COORDINATION OF CENTER OF MASS VELOCITY AND UPPER EXTREMITY KINEMATICS DURING BASKETBALL SHOTS FROM TWO DISTANCES

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The purpose of this study was to analyze the coordination patterns for individual players when shooting from different distances. Seven experienced basketball players attempted at least 10 shots from 4.19 m and 6.02 m from the hoop. The coordination between the player's center of mass vertical velocity, upper arm angular velocity, and forearm angular velocity were characterized using phase-plane analysis. Within player, coordination of center of mass vertical velocity and arm kinematics were found to be unique to each individual and comparable between shot distances, particularly during the shot preparation phase. Deviations in coordination patterns between shot distances were attributed to increases in center of mass vertical velocity at ground departure and ball release, consistent with the need for a greater ball velocity at release at further shot distances.

KEYWORDS: multijoint coordination, basketball.

INTRODUCTION: The trajectory of the basketball during flight is determined by the ball velocity at release. The body center of mass (CM) velocity and the arms contribute to the ball velocity at release (Hay, 1985). As the shot distance increases, the CM vertical velocity at ball release tends to increase (Miller & Bartlett, 1996, 1993; Okazaki & Rodacki, 2012; Walters et al., 1990; Wiens & McNitt-Gray, 2020), which reduces the relative contribution of the arms to the ball velocity at release (Elliot, 1992; Wiens & McNitt-Gray, 2020). Changes in multijoint kinematics also occur when increasing the shot distance, as elbow and shoulder angular velocities at ball release increase (Miller & Bartlett, 1993; Okazaki & Rodacki, 2012).
Regulation of the ball velocity at release involves regulation of momentum of the whole body and multijoint coordination of the limbs and trunk during shot preparation and the final push applied to the ball prior to release. The use of the arms during a jump is known to contribute to the vertical impulse generation during ground contact (Harman et al., 1990). During a basketball jump shot, an increase in CM velocity at ground departure increases the potential for the CM velocity to contribute to ball velocity at release (Elliot, 1992; Wiens & McNitt-Gray, 2020) and the potential height of the ball at release.
Coordination during impulse generation and the final push on the ball by the arms prior to ball release involves multijoint coordination of the trunk, legs, and arms. During a free throw, the upper arm contribution is evident during the initial phase of shot preparation followed by rotation of the forearm, and then the hand (Hayes, 1987) during the final push on the ball. Model simulation results indicate that the upper arm kinematics contributes to the vertical velocity of the ball at release, while the forearm and hand kinematics contribute to the horizontal velocity of the ball at release (Okubo & Hubbard, 2015). Determinants of successful shots (Coves et al., 2020 are expected to reflect shooting strategies unique to each player (Okazaki & Rodacki, 2012) particularly when accommodating for increases in shot distance.
In this study, our aim was to examine if coordination between CM vertical velocity generation and the upper extremity kinematics used by individual players during basketball shots could be characterized using a phase plane analysis, which would then be used to determined how individual players modify these coordination patterns when shooting from two different distances from the hoop. We hypothesized that each player would use a unique coordination pattern to generate ball velocity at release and that modifications in their coordination would occur either in the shot preparation phase or the final push action on the ball prior to ball release.

METHODS: Seven experienced participants (four female players on the university club team; three male recreational players) provided informed consent in accordance with the institutional

review board. Each participant shot a minimum of ten shots from two distances (free throw line: 4.19 m; American high school three-point line: 6.02 m) after receiving a chest pass from an individual under the hoop. Participants were instructed to receive and shoot the ball “as if you were in a game.” Shots were performed using the size of basketball that the player uses during competition (male: size 7, 0.75 m CIR, 22 oz; female: size 6, 0.72 m CIR, 20 oz).
Ball and body kinematics in the sagittal and frontal planes were recorded using high-speed cameras (120 Hz, Panasonic GH5s, Newark, NJ, USA). Ground reaction forces generated by each leg were measured using two portable force plates (1200 Hz, Kistler, Amherst, NY, USA). Segment acceleration, angular velocity, and orientation were measured using five inertial measurement units (120 Hz, APDM, Portland, OR, USA). Sensors were secured to the trunk and the shank, thigh, upper arm, and forearm on the shooting side of the body.
Segment angular velocities were rotated from the local reference system into the gym reference system (Figure 1). Net vertical impulse was calculated from the initial static position (CM ~ 0 velocity) to last contact with the ground. The body CM vertical velocity at release was calculated using the net vertical impulse and the time in the air prior to ball release. Coordination between upper extremity kinematics and CM vertical velocity generation during the shot was characterized by plotting CM vertical velocity, upper arm angular velocity, and forearm angular velocity during shot preparation and last push on the ball phases (Figure 2). Only successful shots were used in the analyses (median number of shots per participant: 7.5).

