Proceedings

Kinematic Differences between Set- and Jump-Shot Motions in Basketball †

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Abstract: Shooting arm motions at release in one-hand set and jump basketball shots have been analyzed using a kinematic model. Set and jump shots are classified by the vertical velocity and acceleration of the shooter's shooting-side shoulder at release. The two-dimensional three-segment model includes the vertical shooting-side shoulder velocity and acceleration. Numerical simulation investigates the effect of shoulder motion. Release backspin angular velocity can be described as a function of the vertical shoulder acceleration and the vertical fingertip acceleration relative to the shoulder. For proper backspin, jump shots require large vertical fingertip acceleration relative to the shoulder. The upward shoulder speed at release contributes to the vertical fingertip velocity relative to the shoulder for a given desired ball release speed, angle and backspin. On the other hand, upward shoulder motion does not contribute to the horizontal direction. As horizontal shot distance increases, upper arm angular speed also increases to produce the ball release conditions. Ball release with upward shoulder speed reduces the magnitudes of the upper arm, forearm and hand angular velocities. All these facts imply that the shooting arm motion in the jump shot is different from that of the set shot.

Keywords: basketball; kinematics; shooting arm motion; set shots; jump shots; upward shoulder motion

1. Introduction

When neophyte basketball players first try jump shots using techniques previously learned for set shots, they can find that the ball does not reach the hoop and has too little backspin. A set shot is defined as one in which the shooters feet are on the ground when the ball is released whereas the jump shot is characterized by a flight phase during which the ball is released. Jump shot ball-release typically occurs near the zenith of the shooter's vertical path. But in the set shot, the shooter uses knee and hip extension to accelerate the body upward and typically releases the ball before vertical body motion ceases. Thus upward body motion may contribute to ball release speed, angle and backspin in the set shot, but in the jump shot the shooting arm motion mostly produces the ball release condition because the body has almost no velocity at release.

Some previous basketball studies have commented on the mechanics of set and jump shots. Cooper and Siedentop [1] stated that, in terms of mechanics, the jump shot was remarkably similar to the set shot and it was probably correct to state that the jump shot was a set shot made by a player in the air after jumping. Satern [2] (p. 10) also mentioned that the mechanics of the set and jump shot are similar. Knudson [3] reviewed the biomechanics research on the jump shot and free throw to identify key points related to technique. Miller and Bartlett [4,5] and Okazaki and Rodacki [6] measured the shooting arm joint displacements and velocities, and investigated effects of increased shot distance. Tsarouchas et al. [7] measured shooting arm motions in free throws. These previous measurements of shooting arm motion achieved different results because they measured different sets of shooters' skill and situations.

The main kinematic differences between set and jump shots are the ball release height and the vertical motion of the shooter's shooting-side shoulder joint. The jump shot has zero or very small vertical speed of the shooting-side shoulder, whereas the set shot and the jumping shot in which shooters release the ball before the peak of the vertical path have a non-zero upward velocity of the shoulder. For a shot with a motionless shooting-side shoulder, large angular velocities at the arm joints may be required at release. Large angular velocities at the arm joint may not be required for the shot with high release point. In this paper, a kinematic model is used to analyze shooting arm velocities and accelerations with different speeds of the shooting-side shoulder at release and compare the calculated results with the previous measurements [2,4–7].

2. Kinematic Model for Shots, Assumptions and Simulation Parameters

Biomechanical research has suggested that shooters should keep the ball center, wrist, elbow and shoulder joints in a vertical plane aligned with the target [3] (pp. 67–68). A shooting arm model similar to the two-dimensional three-segment model of Schwark et al. [8] (pp. 155–156) is used. The shooting arm is assumed to move in the vertical plane and have three rigid links of an upper arm, forearm and hand with rotational joints at the shoulder, elbow and wrist joints in Figure 1. The Newtonian frame XYZ with unit vectors $\boldsymbol{I}$, $\boldsymbol{J}$, $\boldsymbol{K}$ is fixed relative to the hoop center with the XY plane horizontal and the Z axis up. The YZ plane includes the arm links. Links U, F, H and points S, E, W and $\hat{H}$ denote the upper arm, forearm and hand links, and the shoulder, elbow and wrist joints and fingertip, respectively. Body B and point B^* represent the basketball and the ball center. Arm configuration is defined using counterclockwise angular displacements of the segments from the horizontal plane; Ψ_U of the upper arm; Ψ_F of the forearm; Ψ_H of the hand and Ψ_B of the line including the fingertip and the ball center. The arm lengths are calculated by using the measurement of De Leva [9] (p. 228) and the lengths $L_U = 0.325$ m, $L_F = 0.310$ m and $L_H = 0.230$ m for a 201-cm forward player are chosen.

