THE CONTRIBUTION OF BODY CENTER OF MASS VELOCITY TO BASKETBALL BALL RELEASE VELOCITY ACROSS SHOT DISTANCES

Casey Wiens[1] and Jill L. McNitt-Gray[1,2]

Department of Biological Sciences, University of Southern California, Los Angeles, United States of America[1]
Department of Biomedical Engineering, University of Southern California, Los Angeles, United States of America [2]

This study investigated the contribution of the body center of mass velocity to basketball ball velocity at release when taking shots from different distances from the hoop. Seven basketball players with ten years of experience performed at least ten shots from progressively greater distances: close (< 2.5 m), medium (4.57 m, free throw line), and long (6.02 m, American high school three-point line). As the distance from the hoop increases, the ball velocity required at release increases. Our hypothesis was that an increase in the shot distance would increase the contribution of the body center of mass velocity to ball velocity at release was hypothesized. Kinematics of the ball were recorded using video. Reaction forces generated by each leg were measured using two force plates and used to determine the velocity of the body center of mass during the shooting motion. The results indicate that the percent contribution of the body center of mass velocity to ball velocity at release increased, and the arm contribution decreased with an increase in shot distance. Releasing the ball earlier in the body center of mass trajectory before the apex resulted in a greater percent body contribution of the center of mass vertical velocity to ball vertical velocity.

KEYWORDS: basketball, body center of mass velocity, ball velocity

INTRODUCTION: In basketball, shots occur from a variety of locations on the court. The current style of play relies more on the three-point shot, so it is beneficial to know what contributes to the mechanics of shooting at further distances. As the player releases the ball from the hands, it becomes a projectile. The trajectory of the basketball in flight is dependent on the height of the ball at release, the magnitude and direction of the ball velocity at release, and air resistance minimally influences it (Hay, 1978). The likelihood of a successful shot is dependent on ball position and velocity relative to the hoop, more than one ball trajectory can produce a successful shot from the same position on the court. The generation of the ball velocity at release is dependent on the velocity of the player (body center of mass (CM)) and the velocity of the ball relative to the CM, reflecting the contributions of the arms (Hay, 1978). Previous research of experienced players has shown with an increase in shot distance, the CM vertical velocity (Vv) at release increases (Miller and Bartlett, 1993; Okazaki and Rodacki, 2012); however, it is currently unknown if the increase in CM velocity at release reduces the percent contribution of the arms. The study aimed to determine CM velocity contributions to ball velocity at release when taking shots from different spots on the court and whether these contributions would vary across recreational players. We hypothesized that the greater the CM velocity at release, the greater the percent contribution CM velocity to ball velocity at release, consequently reducing the contribution from the arms at longer shot distances.

METHODS: Four members of the University's women's club basketball team and three male recreational basketball players with more than ten years of experience volunteered and provided informed consent. Each player shot a minimum of ten shots from three locations directly in front of the hoop: close (< 2.5 m), medium (4.57 m, free throw line), and long (6.02 m, American high school three-point line). The player received a chest-pass from someone under the hoop before shooting. The instruction was "shoot as if you were in a game." The participants shot with the size of ball they would use in competition (male: 29.5; female: 28.5).

Ground reaction forces generated by each leg were measured using two portable force plates (1200Hz, Kistler, Amherst, NY, USA). Kinematics of the ball trajectory were recorded using video (120Hz, Panasonic, Newark, NJ, USA). The CM trajectory during the shooting motion was determined using the reaction forces and measured body weight, from the when the body CM velocity ~ 0 after receiving the pass (shot initiation) to the time of ball release. Shot initiation was defined when vertical reaction force was within 20 N of body weight, and both horizontal components were +/- 30 N. Ball release was visually determined as the last moment the player was in contact with the ball. Ball trajectories after release were automatically detected from video using a custom Python code. Automatic identification of ball entry was when the center of the ball was 0.13 m above the rim (men's ball radius is 0.12 m). Ball velocity at release and entry were determined using equations of motion. All successful shot attempts and those making contact with the rim were analyzed. Pairwise comparisons using a percentile bootstrap method for medians tested for within-group differences between shot distances, and *p*-values were adjusted using the Benjamini-Hochberg method (Wilcox, 2017). Multiple comparisons using medians on difference scores tested for differences within-participant between shot distance comparisons: close-medium, close-long, and medium-long (Wilcox, 2017).

RESULTS: As expected, based on projectile equations of motion and the experimental design, the resultant, vertical, and horizontal velocity of the ball at release increased with increases in the shot distance (Figure 1). Significant group and within-participant differences between close-medium ($p<0.001$), close-long ($p<0.001$), and medium-long ($p<0.001$) shots were observed in both vertical and horizontal components of ball velocity at release.