Figure 1 The gym reference system. The origin (0, 0) is located on the floor directly beneath the center of the hoop. Positive x is in the direction of the hoop. Positive y is in the direction to the left of the hoop from the shooter’s perspective. Positive z is up. Positive angular velocity about the y-axis is clockwise.

RESULTS: Phase plane analysis within-player and between-shot distances indicates that coordination between the CM vertical velocity and upper arm and forearm angular velocities were unique to each individual (Figure 2). Rotation of the upper arm and forearm together during the shot preparation phase – as observed in 4 of the 7 players – likely contributed to impulse generation while also placing the ball in their set position prior to the final push on the ball (Figure 2, exemplar participant P1, P2). Whereas, 3 of the 7 players waited until ground departure – approximately the time of maximum CM vertical velocity – to begin rotating the arm segments (Figure 2, participant P3). Whether the individual rotated their arms during the shot preparation phase or not, the coordination patterns were similar between shot distances. Arm contribution to impulse generation was associated with rotation of the upper arm and forearm as a unit (elbow angle remains constant) about the shoulder (Figure 2, participant P1, P2). Separation between the upper arm and forearm marked the beginning of the last push on the ball towards the hoop and typically occurred during flight. Timing of the push action was specific to the individual. For example, participant P3 began their upper arm and forearm rotation during the final push action when their CM vertical velocity was at its maximum (Figure 2, participant P3). However, participant P1 began their forearm rotation toward the hoop before they left the ground, and to a greater extent at the further shot distance (Figure 2, participant P1).

Coordination patterns within individuals were comparable between shot distances. However, greater CM vertical velocities at ground departure and at ball release were achieved when initiating the shot from the three-point line as compared to the foul line. Both the upper arm and forearm angular velocities at ball release tended to be greater for 6 of the 7 participants when shooting at the further distance (Figure 2, exemplar participant P3).

