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Differences in Biomechanical Characteristics between Made and Missed Jump Shots in Male Basketball Players

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Abstract: While the importance of optimal two-point and three-point jump-shooting performance for securing the desired game outcome on various levels of basketball competition has been well documented, there is a limited amount of scientific literature on what biomechanical adjustments in shooting technique comprise the success of each shooting attempt. Therefore, the purpose of the present study was to examine the difference in kinetic and kinematic characteristics during the preparatory and release phases of the shooting motion between made and missed jump shots. While standing on a force plate, twenty-nine recreationally active males with prior basketball playing experience attempted 10 two-point and 10 three-point jump shots, combining for a total of 580 attempts. Simultaneously, two high-definition cameras were used to capture kinematic characteristics of interest. Higher elbow positioning during the preparatory phase of the shooting motion, relative to the shooter's stature, was shown to be a critical kinematic adjustment that differentiated made from missed two-point jump shots. Alongside identical observations regarding the importance of the elbow placement, keeping the torso in a more erect position during the preparatory phase of the shooting motion, having a greater release angle and vertical jump height at the timepoint of the ball release, and attaining higher maximal trajectory height were critical kinematic adjustments that differentiated made from missed three-point jump shots.

Keywords: sport; coaching; shooting technique; performance; kinetics; kinematics; team sports

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1. Introduction

A considerable amount of scientific literature has documented the importance of optimal two-point and three-point jump-shooting performance for securing the desired game outcome on various levels of basketball competition [1–3]. In balanced games (i.e., final score difference between 10 and 29 points) at the Under-16 junior competitive level, two-point shooting performance was one of the key game-related statistical parameters capable of discriminating winning from losing teams [1]. At the NCAA Division-I level of competition, winning teams attempted less and made more three-point field goals, implying superior offensive efficiency from long-range shooting distances [2]. In addition, when analyzed at the top level of European professional basketball competition, winning teams had better two-point and three-point shooting efficiency [3]. Therefore, it is evident why coaches and players are dedicating a considerable amount of practice time towards improvements in both mid-range and long-range jump-shooting performance (i.e., two-point and three-point shots).

Currently, there is a limited amount of applied scientific literature focused on examining biomechanical characteristics of shooting motion that can be readily implemented during everyday coaching sessions (e.g., elbow positioning, trunk flexion, knee bend).

When teaching a proper jump-shooting form, Knudson [4] has indicated that coaches should instruct players to minimize horizontal motion and jump as close as vertically as possible, release the ball at the top of the jump, and aim for a release angle between 49–55 degrees above the horizontal. Although examining optimal release conditions for the free-throw shooting motion, Tran & Silverberg [5] estimated that the shooting accuracy will increase by approximately 5% with each 0.152 m increase in release height above 2.0 m. The increase in release height will diminish the need for a large release angle and reduce the need for high-velocity movements, which have been shown to be inversely related to greater movement accuracy [6–8]. In addition, previous research has found that release angle is related to the entry ball angle at the rim [7,9]. Theoretically, a 90 degrees entry angle allows a player to use the greatest basket area (i.e., full diameter), but this is not feasible to attain in a practical setting as shooting efficiency would be considerably impaired [7]. The optimal entry angle has not been determined as it is contingent upon individual multiple biomechanical parameters such as release velocity, angle, and height [9]. However, based on mathematical computations, it is clear that for the ball to clear both rims and enter the basket, the minimum entry angle is 32 degrees [10].

Based on the previously mentioned studies, it is obvious that the majority of scientific literature has been directed towards examining optimal basketball release parameters while overlooking the preparatory phase of the shooting motion. Additional research is needed to understand the difference in biomechanical characteristics between proficient and non-proficient shooters, as well as what alterations in shooting form differentiate made and missed shots. In one recently published study, Cabarkapa et al. [11] found that lower elbow positioning during the preparatory phase of the shooting motion achieved by greater flexion in the hip, knee, and ankle joints was one of the key factors in discriminating proficient from non-proficient free-throw shooters. On the other hand, Ammar et al. [12] found that improvements in free-throw shooting accuracy were related to lower knee flexion during the preparatory phase of the shooting motion and near-complete knee extension at the timepoint of the ball release. Moreover, there is a limited amount of scientific literature focused on examining kinetic characteristics of jump shooting motions. Despite similar ground reaction force curve patterns, Struzik et al. [13] have found that mean and peak power were greater for a simulated jump shot without a ball than a countermovement vertical jump without an arm swing. Peak landing forces among the NBA players were greater for the jump shot than the vertical jump [14]. Interestingly, no differences in peak concentric and landing forces, impulse, and rate of force development have been found between different types of jump shooting approaches (e.g., stationary, step-in) [15].