The set and jump shots are classified by the vertical velocity and acceleration of the shooter's shooting-side shoulder at release. It is assumed that the motion of the shoulder coincides with the motion of the mass center of the shooter including the basketball. Also, the horizontal velocity and acceleration of the shoulder are assumed to be zero because highly skilled shooters have less horizontal shift in the mass center during the shot [3] (p. 67). Arm position is specified by the arm angular displacements $\Psi_F = \Psi_H = \Psi_B = \pi/2$ rad and $\Psi_U = \pi/4$ rad referred to [10] (p. 445). Because the angular velocities of the forearm and hand are usually negative and the magnitude of angular velocity of the hand is usually larger than that of the forearm, the range of the angular velocities is $\dot{\Psi}_H \leq \dot{\Psi}_F \leq 0$ [10] (p. 446). The ball is released l m away from and h m below the hoop center with the release speed v, angle α and backspin angular velocity ω. When the shooter releases the ball without slipping between the fingertip and the ball surface at the fingertip contact point, the ball release angular velocity ω equals $\dot{\Psi}_B$. The kinematic model compares the shots with different ball release position ($4 \leq l \leq 7$ m, $0.15 \leq h \leq 0.60$ m) of the minimum ball release speed [11] (pp. 358–359) in the pure gravitational flight with no air drag. The release angle can be written as $\alpha = (\pi/4) + (1/2)\tan^{-1}(h/l)$ rad. The release speed is $v = \sqrt{gl/[2\cos^2\alpha\,(\tan\alpha - h/l)]}$. The backspin is assumed to be a function of the horizontal shot distance $\omega = 2\pi(l + 2)/3$ rad/s where the middle-(l = 4 m) and long-range (l = 7 m) shots have 2 Hz and 3 Hz backspin, respectively. The vertical shoulder speed $\dot{z}_S$ at release is also assumed to be $\dot{z}_S = \sqrt{2g(h - 0.15)}$ m/s. When the shooter releases the ball with the release height 0.15 m below the hoop, the shot is the jump shot with the zero vertical shoulder speed. For example, when the shooter releases the ball at $(l, h) = (7, 0.15)$ m, the ball release speed, angle, and backspin angular velocity are $v = 8.376$ m/s, $\alpha = 0.2534\,\pi$ rad and $\omega = 6\,\pi$ rad/s and the vertical shoulder speed is zero.

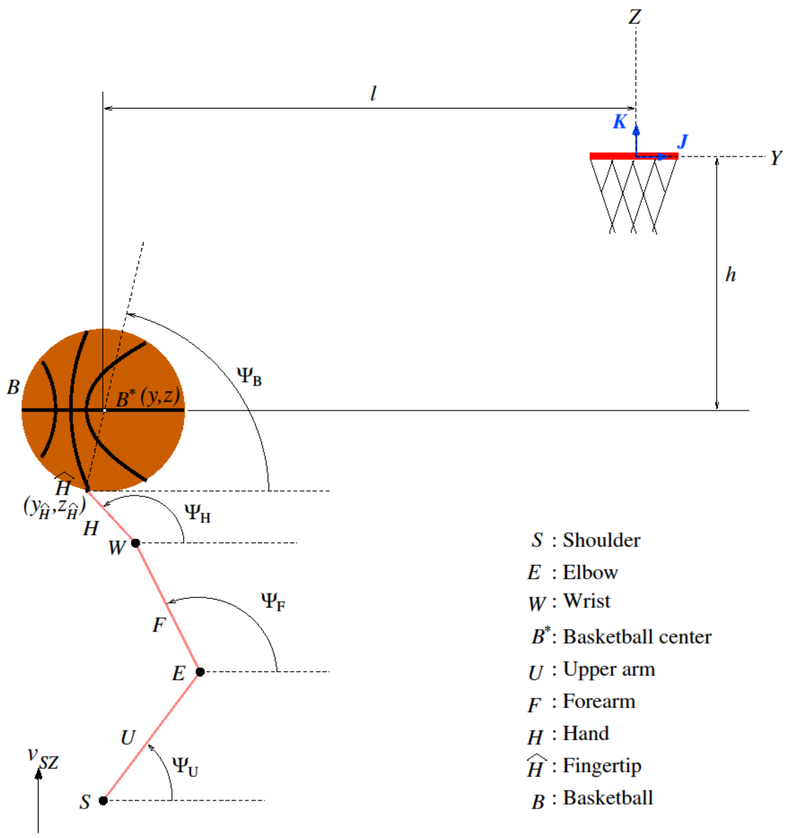

Figure 1. Geometry of shooting arm motion with a basketball.