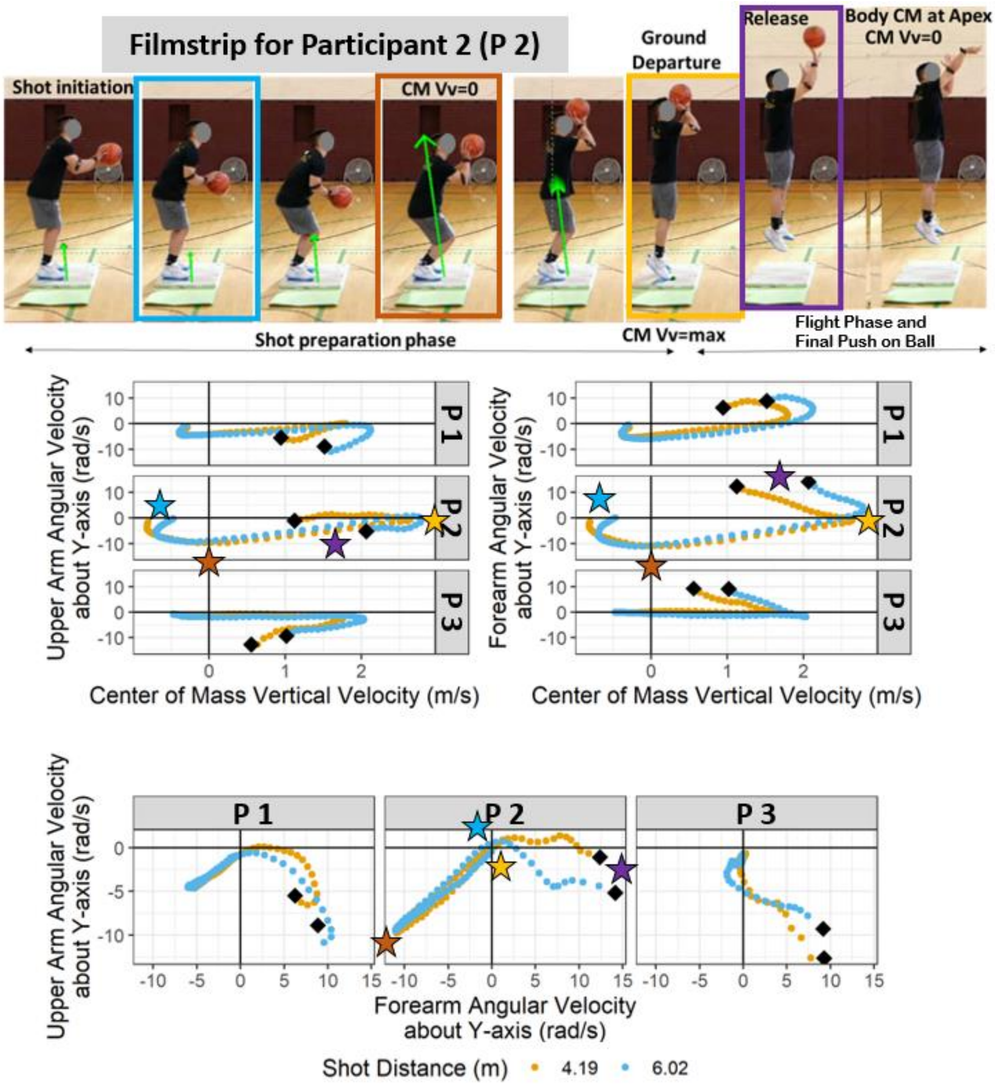

Figure 2. Coordination between median center of mass vertical velocity and upper arm (middle left) and forearm (middle right) angular velocities at two different shot distances (gold: 4.19 m; blue: 6.02 m) for three exemplar players (grey boxes). Black diamonds represent time of ball release. The colored stars correspond to key events during the shot preparation and push on the ball phases, as highlighted by the corresponding colored boxes in the filmstrip for exemplar participant P2.

DISCUSSION: The velocity of the ball at release reflects the center of mass velocity at release and the contributions of the arms. In this study, coordination of the CM vertical velocity generation and the upper extremity kinematics used by individual players to generate ball velocity during a basketball shot was characterized using phase-plane analyses. Coordination patterns within individuals were comparable between shot distances. Deviations in coordination patterns were attributed to greater CM vertical velocities at ground departure and at ball release when initiating the shot from the further distance.

During the shot preparation phase, some players rotated the upper arm and forearm together about the shoulder as a means to assist in generating vertical impulse during contact with the

ground and position the ball prior to the final push action on the ball. Using the arms to increase net vertical impulse generation during ground contact is likely beneficial when greater ball velocity at release is needed for shots initiated further from the hoop. In contrast, other players waited until ground departure to initiate the last push action on the ball by the arms.
Future studies can address the current limitations by increasing the sample size needed for statistical analyses, analyzing a more experienced population, increasing the number of successful shots analysed, and determining how an individual's coordination patterns are modified when a defender contends the shot.
For most individuals, the coordination between the body CM vertical velocity generation and arm kinematics were similar during the shot preparation – when the individual is generating impulse and raising the ball to set position. Observed differences in coordination between distances occurring during the last push action on the ball prior to ball release were attributed to the need for a greater ball velocity at release achieved by increases in the body CM vertical velocity and/or arm segment angular velocities, consistent with previous research (Miller & Bartlett, 1996, 1993; Okazaki & Rodacki, 2012; Walters et al., 1990; Wiens & McNitt-Gray, 2020).

CONCLUSION: Understanding how individuals coordinate their whole body and arms to generate the ball velocity needed at release can assist in targeted training to improve performance. This study explored how individual players coordinated CM vertical velocity generation and arm kinematics during basketball shots initiated from different distances. Generation of the ball velocity at release involved coordination between the CM vertical velocity and arm kinematics during the shot preparation and last push action on the ball. Deviations in coordination patterns between shot distances were attributed to increases in center of mass vertical velocity at ground departure and ball release, consistent with the need for a greater ball velocity at release at further shot distances. Understanding how an individual times their arm movement relative to their whole body velocity could be useful in providing feedback to improve performance.

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