with any musculoskeletal injuries were not permitted to participate in the study. All testing procedures performed in this study were previously approved by the University's Institutional Review Board.

### *Procedures*

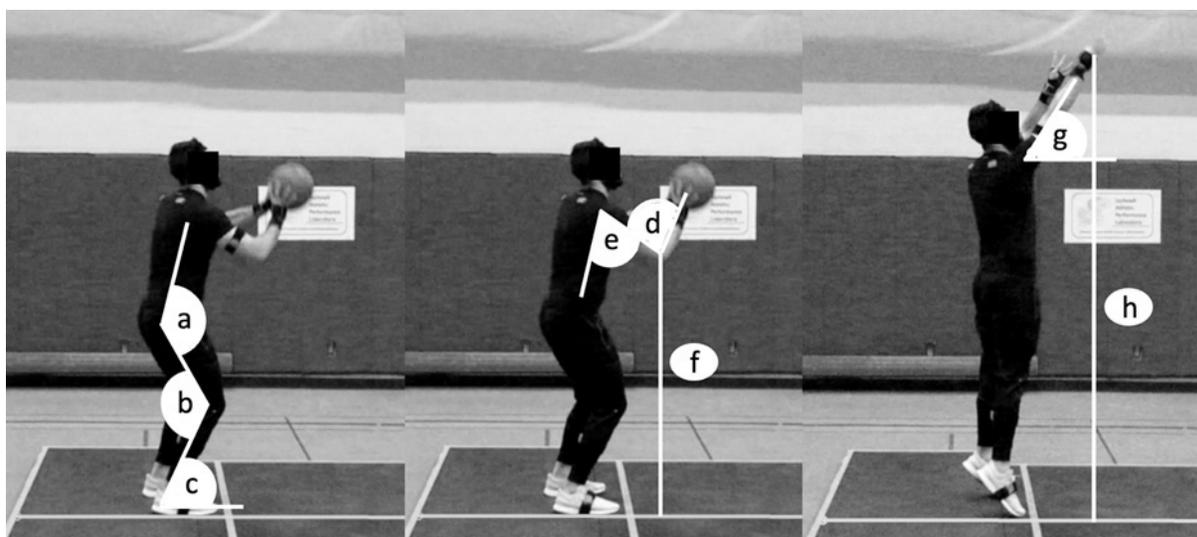
Upon arrival at the testing facility, subjects completed a standardized warm-up procedure consisting of a five-minute treadmill run at moderate intensity, and a set of dynamic exercises involving high knees, butt-kicks, lunge-and-twist, lateral slides, high skips, and lateral lunges. Each subject was individually familiarized with the testing procedures and equipment. A high definition camera (Canon PowerShot SX530) recording at 30 fps was used to capture the free throw shooting motion from a sagittal point of view. Video analysis software (Kinovea, Version 0.8.27) was used to analyze the kinematic data. The subjects shot three sets of ten consecutive free throws from the same regulation distance from the basket (4.57 m). Each set was performed under 3 minutes with 1-2-minute rest between each set. A rebounder was present throughout the whole testing procedure to preserve the subject's energy and permit optimum focus on free throw shooting form. To eliminate any kind of possible distraction, subjects individually performed the free throw shooting procedures. The basketball goal was positioned at a standardized

height of 10 ft (305 cm) while each subject was provided with a standardized size seven (75 cm) basketball.

### Variables

This study focused on observing seven kinematic variables estimated to be important predictors of proficient free throw shooting form. The *internal hip flexion* variable represents the magnitude of the internal angle between the torso and thigh at the initial concentric phase of the shooting motion (Figure 1a). The *internal knee angle* variable represents the internal angle between the thigh and shank at the initial concentric phase of the shooting motion (Figure 1b). The *relative ankle flexion* variable represents the angle between the shank and ground at the initial concentric phase of the shooting motion (Figure 1c). The *internal elbow angle* variable represents the

angle between the upper arm and forearm at the initial concentric phase of the shooting motion (Figure 1d). The *relative shoulder angle* variable is quantified as the angle between the upper arm and torso at the initial concentric phase of the free throw shooting motion (Figure 1e). The *relative elbow height* variable is the perpendicular distance between the elbow and the ground divided by subject's height at the initial concentric phase of the shooting motion (Figure 1f). The *relative release angle* variable is the angle formed between the fully extended arm and a line parallel to the ground at the time point of the ball release (Figure 1g). The *relative hand release height* represents the perpendicular distance between the wrist joint and the ground divided by the subject's height at the time point of the ball release (Figure 1h).



a) internal hip flexion, b) internal knee angle, c) relative ankle flexion, d) internal elbow angle, e) relative shoulder angle, f) relative elbow height, g) relative release angle, and h) relative hand release height.