3. Results and Discussion

The four constraints [12] (pp. 134–135) relating fingertip velocity and acceleration as a function of the ball release speed, angle, and backspin become:

$$
\begin{aligned}
{}^{N}\boldsymbol{v}^{\hat{H}} &= (v\cos\alpha + R_b\omega\sin\Psi_B)\boldsymbol{J} + (v\sin\alpha - R_b\cos\Psi_B)\boldsymbol{K},\\
{}^{N}\boldsymbol{a}^{\hat{H}} &= R_b\omega^2\cos\Psi_B\boldsymbol{J} + (R_b\omega^2 - g)\boldsymbol{K}.
\end{aligned}
\tag{1}
$$

By adding the vertical shoulder motion and substituting $\Psi_B = \pi/2$ rad, the constraints become

$$
\begin{aligned}
{}^{N}\boldsymbol{v}^{\hat{H}/S}\cdot\boldsymbol{J} &= v\cos\alpha + R_b\omega,\\
{}^{N}\boldsymbol{v}^{\hat{H}/S}\cdot\boldsymbol{K} + v_{SZ} &= v\sin\alpha,\\
{}^{N}\boldsymbol{a}^{\hat{H}/S}\cdot\boldsymbol{K} + a_{SZ} &= R_b\omega^2 - g.
\end{aligned}
\tag{2}
$$

where v_{SZ} and a_{SZ} are the vertical shoulder velocity and acceleration.

The backspin can be written as

$$
\omega = \sqrt{\frac{{}^{N}\boldsymbol{a}^{\hat{H}/S}\cdot\boldsymbol{K} + a_{SZ} + g}{R_b}}
\tag{3}
$$

The backspin is a function of the vertical shoulder acceleration and the vertical fingertip acceleration relative to the shoulder. Figure 2 highlights the possible backspin when the shooter releases the ball in the air $(a_{SZ} = -g)$ and just before the shooter takes off the floor $(a_{SZ} = 0)$. When the shooter attempts the jump shot, large magnitude of the vertical fingertip acceleration relative to the shoulder is required. This may be one of reasons why unskilled players are not able to impart the proper backspin in the jump shot.

The horizontal and vertical components of the fingertip velocity relative to the shoulder are plotted with the different ball release positions in Figure 3. Higher ball release has the lower vertical shoulder speed on the assumption. Lower ball release requires larger ball release speed. The shot with large upward shoulder speed at release has small vertical fingertip speed relative to the shoulder. The shot with the same horizontal shot distance has the same horizontal fingertip speed relative to the shoulder. The vertical shoulder speed contributes to the vertical fingertip speed relative to the shoulder but does not contribute to the horizontal.

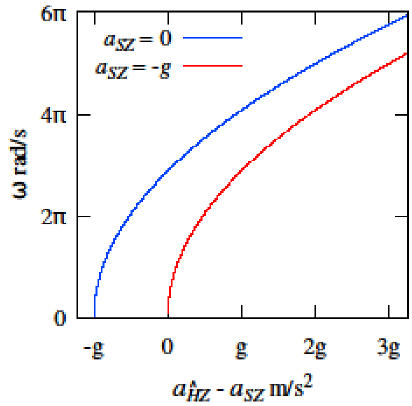

Figure 2. Possible backspin angular velocities as a function of the vertical fingertip acceleration relative to the shoulder for the shots with the vertical shoulder acceleration $a_{SZ} = 0$ with and $a_{SZ} = -g$.

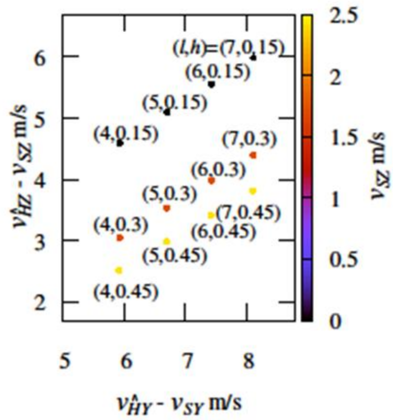

Figure 3. Horizontal and vertical components of the fingertip velocity relative to the shoulder as a function of the vertical fingertip speed relative to the shoulder.

The model investigates shooting arm motions for the shots with the different ball release positions. When $\Psi_U = \pi/4$ rad, the constraints including the shooting arm angular velocities become

$$-\frac{L_U}{\sqrt{2}}\omega_U - L_F\omega_F - L_H\omega_H = v\cos\alpha + R_b\omega$$
$$\frac{L_U}{\sqrt{2}}\omega_U + v_{SZ} = v\sin\alpha \quad (4)$$

where ω_U, ω_F, and ω_H are the angular velocities of the upper arm, forearm and hand, respectively. Figure 4 shows the upper arm angular velocity for the different horizontal shot distance. As horizontal shot distance increases, angular velocity of the upper arm also increases for the different release heights. We have previously pointed out that shoulder rotation is important for making a good arch [10] (pp. 446–447) of the jump shot with zero vertical shoulder speed at release. Although large vertical ball release speed is required in the set shot, the upper arm angular velocity is smaller than that in the jump shot because of upward shoulder speed. Miller and Bartlett [4] (p. 289) mentioned that the values for shoulder angular velocity tended to remain constant for different shot distances. Their measurements of the ball release speed and angle were different from the suggestion of the optimal ball release angle [11] (pp. 358–359). The measurements of Okazaki and Rodacki [6] (p. 235) showed that as horizontal shot distance increased the upper arm angular velocity also increased but the relations were not proportional.