Therefore, to bridge a gap in the scientific literature, the purpose of the present study was to examine the differences in kinetic and kinematic characteristics between made and missed shots during both preparatory and release phases of two-point and three-point jump shooting motions.

2. Materials and Methods

2.1. Participants

Twenty-nine recreationally active males (height = 182.6 $\pm$ 9.1 cm; body mass = 84.1 $\pm$ 15.4 kg; age = 22.6 $\pm$ 4.1 years) volunteered to participate in this study. All participants had $\geq$4 years of previous basketball playing experience, participated in basketball or related recreational activities at the time of the study, and did not report any current or previous musculoskeletal injuries that could potentially limit a full joint range of motion. All testing procedures performed in this study were previously approved by the University's Institutional Review Board and all participants signed the informed consent document.

2.2. Procedures

Based on the methods used by Cabarkapa et al. [15], upon arrival at the laboratory, participants performed a standardized warm-up procedure consisting of a set of dynamic stretching exercises (e.g., butt-kicks, quad pulls, lateral lunges, A-skips, walking quad stretch) and 5–10 practice shots from self-selected distances. While standing on a uni-axial force plate (0.91 m × 2.44 m, RoughDeck, Rice Lake, WI, USA), each participant performed 10 two-point (5.10 m) and 10 three-point shots (6.75 m), combining for a total of 580 attempts. A data acquisition system (BioPac Systems Inc., Goleta, CA, USA) sampling at 1000 Hz was used to derive kinetic variables of interest: peak concentric force (PCF; greatest ground reaction force recorded during the concentric phase of the shooting motion), peak landing force (PLF; greatest ground reaction force recorded during the landing phase of the shooting motion), impulse (IMP; calculated as an area under the curve above the subject's body weight during the concentric phase of the shooting motion), and rate of force development (RFD; slope between the time point when the ground reaction force reached the subject's body weight and the peak concentric force).

Simultaneously, two high-definition cameras (PowerShot SX530, Canon Inc., Tokyo, Japan) recording at 30 fps were used to capture shooting motion from a sagittal point of view. The first camera was positioned 10 m away from the shooting location (i.e., two-point and three-point), while the second camera was positioned 20 m away from the mid-point distance between the shooting location and the basket, both perpendicular to the shooting plane of motion. Video analysis software (Kinovea, Version 0.8.27) was used to analyze the kinematic variables of interest: knee angle (KA; internal angle between the thigh and shank during the preparatory phase of the shooting motion), hip angle (HA; internal angle between the torso and the thigh during the preparatory phase of the shooting motion), elbow angle (EA; internal angle between the upper arm and forearm during the preparatory phase of the shooting motion), ankle angle (AA; relative angle between the shank and the ground during the preparatory phase of the shooting motion), shoulder angle (SA; relative angle between the upper arm and torso during the preparatory phase of the shooting motion), elbow height (EH; perpendicular distance between the olecranon process and the ground divided by participant's height during the preparatory phase of the shooting motion), release angle (RA; relative angle between the fully extended upper limb and a line parallel to the ground at the timepoint of the ball release), heel height (HH; perpendicular distance between the calcaneus and the ground at the time point of the ball release), maximal trajectory height (MTH; perpendicular distance from the center of the basketball to the ground at the highest trajectory point), and entry angle (ENA; relative angle at which basketball enters the rim). The preparatory phase of the shooting motion was defined as an initial upward/concentric body movement while the shooter was still on the ground. The ball release phase of the shooting motion was defined as the timepoint when the shooter completely lost contact with the ball while vertically displacing the body to propel the ball to the basket. See Figure 1 for a detailed graphical representation of kinematic variables examined in the present study.