**Figure 1.** Dependent variables examined in the study.

### Statistical Analysis

Descriptive statistics and standard deviations ( $\bar{x} \pm SD$ ) were calculated for each of the dependent variables. A multivariate Hotelling's *T*-squared test was used to determine the difference in the dependent variables be-

tween a group of proficient ( $\geq 70\%$ ;  $n=8$ ) and non-proficient ( $< 70\%$ ;  $n=5$ ) free throw shooters. A full-model discriminant function analysis was used to examine the magnitude of the relative contribution of each of the examined variables, as well as to determine the ability to

predict between proficient and non-proficient free throw shooters. Additionally, Hotelling's  $T$ -squared test was used to determine the difference in the dependent variables between made and missed shots within the proficient group of free throw shooters. Levene's test was used to test the homogeneity of variance assumption. Statistical significance was set a priori to  $p < .05$ . All statistical analyses were completed with SPSS Version 25.0 software statistical package (SPSS Inc. Chicago, IL, USA).

## RESULTS

Mean and standard deviations ( $\bar{x} \pm SD$ ) for all kinematic variables examined in this study are presented in Tables 1 and 2. The total number of free throw shots that subject performed was 390, from which 240 were performed by proficient and 150 by non-proficient shooters. To avoid violation of homogeneity of variance and assure equal sample sizes, 90 shots from the proficient group of shooters were randomly removed by SPSS software. Proficient free throw shooters had smaller internal knee angles, internal hip flexion, relative ankle flexion, relative release angle, relative

hand release height, and relative elbow height when compared to the non-proficient group of shooters (all  $p < .001$ ), while no difference in internal elbow angle and relative shoulder angle variables was observed ( $p > .05$ ). While all standardized discriminant function coefficients demonstrated moderate to strong magnitudes, the greatest factor in discriminating between proficient and non-proficient free throw shooters were relative elbow height, relative release angle, relative shoulder angle, and relative hand release height variables. All discriminant function standardized coefficient values are presented in Table 3, and classification results for predicted group membership are in Table 4. By using these kinematic variables to create the discriminant function projection model, 94% of cases were accurately classified as proficient or non-proficient free throw shooters. Additionally, while notable differences were presented between the proficient and non-proficient free throw shooters, no differences were found for the examined kinematic variables between missed and made shots within the proficient group of free throw shooters ( $p > .05$ ), see Table 2.

**Table 1.** Comparison of kinematic variables between proficient ( $\geq 70\%$ ;  $n=8$ ) and non-proficient ( $< 70\%$ ;  $n=5$ ) free throw shooters. The detailed graphical representation of the examined kinematic variables is presented in Figure 1

Dependent Variable	Proficient ( $\geq 70\%$ )	Non-Proficient ( $< 70\%$ )
Internal Knee Angle	101.1 $\pm$ 8.1	114.3 $\pm$ 5.9 *
Internal Elbow Angle	60.8 $\pm$ 7.5	61.1 $\pm$ 16.8
Internal Hip Flexion	126.5 $\pm$ 14.1	135.6 $\pm$ 6.0 *
Relative Ankle Flexion	52.6 $\pm$ 3.9	58.9 $\pm$ 5.2 *
Relative Release Angle	56.5 $\pm$ 6.3	58.6 $\pm$ 3.1 *
Relative Shoulder Angle	92.3 $\pm$ 19.8	92.6 $\pm$ 9.9
Relative Hand Release Height	1.15 $\pm$ 0.04	1.13 $\pm$ 0.03 *
Relative Elbow Height	0.68 $\pm$ 0.11	0.72 $\pm$ 0.05 *

\*significant difference ( $p < .05$ )

**Table 2.** Comparison of kinematic variables between made and miss shots within a group of proficient free ( $\geq 70\%$ ) throw shooters

