RELATIONSHIP BETWEEN KINEMATIC SEQUENCE CHARACTERISTICS, UPPER EXTREMITY JOINT WORK, AND FREE-THROW SHOOTING ACCURACY

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This study investigates the relationship between spatiotemporal, kinematic sequence, and upper extremity joint work variables in free-throw shooting. Thirty-four participants performed free-throw shots, analyzed using a 3D markerless motion capture system (ENABLE). The study focused on the timing sequence of peak angular velocities and their relation to joint work in the shooting shoulder and elbow. Significant correlations were found between the timing of peak angular velocities and upper extremity joint work. The findings suggest that proficient basketball shooters demonstrate a more efficient kinematic sequence, characterized by longer duration of time between knee, pelvis, and elbow peak angular velocities and reduced upper extremity workload. This study underscores the importance of understanding the biomechanics of shooting for training and skill development in basketball.

KEY WORDS: basketball, shooting, performance, markerless

INTRODUCTION: Multiple factors influence the outcome of a basketball game, including shooting accuracy, rebounding performance, and tactical discipline (Jaguszewski, 2020, Cabarkapa, Deane, et al., 2022). Among these, shooting proficiency, especially free throws, is crucial in distinguishing between winning and losing (Sampaio & Janeira, 2003). As a result, improving free-throw shooting performance is often a key focus of players and coaches. Previously, research has been conducted to identify characteristics that contribute to successful free throws (Cabarkapa et al., 2021, Knudson, 1993). These studies highlight the importance of a staggered stance and vertical jump, aligned shot plane, optimized height of release, and angle of release. However, the influence of movement coordination and efficiency on the basketball shooting performance remains uncertain.

A widely used method for evaluating movement coordination and efficiency in sports movements is through the analysis of the timing of peak segmental angular velocities. This study of body segment angular velocities became known as the “kinematic sequence” through the seminal work by Jorgensen et al. (1993) and has become widely used in the analysis of baseball pitching and the golf swing. Studies on the kinematic sequence have consistently found that efficient movement patterns are characterized by a proximal-to-distal movement pattern where the angular velocity of proximal segments precede that of distal segments. These studies have suggested those who best utilize the kinematic sequence maximize performance and minimize upper extremity kinetics.

Previous studies have used angular velocity measures to analyze basketball shooting (Elliott & White, 1989; Miller & Bartlett 1993). However, to our knowledge no study has investigated how the kinematic sequence influences upper extremity kinetics and basketball shooting proficiency. Therefore, the purpose of this study is to explore the relationship between the timing of knee, pelvis, and elbow peak angular velocities on upper extremity joint work.

METHODS: 34 males (age = 23.9 ± 7.4 years; height = 182.7 ± 7.4 cm; mass = 80.1 ± 11.6 kg) with >4 years of previous basketball playing experience (6.5 ± 2.2 years) volunteered to participate in this study. All the testing procedures were approved by an Institutional Review Board committee at the University of Kansas. On arriving at the basketball gym, participants were allowed 5-10 minutes for practice shots at self-selected distances. Following this warm-up, each participant performed 10 successive free-throw shots, taking 10-15 second breaks between shots to reduce fatigue effects.

To analyze each shot, a 9-camera, 3D markerless motion capture system operating at 120 Hz was employed (Templin et al., 2023). Additionally, a previously described computer vision tool was utilized to pinpoint the basketball's location in each video frame (Templin et al., 2023). The starting point, set point, and release were identified for each shot using previously described methods (Templin et al., 2023).

For analysis of the kinematic sequence, we first identified timings of the peak angular velocities of the following degrees of freedom: knee flexion/extension, pelvis list, and elbow flexion/extension. These were chosen as representative degrees of freedom for the legs, torso, and arms, respectively. We then calculated the relative timing of the peak pelvic list (PLR) and elbow extension relative (EER) to the timing of the knee extension as a way to standardize the comparison of times between each shooter (Figure 1).

The upper extremity kinetics outcomes were the joint work produced by the shooting shoulder and elbow. Joint work was evaluated as the time integral of joint power. Joint power was calculated as the product of the joint moment and joint angular velocity. The shoulder and elbow joint moments were calculated using the inverse dynamics tool in OpenSim (Delp et al. 2007). The inputs necessary to run the inverse dynamics tool in OpenSim are a scaled model of the subject and the inverse kinematics results, which are both standard outputs of the ENABLE markerless system (Templin et al., 2023). The shoulder and elbow joint work were calculated from the set point to ball release to isolate the upper extremity work of the final push phase of the shot. The combined upper extremity work was calculated as the sum of the shoulder and elbow work.

For data analysis, Pearson *r* correlations values were calculated between the kinematic sequence variables (PLR and EER) on each of the upper extremity kinetic outcomes (shoulder, elbow, and combined joint work). Then, participants were classified as proficient if they made 70% or more of their free-throws or non-proficient if they made 50% or less. The two subjects that shot between 51%-70% were excluded from the proficient-nonproficient comparison. Independent *t*-tests were used to compare the two groups across kinematics sequence and joint work variables. Statistical significance was set to $p < 0.05$.