To minimize any possible influence of fatigue, each shot was separated by a 5–10 s rest interval and all rebounding tasks were completed by a designated research assistant. The basketball goal was positioned at a standardized regulation height of 3.05 m. Moreover, no instructions on how to properly perform shooting motions were given to participants and all shooing procedures were performed individually to avoid any possible distractions that could impair shooting performance.

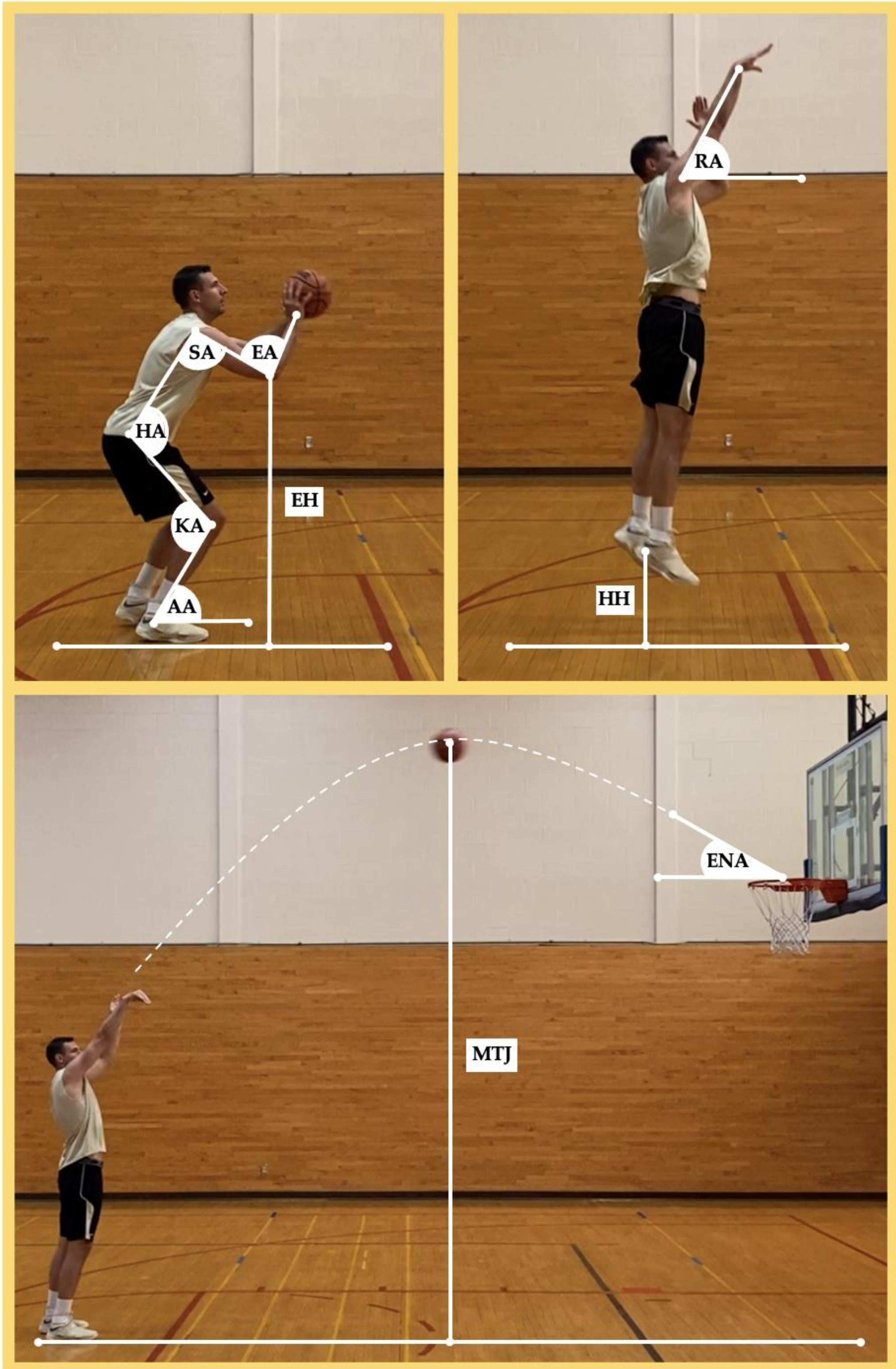

Figure 1. Graphical representation of the kinematic variables examined in the present study. KA—knee angle; HA—hip angle; EA—elbow angle; AA—ankle angle; SA—shoulder angle; EH—elbow height; RA—release angle; HH—heel height; MTH—maximal trajectory height; ENA—entry angle.

2.3. Statistical Analysis

Shapiro–Wilk test was used to test for the assumption of normality. All dependent variables, except MTH and IMP for two-point shooting motions, violated the assumption of normality. Therefore, Mann–Whitney U tests were used to examine statistically significant differences between made and missed two-point and three-point shots for non-normally distributed variables and independent t-tests for normally distributed variables. Statistical significance was set a priori to $p < 0.05$. All statistical analyses were completed with SPSS (Version 26.0; IBM Corp., Armonk, NY, USA).

3. Results

The average two-point and three-point shooting accuracy was 51.7% and 41.7%, respectively. A statistically significant difference between made and missed two-point shots was only detected for the EH variable, with greater magnitudes observed for made shots. However, no significant