Dependent Variable	Made	Missed
Internal Knee Angle	100.9 $\pm$ 8.2	102.4 $\pm$ 7.8
Internal Elbow Angle	60.8 $\pm$ 7.3	60.8 $\pm$ 8.8
Internal Hip Flexion	126.4 $\pm$ 14.1	127.0 $\pm$ 12.8
Relative Ankle Flexion	52.5 $\pm$ 3.9	53.2 $\pm$ 3.7
Relative Release Angle	56.3 $\pm$ 6.4	57.5 $\pm$ 5.9
Relative Shoulder Angle	92.1 $\pm$ 19.9	93.9 $\pm$ 19.5
Relative Hand Release Height	1.15 $\pm$ 0.04	1.15 $\pm$ 0.04
Relative Elbow Height	0.68 $\pm$ 0.11	0.68 $\pm$ 0.11

The detailed graphical representation of the examined kinematic variables is presented in Figure 1. No variables were significantly different ( $p < .05$ ).

**Table 3.** Standardized discriminant function coefficients, percentage of explained, and percentage of total variance for each of the dependent variables examined in this study

Dependent variables	Standardized coefficients	Percentage of explained variance	Percentage of total variance
Internal Knee Angle	.351	5.6	5.3
Internal Elbow Angle	.365	5.8	5.5
Internal Hip Flexion	-.219	3.5	3.3
Relative Ankle Flexion	.499	7.9	7.4
Relative Release Angle	1.017	16.1	15.1
Relative Shoulder Angle	-1.014	16.0	15
Relative Hand Release Height	-.981	15.6	14.7
Relative Elbow Height	1.860	29.5	27.7
Total		100	94.0

\*canonical correlation = 0.82 (effect size = 0.67)

**Table 4.** Classification results for predicted group membership for each free throw.

Actual Group	Predicted group membership		Number of cases
	Non-Proficient	Proficient	
Non-proficient	142 (94.7%)	8 (5.3%)	150
Proficient	10 (6.7%)	140 (93.3%)	150

\*94.0% of subjects correctly classified ( $p < .05$ )

## DISCUSSION

The findings of this study revealed significant differences in the kinematic characteristics between the proficient and non-proficient groups of free throw shooters. During the preparatory phase of the free throw shooting mo-

tion, the proficient group demonstrated greater knee, hip, and ankle flexion magnitudes when compared to the non-proficient group. Our findings are contradictory to the findings of Ammar et al. (2016) suggesting that less knee flexion was positively associated with superi-

or free throw shooting accuracy. Furthermore, findings by Hudson (1983) revealed no difference in trunk inclination between players with a high and low shooting ability, although trunk inclination is likely influenced by the degree of knee flexion. While being distinctively lower in magnitude and capable of distinguishing between proficient and non-proficient free throw shooters in the present study, the dissimilarities in the knee, hip, and ankle flexion variables disappear when comparisons are made between made and missed free throw shoots within the proficient group of shooters. Uygur et al. (2010) studied ten male collegiate basketball players and revealed similar findings. The researchers found no significant differences in the knee, hip, and ankle flexion between successful and unsuccessful free throw shooting attempts (Uygur et al., 2010). The inability to observe the differences in the previously mentioned kinematic variables stayed consistent even when fatigued (Uygur et al., 2010). Considering that collegiate basketball players presumably need to have a decent shooting percentage in order to qualify to play at that specific level of competition, their shooting ability may resemble the shooting percentage of the proficient group of shooters examined in this study. Thus, the inability to observe significant kinematic differences between made and missed free throw shots may be attributed to the performance characteristics in the cohort of the examined subjects, as well as the specific variables examined.

Upon conducting the full discriminant function analysis, the variable with the greatest distinguishing power between proficient and non-proficient free throw shooters was the relative elbow height. When adjusted for the subject's body height, our findings indicated that higher elbow placement during the preparatory phase of the free throw shooting motion was inversely associated with the shoot-