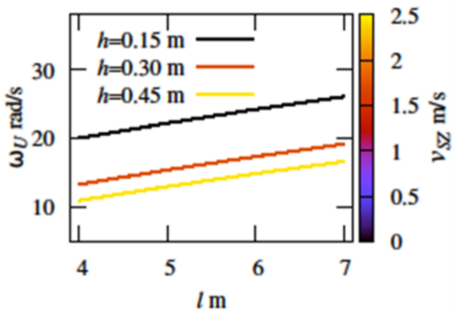

Figure 4. Upper arm angular velocity for the different ball release positions. Lower release shots have larger vertical shoulder speed at release. As horizontal shot distance increases, upper arm angular velocity also increases.

The model estimates the hand and forearm angular velocities for the different horizontal shot distances of h = 0.15 m and h = 0.30 m as shown in Figure 5. For the shot with the low release and large vertical shoulder speed at release (Figure 5b), smaller magnitudes of the hand and forearm angular velocities are required. We have also pointed out that upper arm rotation contributes to the vertical component of release velocity of the ball, and the forearm and hand actions mostly produce the horizontal component of ball release velocity and the release backspin for the shot with zero shoulder speed at release [10] (pp. 447–448). The upward shoulder speed at release reduces the magnitudes of the hand and forearm angular velocities, although the vertical shoulder speed at release contributes to the vertical fingertip velocity relative to the shoulder and does not contribute to the horizontal fingertip speeds relative to the shoulder (Figure 3). The direction of the angular velocity of the upper arm is opposite to that of the forearm and hand at release. When the magnitude of the upper arm angular velocity increases, the shooter must produce large magnitudes of the hand and forearm angular velocities. For the shot with upward shoulder speed, the angular speeds of upper arm, forearm and hand can be reduced.

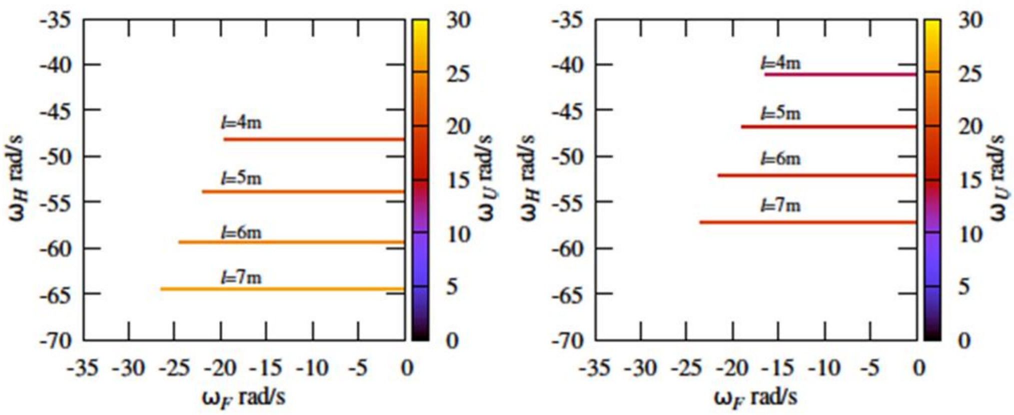

Figure 5. Hand and forearm angular velocities as a function of the upper arm angular velocity for the different horizontal shot distances of (**a**) h = 0.15 m and (**b**) h = 0.30 m.

4. Conclusions

A kinematic model including the shoulder vertical motion has analyzed the shooting arm motions. When the shooter releases the ball in the air, large fingertip acceleration relative to the shoulder is required for the proper backspin. The vertical shoulder speed directly contributes to upper arm rotation. As horizontal shot distance increases, upper arm angular speed also increases. The ball release with non-zero vertical shoulder speed reduces the magnitudes of the upper arm, forearm and hand angular velocities. In the jump shot, upper arm rotation produces good arch, and the motion of forearm and hand controls the horizontal shot distance and backspin. In the set shot, thanks to upward shoulder motion, the speeds of shooting arms can be reduced at release and the shooter has more chance to attempt long-range shots. Our results are related to what is the optimal combination of the shooting arm motion for high percentage shots. Dynamics with kinetic analysis suggest the best strategy for basketball shooting motion.

Conflicts of Interest: The authors declare no conflict of interest.

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