RELATIONSHIP BETWEEN KINEMATIC CHARACTERISTICS AND FREE-THROW SHOOTING PRECISION: MARKERLESS MOTION CAPTURE ANALYSIS

The search for aspects of basketball shooting that characterize successful performance is an area of focus for sports biomechanists. Thus, the purpose of the present study was to evaluate the relationship between some of the key kinematic variables extracted from a markerless motion capture system on free-throw shot performance. Multivariable linear regression analysis indicated that shot plane alignment, trunk rotation, entry angle, and timing of elbow extension were some of the key contributors to free-throw shot precision. Overall, these kinematic variables serve as a preliminary set of outcomes that can be reported to coaches and players that decide to use markerless motion capture technology for free-throw shooting biomechanical analysis.

KEY WORDS: Basketball Shooting, Free Throw, Sports Performance, Markerless Motion Capture

INTRODUCTION: The outcome of a basketball game is determined by multiple on-court performance parameters such as shooting proficiency, rebounding performance, and the overall tactical discipline (e.g., turnovers, assists) (Jaguszewski, 2020, Cabarkapa, et al., 2022). However, one of the key game-related statistics that discriminate winning from losing game outcomes is shooting proficiency, particularly from the free-throw line. Free-throw shooting has previously been identified as one of the most important aspects in determining the outcome of a basketball game (Sampaio & Janeira, 2003). As a result, improving free-throw shooting performance is often a key focus of players and coaches. Previous research has also aimed to identify key features that are related to free-throw success (Cabarkapa et al., 2021, Knudson, 1993). For example, Knudson (1993) identified six teaching points to improve shooting success including: staggered stance and vertical jump, aligned shot plane, optimized height of release, angle of release, cooperation of the upper and lower extremities, and ball rotation This summary highlights the importance of executing proper biomechanical motion that leads to the optimal trajectory of the ball. However, these principles identified in the scientific literature have had limited impact in translating to regular shooting sessions.

One main challenge of providing biomechanical information to coaches and athletes is the difficulty in collecting and analyzing the data in a timely manner. However, 3D markerless motion capture technology (Templin et al., 2022) allows kinematic data of the shooter and the ball to be collected in a basketball gym on a relatively large number of subjects in a natural basketball training environment with no additional sensors required. Therefore, the purpose of the present study was to examine the relationships between kinematic characteristics captured by a 3D markerless motion capture system and shot precision during repeated free-throw attempts.

METHODS: 34 subjects volunteered to participate in the present study. All the testing procedures were approved by an Institutional Review Board committee. Subjects had a broad range of basketball experience ranging from <1 year to collegiate and professional players. Upon arrival at the basketball gym, subjects were given 5-10 minutes to take practice shots from self-selected distances. Following the aforementioned warm-up procedure, each participant performed 10 consecutive shots from the free-throw line with 10-15 second rest interval, to minimize a possible influence of fatigue.

A 9-camera video-based 3D markerless motion capture system was used to capture each shot at 120 Hz (Templin et al., 2022). In addition to tracking the kinematics of the shooters, a computer vision tool was developed to identify the location of the basketball in each frame (Figure 1). In order to do so, a frame differencing technique was first applied to subsequent images from each camera to identifying pixels that changed between frames. We then used an OpenCV tool (Bradski, 2000) to identify the basketball in the images. The 2D location of the ball from each camera was then converted to a 3D position using the same triangulation procedure described above.