ing percentage. The lack of differences in the internal shoulder angle between the proficient and non-proficient groups of free throw shooters suggests that shoulder flexion was not the main cause for a decrease in the elbow height magnitudes during the preparatory phase of the shooting motion. Based on the previously mentioned findings, we can conclude that the lower elbow placement within the proficient group of free throw shooters was produced as a consequence of greater knee, hip, and ankle flexion. Despite accounting for a small percent of the explained variance, knee, hip, and ankle flexion influence is crucial for the optimal elbow positioning. Similar observations made by Hudson (1983) indicated that high and moderate skill free throw shooters were capable of attaining a lower center of gravity ratios, and further supports the intertwined nature of the free throw shooting kinematics. Moreover, previous research has indicated that free throw shooting is a complex motion that in many instances encompasses compensatory mechanisms that can ultimately influence the overall body kinematic changes (Schmidt, 2012). The major contribution of force production necessary to propel a basketball towards the basket during the propulsion phase of the shooting motion is attributed to the lower body and close to the ball release phase gradually transitioned to the upper body (Hayes, 1987). Therefore, we may assume that inadequate kinematics of knee, hip, and ankle can ultimately decrease the likelihood of successful free throw shooting outcome via kinematic compensations that may inhibit optimal upper body force production and transmission.

Along with elbow height, relative release angle and relative hand release height were the two variables with a considerable contribution to the overall free throw shooting proficiency prediction model. When compared to the non-proficient group of free throw shoot-

ers in the present study, significantly greater release heights and lower release angles were observed for the proficient group of free throw shooters. Our findings contradict the findings of Hudson (1983) who reported no difference in the angle of projection between high, moderate, and low skill free throw shooters. Moreover, it was reported that the release angle for the high skill group ranged between 46-60°, with a mean value of 52° (Hudson, 1983). Previous research, conducted with the purpose of theoretically estimating the optimal release angle, further supports the findings of Hudson (1983) and indicates almost identical release angles of approximately 52° (Huston & Grau, 2003; Tran & Silverberg, 2008). However, our findings for the proficient group of free throw shooters displayed slightly larger release angles. It was found that the mean release angle for the proficient group of shooters was 56.5° which was significantly lower when compared to the non-proficient group. Also, our findings regarding the height of the ball release agree with previous research findings suggesting that higher release heights may be positively associated with increases in free throw shooting accuracy (Tran & Silverberg, 2008). Basketball players with high free throw shooting capabilities released the ball at greater heights when compared to players with poor free throw shooting capabilities, regardless of their body size (Hudson, 1983). Moreover, it is interesting to note that the release angle displayed an inverse relationship with the hand release height variable. The results of this study show that proficient free throw shooters were capable of releasing the basketball at greater heights while maintaining lower release angles. These observations offer further support to the previously studies suggesting that player's ability to increase the height of the release may allow for the reduced angle of release and are likely associated with lower body kinematics (Hamil-

ton & Reinschmidt, 1997; Miller and Bartlett, 1996; Okazaki et al., 2015).

While notable kinematic differences were present and were able to differentiate between proficient and non-proficient free throw shooters, when the same dependent variables were examined between made and missed free throw shots within the proficient group of shooters, no statistical differences were found. The elbow height and hand release height magnitudes, the two variables with the previously discussed greatest discriminating power, were identical between made and missed free throw attempts while the rest of the variables differ by approximately one degree. Based on these findings, we can conclude that the ability to differentiate between made and missed free throw shots within subjects with good free throw shooting ability (i.e.,  $\geq 70\%$ ) is minimal. Mullineaux & Uhl's (2010) findings offer further support to our findings suggesting that the margin of error affecting the success of the free throw shot is very small and most likely is caused by player's intention to correct shooting technique. These corrections are most likely to occur upon a player's ability to perceive certain flaws in their execution just before the time point of ball release (Mullineaux & Uhl, 2010). Thus, despite not reaching the level of statistical significance, the minimal differences in knee, hip, and release angles may be an underlying factor leading to the unsuccessful free throw shooting outcome.

## CONCLUSION

The findings of this study suggest that lower elbow positioning influenced by greater knee, hip, and ankle flexion during the preparatory phase of the free throw shooting motion may lead to improvements in basketball free throw shooting accuracy. Moreover, greater ball release height and release angle values closer to previously estimated standards could

decrease the margin of error and aid in further improvements in free throw shooting performance. Although using the kinematic variables examined in this study may perhaps distinguish between proficient and non-proficient free throw shooters in 94% of the cases, small changes in their magnitudes may lead to unsuccessful free throw shooting outcomes. Further research should focus on determining the optimal magnitudes for each of the examined variables as well as how they differ between playing positions and various levels of basketball competition (high school, collegiate, and professional).

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