RESULTS

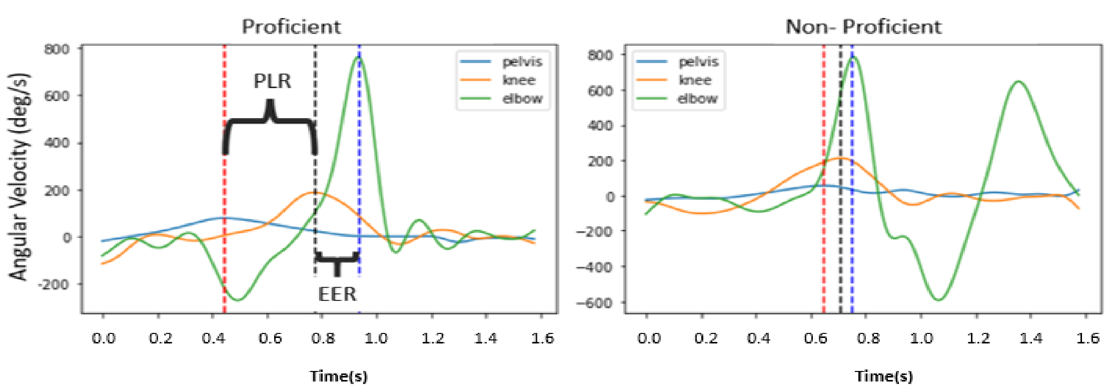

Figure 1: Representative plots of angular velocities of pelvic list (blue), knee flexion/extension (orange), and elbow flexion/extension (green) for proficient and non-proficient shooters. Dashed lines represent frame number of peak angular velocity of pelvis (red), knee (black), elbow (blue). PLR is annotated as time difference between peak knee and pelvis angular velocity, and EER is annotated as time differences between peak elbow and knee velocity.

PLR and EER showed a significant positive correlation with elbow work and a significant negative correlation with shoulder and combined shoulder and elbow work (Table 1).

Table 1: Coefficients of correlation between kinematic sequence variables and upper extremity work.

Variable	Correlation with Shoulder Work	Correlation with Elbow Work	Correlation with Combined Work
Peak Pelvic List Timing Relative to Peak Knee Extension (PLR)	-0.62*	0.59*	-0.52*
Peak Elbow Extension Timing Relative to Peak Knee Extension (EER)	-0.64*	0.71*	-0.51*

*Statistically significant difference between proficient and non-proficient shooters ($p < 0.05$).

Proficient shooters had significantly earlier peak pelvic list angular velocities and later elbow extension velocities than non-proficient shooters (Table 2). Proficient shooters also had significantly lower shoulder work and combined shoulder and elbow work than non-proficient shooters (Table 2).

Table 2: Kinematic and upper extremity work differences between proficient and non-proficient shooters.

Variable	Proficient	Non-Proficient
Peak Pelvic List Timing Relative to Peak Knee Extension (s) *	-0.22 ± 0.10	-0.11 ± 0.13
Peak Elbow Extension Timing Relative to Peak Knee Extension (s) *	0.13 ± 0.05	0.08 ± 0.03
Shoulder Work (J) *	146 ± 102	372± 191
Elbow Work (J)	108 ± 46	76 ± 49
Combined Work*	254 ± 88	448 ± 172

*Statistically significant difference between proficient and non-proficient shooters ($p < 0.05$).

DISCUSSION: The purpose of this study was to identify the relationships between kinematic sequence variables and upper extremity joint work during free throwing shooting and to use these relationships to differentiate proficient and non-proficient shooters. There were several clear differences between the proficient and non-proficient shooters. First, non-proficient shooters exhibited significantly closer kinematic sequence timings of peak angular velocities for the pelvis, knee, and compared to proficient shooters. In addition, non-proficient shooters utilized increased combined upper extremity joint work compared to proficient shooters, particularly at the shoulder. Taken together these findings suggest that the larger temporal differences between peak joint angular velocities in the kinematic sequence characteristic of proficient shooters may provide a more efficient mechanism of transferring energy to and offloading the necessary work produced by the shooting arm. Unlike baseball pitching and swinging a golf club, the primary objective of shooting a basketball is not to maximize the exit velocity of the ball. However, it is likely still advantageous for basketball shooters to effectively utilize the flow of energy through the body, reducing the amount of upper extremity work, to be more consistent and proficient shooters. Interestingly, non-proficient shooters used significantly more shoulder work but less elbow work (though not significantly different) than proficient shooters. When learning a new motor skill like shooting a basketball, the human nervous system faces the challenge of managing multiple degrees of freedom. Initially, this is an overwhelming task due to the complexity and variability inherent in coordinating many moving parts. It has been previously proposed that the nervous system simplifies these complex tasks by "freezing" distal degrees of freedom in order to master proximal degrees of freedom (Bernstein 1967). The observation that non-proficient shooters demonstrate increased shoulder work and decreased elbow work aligns with Bernstein's (1967) theory of "freezing" distal degrees of freedom in early skill acquisition. This reliance on proximal joint (shoulder) over a distal joint (elbow) in less proficient shooters might reflect their stage in motor learning, where complex tasks are simplified by initially limiting the movement of more distal joints.

CONCLUSION: This study contributes to the growing body of knowledge surrounding the biomechanics of basketball shooting by elucidating the relationship between kinematic sequence variables and upper extremity joint work. These findings indicate that proficient shooters exhibit a distinct kinematic pattern characterized by a greater temporal separation of peak angular velocities across the pelvis, knee, and elbow. This pattern suggests a more efficient transfer of energy throughout the body, which reduces the workload on the shooting arm, potentially enhancing shooting consistency and proficiency.

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