Influence of Selection of Release Angle and Speed on Success Rates of Jump Shots in Basketball

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Abstract: Enhancing the successful jump-shot percentages in basketball is critical for winning a game. A selection of release parameters and variability can influence the success rate, but the actual selection of the release parameters and variabilities in those during jump shots and the influence of this selection on success rate have not been investigated and are not understood well. Thus, the purpose of this study was to investigate the influences of the selection of release angle, release speed and spin rate, and variability on the success rate of jump-shots in basketball. Ten male collegiate basketball players participated in the study and actual ball trajectories for the jump-shots from the free-throw (FT) and three-point (3P) lines were recorded by the three-dimensional motion analysis system. The experimental data was compared with the theoretical optimal release parameters. We found that the players with higher success rate in FT shots had a higher release position, a lower release velocity, and a larger margin for error for the release speed. On the other hand, for the 3P shots, the player with a larger margin for error for the combination of the release speed and angle had higher success rate. Variability in release parameters did not have significant correlation with the success rate. Thus, it can be said that selecting the release parameters that allow greater margin for error was important for increasing the success rate. Also, depending on the required release speed or the shooting distance, the strategies for the selection of the release parameters must be adjusted to increase the success rate in jump-shots.

1 INTRODUCTION

Shooting is the only way to score in basketball, and needless to say, it is very important skill in a basketball game. In particular, it has been reported that jump shots are effective and one of the most frequently used styles of shots in a basketball game (Knudson, 1993). Thus, enhancing the successful jump-shot percentages is critical for winning a game.

A ball trajectory with higher success rate can be considered from the number or range of possible successful trajectories from a certain release position. Since the size of the basketball ring (diameter: 0.45 m) is about the twice the size of the basketball (diameter: 0.25 m), the range for a successful paths for a ball passing through the basket is not limited to one, but there is a margin for error for the trajectories (Brancazio, 1981). Thus, the selection of the conditions that increase this margin for error is one factor that enhances the shooting success rate.

The range of successful paths is influenced by the entry angle of the ball into the basket ring. This is because a higher entry angle (closer to perpendicular) provides a larger area for the successful paths of a ball passing through the basket. Since the trajectory of the ball after it is released from the hand of a player can be regarded as parabolic motion, the release parameters such as the release speed, release angle, and release height are the main factors that influence the trajectory and arrival position of the ball. In particular, influences of selection of release angle and speed with a fixed release height have been investigated. As for the release angle, since it affects the entry angle into the basket ring (Brancazio,1981; Miller and Bartlett, 1996) and a greater release angle provides a larger area for the ball to pass through the ring, a higher release angle can be regarded as advantageous. That is, the range of speed for a successful trajectory becomes larger for a higher release angle. The range of release speeds at a selected release angle is called the margin for error for the speed. Thus, it can be assumed that it is advantageous to increase the release angle in order to achieve a larger margin for error for the speed.

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However, if the release angle is increased, a higher release speed is required, which can negatively affect the consistency and accuracy of the movement (Knudson, 1993). This is because a low release velocity accompanies a decreased movement variability and results in a lower variability in release velocity (Darling & Cooke, 1987). Thus, increase in the release angle that is higher than necessary can be disadvantageous for enhancing the shooting success rate. At the same time, a margin for error for the angle also exists for a certain release speed; thus, maximization of this margin for error should also be taken into consideration.

Considering this trade-off between the release angle and the release speed, Brancazio(1981) introduced the existence of the "minimum-speed angle". The ratio of the margin for error for the speed to the release speed is very small compared to the release angle. Also, releasing a ball at the minimum speed requires minimum force. Thus, minimizing the release speed was used as the criteria to choose the optimal combination of the release angle and speed. There exists a release angle that causes the ball to arrive at the center of the ring at minimum speed, which was referred to "minimum-speed angle." Thus, theoretically, the minimum-speed angle was regarded as the optimal release angle that maximise the margin for error and achieves movement consistency.