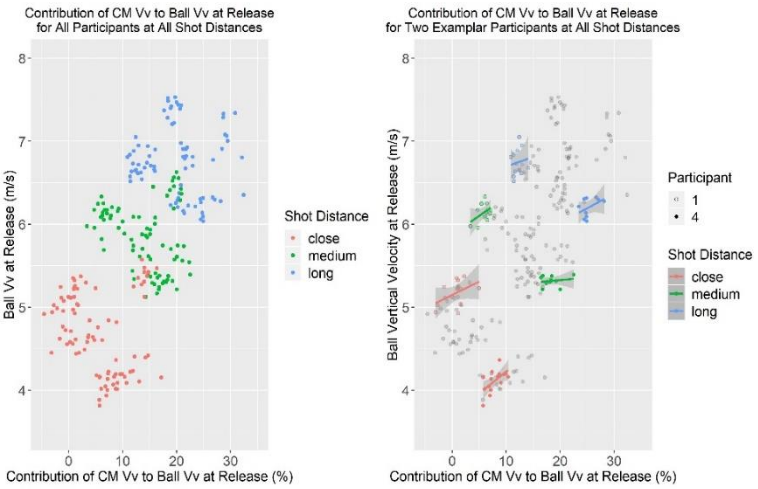

Figure 1: Contribution of CM Vv to ball Vv at release for the group and within-participant.

As a group and within-participant for all participants, CM vertical velocity at release increased with shot distance for all between shot distance comparisons (p<0.001) (Figure 2). As a group, CM horizontal velocity at release significantly increased with shot distance for all between shot distance comparisons (p<0.001) (Figure 2). However, only four of seven participants increased CM horizontal velocity when shooting from close-medium ($p<0.05$) distances. Six of seven participants increased CM horizontal velocity from close-long and medium-long ($p<0.05$), while one of seven decreased ($p<0.05$) from close-long.

As hypothesized, the contribution of CM velocity to ball velocity at release significantly increased as shot distance increased (Figure 1). The upward trend in both the clusters of group data associated with different shot distances (Figure 1: left) as well as the within-participant trends shown for two exemplar players (Figure 1: right) illustrates these differences. The contribution of CM vertical velocity to ball vertical velocity at release significantly increased as shot distance increased for all comparisons ($p<0.001$) for all but one participant (medium-long). As a group, the contribution of CM horizontal velocity to ball horizontal velocity at release also increased with shot distance (close-medium ($p=0.014$), close-long ($p<0.001$), medium-long ($p<0.001$)). Within-participant analysis revealed increased contribution of CM horizontal velocity to ball horizontal velocity at release for three of seven participants in close-medium shots and six of seven participants in close-long ($p<0.001$) and medium-long ($p<0.05$) shots.

For both the horizontal and vertical components, the greater the CM velocity at release, the greater the contribution of the CM velocity to ball velocity at release (Figure 2).

Care must be taken in interpreting group trends within shot distances. The downward trend reflects across player differences that results from across player differences in ball vertical velocities at release (Figure 1: left). Inclusion of the within player analysis avoids the appearance that increases in ball vertical velocity within a shot distance is associated with decreases in percent contribution of the CM vertical velocity to ball velocity. However, within-player analysis of the same data consistently shows nearly equal or increases in CM vertical velocity contributions to ball vertical velocity across shots.

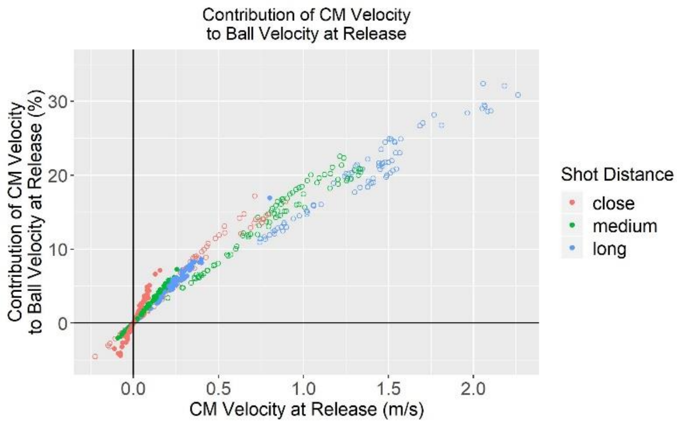

Figure 2: Contribution of CM horizontal (filled) and vertical (open) velocity to ball velocity at release in relation to CM velocity at release.

Increases in CM vertical velocity were achieved with greater net vertical impulse generation and earlier time of release relative to the apex of the CM trajectory. As a group and within-participant (p<0.001), the net vertical impulse generated by the body during shot initiation increased as shot distance increased (close-medium (p=0.018), close-long (p<0.001), medium-long (p<0.001)).