differences between made and missed two-point shots were found in KA, HA, EA, AA, SA, RA, HH, MTH, ENA, PCF, PLF, IMP, and RFD. See Table 1 for detailed results. Alongside a greater EH, made three-point shots were characterized by a greater HA, RA, HH, and MTH. No statistically significant differences between made and missed three-point shots were found in KA, EA, AA, SA, ENA, PCF, PLF, IMP, and RFD. See Table 2 for detailed results.

Table 1. Descriptive statistics, median (interquartile range) or mean (standard deviation), and statistically significant differences between made and missed two-point shots.

Variable	Missed Shots	Made Shots	*p*-Value
Knee Angle (deg)	110 (20)	110 (19)	0.695
Hip Angle (deg)	135 (18.8)	137 (12)	0.093
Elbow Angle (deg)	61 (15)	60 (14.25)	0.601
Ankle Angle (deg)	56 (9.75)	56 (9)	0.523
Shoulder Angle (deg)	78 (41.25)	82.0 (27)	0.387
Elbow Height (cm)	0.66 (0.13)	0.71 (0.14)	0.008 *
Release Angle (deg)	54 (11.75)	55.5 (11)	0.269
Heel Height (cm)	19.3 (7.95)	19.8 (8.53)	0.348
Maximal Trajectory Height (cm) #	390.7 (24.7)	395.6 (23.1)	0.084
Entry Angle (deg)	44 (4)	45 (4)	0.254
Peak Concentric Force (N)	1619 (603)	1699 (433.5)	0.873
Peak Landing Force (N)	1630.5 (718.75)	1739 (763.5)	0.051
Impulse (N·s) #	152.3 (45.9)	150.5 (48.2)	0.744
Rate of Force Development (N·s^{-1})	3976.5 (3111.75)	3709 (3331.25)	0.154

(*)—denotes a statistically significant difference between made and missed shots ($p < 0.05$). (#)—denotes mean (standard deviation) for the normally distributed dependent variable.

Table 2. Descriptive statistics, median (interquartile range), and statistically significant differences between made and missed three-point shots.