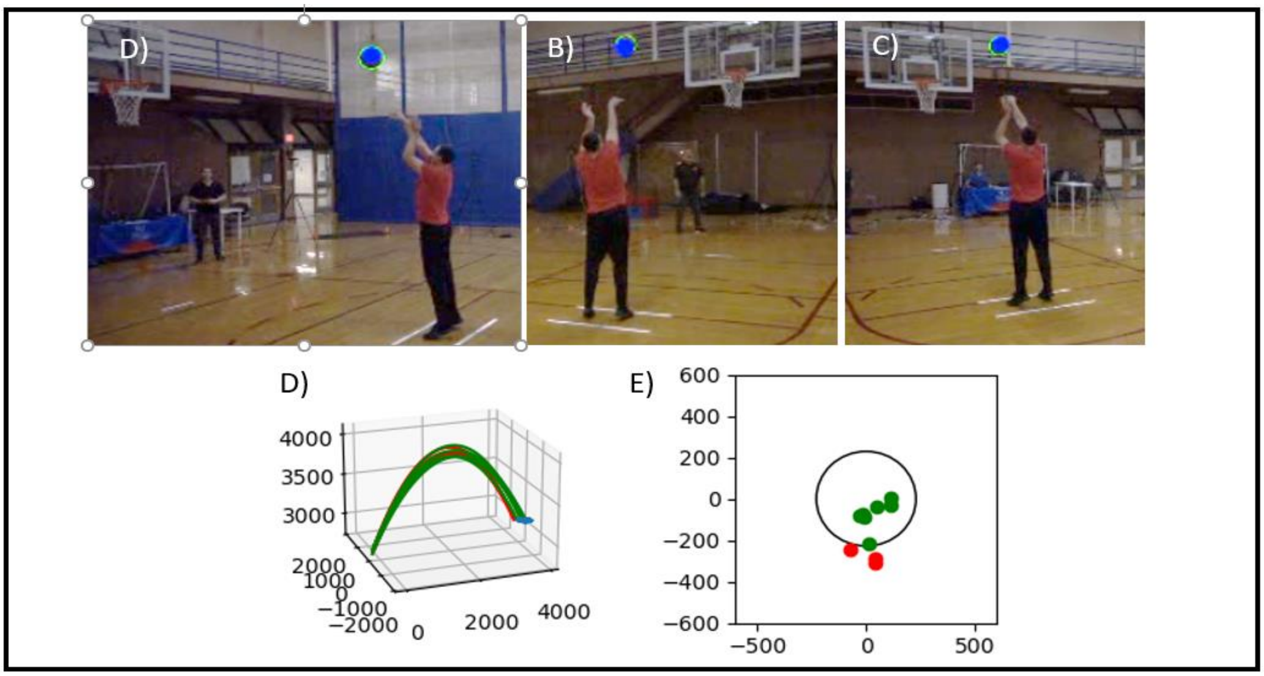

Figure 1: Workflow for measuring ball trajectory. Images A, B, C show three camera views for one time point. The green circles represent the 2D predictions and the blue circle shows the 3D triangulated position of the ball reprojected back into the camera views. Figure D shows the 3D trajectory of the ball for 10 free throws for one subject. Green lines represent made shots and red lines represent missed shot. Figure E shows the end point location of all 10 shots for one subject.

Each shot was trimmed to begin with the preparatory phase and end with ball release (Figure 2). The preparatory phase was defined as the initial extension of the knee from maximum knee flexion (Cabarkapa et al., 2021). Ball release was defined as the first timepoint that the ball lost contact with the hand after the initiation of the preparatory phase. An intermediate time point, denoted as the set point, was also recorded for each shot. The set point was defined as the last time point that the hand changed from traveling away from the basket and began moving toward the basket.

Data were analyzed using a multivariable linear regression model where the dependent variable was the shot precision (i.e., mean root mean square difference of shot end point location relative to mean shot end point location) for each subject and the independent variables included the following mean values across the 10 shots for each subject: shot plane (i.e., angle of the forearm with respect to the vertical axis at the set point), trunk rotation (i.e., transverse plane rotation of the trunk at the set point), release angle (i.e., initial angle of ball trajectory after release), balance M/L (i.e., change in center of mass (COM) displacement between max knee flexion and release along the medio-lateral axis), balance A/P (i.e., change in COM displacement between max knee flexion and release along the anterior-posterior axis), shoulder flexion (i.e., shoulder flexion at release point). The metrics included in the regression analysis model were chosen to correspond to 6 key principles of shooting depicted by Knudson (1993).