As a group, no significant differences in the time from the end of impulse generation (departure from the ground) to time of ball release were observed between shot distances. However, within-participant differences in time of ball release from the end of impulse generation were of mixed results. The same three of seven decreased time for all comparisons, one of seven increased time for all comparisons, two of seven increased time from close-medium and close-long, and one of seven increased time for close-medium and close-long but decreased time for medium-long (p<0.05).

As shot distance increased, the ball was released earlier relative to the apex in the CM trajectory (Figure 3). The time of ball release from the CM apex was significantly different in all shot distance comparisons (p<0.001). Within-participant comparisons were significantly different for all participants (p<0.001). Each participant released the ball earlier before release as the shot distance increased. Time of release to the apex of the CM trajectory during flight illustrates how a delay in release affects the contribution of CM vertical velocity at the time of ball release as well as the variations across players and shot distances (**Error! Reference source not found.**).

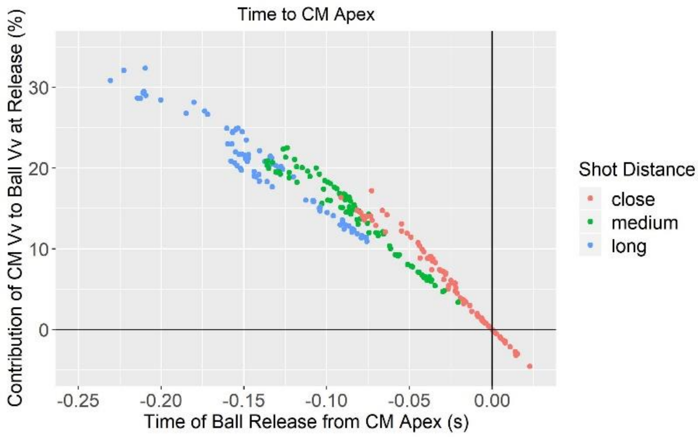

Figure 3: Contribution of CM vertical velocity to ball vertical velocity at release in relation to time of ball release from CM apex.

Ball release height increased from close-medium (p=0.050), but decreased in the other two group comparisons (close-long (p=0.002), medium-long (p=0.002)). At an individual level, three of seven participants increased ball release height from close-medium (p<0.001), two of seven increased and four of seven decreased from close-long (p<0.05), and one of seven increased and four of seven decreased from medium-long (p<0.05).

DISCUSSION: Once the player releases the ball, the ball position of the ball and ball velocity at release define its trajectory. Regulating ball velocity at release involves the utilization of CM velocity generated by the legs during the foot contact phase before release and velocity generated by the arms (Hay, 1978). In today's game, players are shooting farther from the rim. In this study, contributions of the CM velocity to ball velocity at release were compared at three distances. The results indicate, as expected, that the farther the shot, the greater the ball velocity at release. Increases in horizontal and vertical ball velocities occurred as distance increased. The control scheme of how each player increased and utilized CM velocity at release varied. In general, for participants in this study, the contribution of CM velocity to ball velocity at release increased with shot distance. Choosing when to release the ball relative to the CM apex also affected the contribution of the body CM velocity to the ball velocity at release as well as the ball position at release relative to the hoop.

As found previously, CM vertical velocity increased as shot distance increased (Miller and Bartlett, 1993; Okazaki and Rodacki, 2012). Despite a small sample size, the within-participant analysis revealed essential distinctions in how individual players utilized the CM velocity available in the shooting motion. Increasing the variety of experience levels, mainly including more skilled players, would allow us to test if these results hold across skill levels and in the context of more realistic conditions as when playing basketball with and without defenders.

The findings of this study highlight the importance of generating center of mass velocity through the interaction on the ground in that it provides options to the player. Releasing the ball earlier relative to the CM apex increases the contribution of the CM velocity to ball velocity at release, thus reducing the contribution from the arms. On the other hand, releasing the ball closer to CM apex provides an increase in the height of the ball at release, which may be advantageous when needing to shoot over an opponent.

CONCLUSION: As shot distance increases, the required velocity of the ball at release increases. Consistent with previous research, increases in shot distance caused an increase in both vertical and horizontal CM velocity at release. With increases in CM velocity, the contribution of the CM velocity to the ball velocity at release increases, consequently reducing the velocity attributed to the arms. When investigating shooting strategies, group trends may mask individual tendencies. When releasing the ball earlier before CM apex, there was a greater percent contribution from the CM vertical velocity to ball vertical velocity at release. Time of release relative to CM apex could serve as a better indicator to characterize shooting strategies than the time of release relative to the end of ground departure. Further studies will investigate the effects of the CM contributions on shooting accuracy, as well as choices made when being guarded by an opposing player.

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