Variable	Missed Shots	Made Shots	*p*-Value
Knee Angle (deg)	104 (15)	104 (18.5)	0.565
Hip Angle (deg)	129 (17)	133 (15.5)	0.037 *
Elbow Angle (deg)	62 (14.5)	60 (13.5)	0.058
Ankle Angle (deg)	51 (9)	51 (7)	0.683
Shoulder Angle (deg)	68 (39)	71 (36)	0.235
Elbow Height (cm)	0.61 (0.11)	0.66 (0.15)	0.011 *
Release Angle (deg)	48 (14.5)	53 (13.5)	0.002 *
Heel Height (cm)	23.5 (7.1)	25.4 (7.85)	0.015 *
Maximal Trajectory Height (cm)	434.5 (40)	437.2 (26.35)	0.047 *
Entry Angle (deg)	45 (4)	45 (3.5)	0.380
Peak Concentric Force (N)	1885.0 (496)	1896 (491.5)	0.384
Peak Landing Force (N)	2110 (864.5)	2165 (772)	0.431
Impulse (N·s)	180 (47.5)	181 (52)	0.927
Rate of Force Development (N·s^{-1})	5037 (4289)	4580 (3170)	0.136

(*)—denotes a statistically significant difference between made and missed shots ($p < 0.05$).

4. Discussion

The findings of the present study reveal that the only statistically significant difference between made and missed two-point jump shots was in EH placement. While all other kinetic and kinematic parameters of interest remained unchanged, higher elbow positioning during the preparatory phase of the shooting motion appears to be a critical kinematic adjustment that influences the success of two-point jump shots. Moreover, it is important to note that the observed difference was not influenced by the shooter's stature, as the EH variable computed in the present investigation has taken this factor into account. Alongside identical observations regarding the importance of EH placement, the findings of the present study indicate that made and missed three-point jump shots were differentiated by HA, RA, HH, and MTH variables. Keeping the torso in a more erect position during the preparatory phase of the shooting motion, having a greater release angle and vertical jump height at the timepoint of ball release, and attaining higher maximal vertical height along the ball trajectory were critical kinematic adjustments that differentiated between made and missed three-point jump shots.

Cabarkapa et al. [15] recently found that proficient shooters had higher elbow positioning when compared to non-proficient shooters during two-point shooting motions, which is similar to the findings of the present study. When entered into a full discriminant function model, elbow height showed as the key variable capable of classifying proficient from non-proficient two-point shooters; it accounted for approximately 52% of the total explained variance [15]. Besides higher elbow positioning, previous research has indicated that positioning the elbow under the ball in line with the basket (i.e., shooting plane of motion) can elicit further improvements in shooting accuracy [4,7]. This was also the case when examining differences in kinematic characteristics between made and missed free-throw shots within a proficient group of shooters, where greater lateral elbow deviation was linked to a greater number of missed free-throw attempts [16]. Although not examined in the present study due to the shooting motion being video recorded solely from a sagittal point of view, aligning the forearm with the shooting plane of motion (i.e., less lateral elbow deviation), conjointly with higher EH placement, could have been an additional kinematic adjustment that ultimately increases chances of securing the desired outcome of the two-point and three-point jump shots.

Another interesting observation pertaining to the optimal jump shot technique is that skilled shooters and successful shots were related to the player's ability to maintain near-vertical alignment of the trunk during the jump phase of the shooting motion [4]. These findings are similar to the results obtained in the present study, indicating that HA was significantly greater for made three-point jump shots. However, it is worthy to note a slight discrepancy between the previously mentioned findings. Knudson [4] emphasized the importance of the trunk positioning during the jump phase of the shooting motion, whereas HA analyzed in the present study was assessed during the initial concentric phase of the jump-shooting motion (i.e., preparatory phase) while the player was still on the ground. Therefore, we may assume that for making three-point attempts, the shooter already started to make kinematic adjustments to the shooting form by positioning the trunk in a near-vertical position before his feet even left the ground. Although it is suggested that greater trunk extension should be maintained during the jump phase of the shooting motion, exaggerated backward trunk lean (i.e., fade away) needs to be avoided as it will change the appropriate ball release parameters and potentially decrease shooting accuracy [4,17,18]. In addition, Hudson [19] found no difference in trunk inclination between high, moderate, and low-skill female basketball players, despite mean values for the low-skill group being approximately two-fold greater when compared to a high-skill group. Although further research is warranted on this topic, the discrepancy in the previously mentioned findings may be attributed to the biomechanical differences in jump shooting parameters between the sexes and the amount of previous basketball playing experience (e.g., novice vs. experienced players).