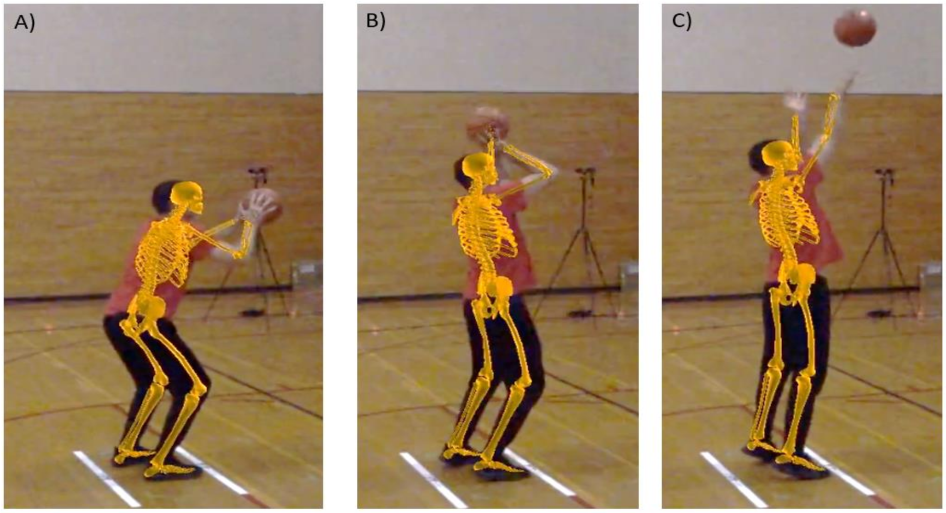

Figure 2: Overlays of the musculoskeletal model at specific time points on the original images. A: Preparatory phase. B: Set point. C: Release.

RESULTS: Shot plane alignment, release angle, and balance M/L showed a significant positive correlation with precision, while trunk rotation showed a significant negative correlation with precision. The remaining variables showed no statistical significance (Table 1).

Table 1: Multivariable regression analysis for free throw shots. Dependent Variable is shot precision. Coefficients are reported as unstandardized β.

Independent Variable	Coefficient
Shot plane	2.17 (0.82)*
Trunk rotation	-1.92 (0.78)*
Release angle	7.15 (1.50)*
Balance M/L	2.37 (0.74)*
Balance A/P	0.67 (0.82)
Shoulder Flexion	0.36 (0.38)

R^2= 0.682 F=9.64*; N= 34; *p<0.05

DISCUSSION: The purpose of the present study was to examine the relationships between kinematic characteristics captured by a 3D markerless motion capture system and shot precision during repeated free-throw attempts. Several biomechanical variables that have previously been postulated as being associated with free-throw shooting precision were shown to be significantly related to shooting precision.

Shooters with higher shot precision tended to more closely align their forearm with the vertical axis at the set point position, and, interestingly, exhibited greater trunk rotation at the set point. Previous studies have suggested that obtaining the proper forearm alignment is difficult with the traditional “square up” coaching cue given to many players (Ingram & Snowden, 1989). Thus, the findings of the present study support the notion that skilled shooters rotate their trunk such that the shooting shoulder is slightly in front of the contralateral shoulder to facilitate lining up the shooting side forearm to the basket.

Shooters with higher shot precision also exhibited reduced release angle. Previous work has identified that reduced release angle corresponds with reduced ball speeds at the release (Inaba et al., 2017.). Slower ball release speeds are desirable as slower movements have been shown to be more easily repeated than faster movements (Darling & Cooke, 2013). However, a precision trade-off exists because increasing the entry angle increases the margin for error afforded to the shooter by increasing the area that a ball can successfully pass through the basket (Inaba et al., 2017). Consequently, while this present study shows increased precision of shooters with reduced entry angles, shooters should take into consideration the increased margin for error with greater entry angles.

Finally, high precision shooters also exhibited a reduced change in COM displacement along the medio-lateral axis suggesting a more balanced shot is advantageous. This finding supports previous work that recommends minimizing medio-lateral shifting during a shot (Knudson, 1993).

CONCLUSION: This study found that shot plane alignment, trunk rotation, release angle, and balance were associated with free-throw shooting precision. These findings may provide coaches and players with beneficial information that can be used to improve free-throw shooting precision during regular training sessions.

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