Though theoretically established, the actual selection of the release parameters by players during jump shots and the influence of this selection on success rate have not been investigated and are not understood well. In addition, the variability in the release parameters has not been investigated thoroughly with a combination of the optimal selection. It is possible that the variabilities in the release angle and speed influence the success rate. Thus, the purpose of this study was to investigate the influences of the selection of the release parameters (the release angle and the release speed) and variability on the success rate by comparing the calculated theoretical optimal release parameters.

In addition to the release angle and release speed, the spin rate possibly influences the trajectory and success rate. It has been reported by numerical analysis that having back spin and increasing the spin rate to about 3 Hz increase the possibility that free-throw shots are made (Hamilton and Reinschmidt, 1997; Silverberg et al., 2003; Okubo and Hubbard, 2006; Tran and Silverberg, 2008). In these studies, the main influence of back spin was not on the trajectory in air, but rather the behavior of the ball upon collision with the ring or backboard. In fact, these studies neglected the influences of the drag force and lift force in air, and some studies reported that the air resistance is negligible and does not have a significant effect on the trajectory of a ball (Okazaki and Rodacki, 2012). However, Brancazio (1981) mentioned that air resistance does have an effect on the trajectory though it is almost neligible. Therefore, in our study, effects of spin and aire resistance on the ball trajectory was examined by analyzing the entire trajectory of the ball from release to arrival at the basket since the selection of the release parameters can be influenced if they affect the trajectories. Thus, the influences of the spin rate on the trajectory and the combination of the release angle and release speed were also investigated by simulating the ball trajectory at different ball spin rates.

By investigating the actual selection of and variability in the release parameters (the release angle, speed, and spin rate) for basketball jump shots and the influence on the success rate, we believe that the results will provide reference for selecting release parameters during coaching or training of jump shots.

2 METHODS

2.1 Participants

Ten male collegiate basketball players (height: 1.86 ± 0.07 m, body mass: 82.1 ± 7.4 kg, age: 22 ± 1 years-old, years of experience in basketball: 13 ± 3 years, mean ± standard deviation (SD)) who belong to a collegiate basketball team in the Japanese Kanto College Basketball Division 1 League participated in this study. Three players were selected to Japanese National Basketball Teams for the Universiade (or World University Games). Written informed consent to participate in the study was obtained from all participants after informing them of the purpose of this study and explaining the procedure and possible risks of the study. The study protocol was approved by the Human Subjects Committee of the Japan Institute of Sports Sciences.

2.2 Experimental Procedure

After a sufficient warm-up period, the participants attempted 100 jump shots. Fifty shots were from the three-point line (6.75 m away from the center of the ring in the horizontal direction: 3P), and another 50 shots were from the free-throw line (4.23 m away from the center of the ring in the horizontal direction: FT). Shots were attempted after receiving a pass from an experienced basketball player positioned under the basketball goal ring. Participants were instructed to “shoot as you do in the game,” or a quick shot released at high position. Participants took a short break after each set of 25 shots.

2.3 Data Collection

Forty-eight reflective markers were attached to the participants, and 9-11 reflective marks were randomly attached to the surface of the basketball. The positions of these markers and the marks during shooting motion were obtained using a three-dimensional motion analysis system using 20 cameras operating at 500 Hz (VICON MX series, Vicon Motion Systems Ltd., Oxford, UK).

2.4 Data Processing

The ball trajectories and spin rate were computed using the obtained markers attached to the ball’s surface. To take the possible influences due to air drag and lift force into consideration, the coefficients of drag and lift, the release speed, the release angle, and the position of the ball at the height of ring were estimated by optimization. A successful combinations of a release angle and release speed from a mean release height and horizontal distance from the ring center, and spin rate was calculated by solving the equation of motion for the ball including the drag and lift forces. The margins for error for the release angle and speed were calculated and theoretically optimal parameters were compared with those that the participants actually selected. The ball trajectories were also simulated at a higher spin rate to investigate the influence of the increased spin rate on shot success possibility.