A considerable amount of scientific literature has been focused on examining and estimating optimal ball release parameters that can lead to successful shooting outcomes [4,7–10]. It has been found that greater shoulder flexion closer to the timepoint of the ball release results in greater release height [7–9]. Moreover, based on theoretical computations, it has been found that the greater the release height, the higher the chances of a shooting attempt being successful, and the margin of error becomes notably larger [10]. The results of the present study indicated that RA and HH were significantly greater for made than missed three-point shots, which is in direct agreement with the previously mentioned findings regarding optimal biomechanical parameters at the timepoint of the ball release. The RA was almost identical to the previously established recommendations, approximately 49–55 degrees [4,7]. Based on the previously mentioned findings, we can assume that attaining greater RA (i.e., shoulder flexion) at the time point of the ball release shooters created an initial biomechanical advantage to increase the likelihood of successful three-point shooting attempts. At the same time, this improvement in shooting technique was accompanied by a greater HH (i.e., an indicator of vertical jump displacement), which likely created an additional biomechanical advantage and ultimately amplified chances for securing the desired outcome of the three-point shooting motion. In addition, the findings of the present study indicated that made three-point shots were characterized by greater MTH. This adjustment in shooting trajectory most likely resulted from greater RA and HH [10]. However, it is important to note that the more time the ball spends in the air traveling to the basket, the greater the effect of air resistance (i.e., drag). Therefore, we can assume that greater MTH, alongside greater RA and HH, during made three-point shots was an additional biomechanical adjustment in shooting technique needed to compensate for changes in ball trajectory shape due to the influence of drag force, especially when shooting from further distances away from the basket [10].

Last but not least, it is important to note that not reaching the level of statistical significance for some of the kinetic and kinematic variables examined in the present study does not mean that their contribution to the proper shooting form is negligible. A cohort of participants examined in the present investigation were not novice players; they possessed at least an elementary knowledge regarding a proper shooting form (i.e., more than four years of basketball playing experience). No statistically significant differences observed in KA, EA, and AA for this subset of subjects can be interpreted that these kinematic adjustments were already implemented during both made and missed two-point and three-point shooting attempts, which have been previously shown to be of critical importance for proper shooting form [11,15,20]. The same applies to the kinetic variables examined in the present study, where no significant differences in PCF, PLF, IMP, and RFD were observed between made and missed two-point and three-point jump shots. The magnitude of the aforementioned kinetic variables was similar to the previous research findings [15]. When compared to some of the other commonly utilized basketball-specific motions, such as dunking [21,22], the PCFs for two-point and three-point jump shots were notably lower, which is expected considering the differences in the complexity and explosiveness of these two types of motions. In addition, it is interesting to note that despite made three-point attempts having greater HH (i.e., an indicator of vertical jump displacement) when compared to missed shots, no differences in PLF were observed. Given that previous research has stressed the importance of soft-landing during jump shooting motions to minimize excessive load on the lower limbs [13], we can assume that the participants in the present study tended to implement soft-landing techniques as the increase in jump height did not result in an increased PLF. This could also be attributed to the participants' experience level and knowledge regarding a proper shooting form.

While the findings of the present study may provide beneficial information that coaches and players can implement during training sessions to elicit advancements in shooting performance, this study is not without limitations. The shooting protocols implemented in the present study were non-fatiguing and did not involve the presence of a defender. Thus, future research should focus on examining changes in biomechanical characteristics of jump shooting motions in an environment similar to in-game competitive conditions, as well as focus on examining differences across broad age and skill ranges to obtain a better insight into the longitudinal development of proper shooting form (i.e., elementary, middle, and high school).

5. Conclusions

Higher elbow positioning during the preparatory phase of the shooting motion, relative to the shooter's stature, was shown to be a critical kinematic adjustment that differentiated made from missed two-point jump shots. Alongside identical observations regarding the importance of the elbow placement, keeping the torso in a more erect position during the preparatory phase of the shooting motion, having a greater release angle and vertical jump height at the timepoint of the ball release, and attaining higher maximal trajectory height were critical kinematic adjustments that differentiated made from missed three-point jump shots.

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