2.4.1 Ball Trajectory

The trajectories of the ball center $\boldsymbol{r}_{\mathbf{ball}} = (x_0, y_0, z_0)$ were computed using the positional data of the marks attached to the surface of the basketball (x_i, y_i, z_i). The relation between $\boldsymbol{r}_{\mathbf{ball}}$ and the positional data of the ball surface marks are expressed as equation of sphere (1).

$$(x_i - x_0)^2 + (y_i - y_0)^2 + (z_i - z_0)^2 = \left(\frac{1}{2}D_b\right)^2 \quad (1)$$

Thus, the position of center of the ball $\boldsymbol{r}_{\mathbf{ball}}$ was determined through optimization to minimize the least-squares deviation.

where D_b is the diameter of the basketball (0.245 m).

2.4.2 Computation of the Drag and Lift Coefficients and Release Parameters

Since the raw ball trajectory data was different from the calculated trajectory from the initial velocity by a significant amount, it was assumed that there were significant influences due to drag and lift forces on the ball. The equation of motion for the ball in air was formulated as follows (Yasuda, 2014):

$$\ddot{\boldsymbol{r}}_{\mathbf{ball}} = \boldsymbol{a}_{\mathbf{D}} + \boldsymbol{a}_{\mathbf{N}} + \boldsymbol{a}_{\mathbf{G}} \quad (2)$$

where $\ddot{\boldsymbol{r}}_{\mathbf{ball}}$ is the acceleration of the ball, $\boldsymbol{a}_{\mathbf{D}}$ is the acceleration by drag force, $\boldsymbol{a}_{\mathbf{N}}$ is the acceleration by lift force, and $\boldsymbol{a}_{\mathbf{G}}$ is the gravitational acceleration. Here, $\boldsymbol{a}_{\mathbf{D}}$ was computed from equation (3):

$$\boldsymbol{a}_{\mathbf{D}} = -\frac{k}{m} q \boldsymbol{v} \quad (3)$$

where m is the mass of the ball, q is the speed of the ball, $\boldsymbol{v}$ is the velocity vector, and k is calculated by the following equation (4):

$$k = \frac{1}{2}\rho S C_{\mathrm{D}} \quad (4)$$

where ρ is the air density, S is the cross sectional area of the ball, C_{D} is the coefficient of drag force. $\boldsymbol{a}_{\mathbf{N}}$ was calculated by the following equation (5):

$$\boldsymbol{a}_{\mathbf{N}} = \frac{l}{m} q \boldsymbol{e}_{\mathbf{A}} \times \boldsymbol{v} \quad (5)$$

where $\boldsymbol{e}_{\mathbf{A}}$ is the unit vector of the axis of rotation of the ball, and l is calculated by the equation (6):

$$l = \frac{1}{2}\rho S C_{\mathrm{L}} \quad (6)$$

where C_{L} is the coefficient of lift force. The release position, the release speed, the coefficient of drag force, and the coefficient of lift force were determined through optimization by a genetic algorithm to minimize the least-squares deviation between the calculated and actual (raw) trajectories.

2.4.3 Computation of Successful Combination of Release Angle and Release Speed

The ball trajectories were recalculated for various combinations of the release angle and the release speed with the mean release height, horizontal distance from the ring center, spin rate, and coefficients of drag and lift of fifty shots of each player by solving the equation of motion using a fourth order Runge–Kutta algorithm. The position of the ball when it reached the height of the goal ring was calculated (arrival position). A shot was regarded as successful if the arrival position was within the successful region ($x < \Delta L$ and $y < \Delta Y$, Fig. 1) where it could go through the ring without touching the rim (swish) or barely touching the rim (swish ± 50 mm region), which were calculated by the following equations:

$$\Delta L = \frac{1}{2}(D_r - \frac{D_b}{\sin\theta_e}) \tag{7}$$

where D_r is the diameter of the ring (0.45 m) and θ_e is the entry angle calculated by equation (8) as reported in Brancazio (1981) :

$$\theta_e = \arctan(\tan\theta_0 - \frac{2h}{L}) \tag{8}$$

where θ_0 is release angle, h is the vertical distance between release height and basket height (3.05 m). Also, the mediolateral boundary was calculated as equation (9):

$$\Delta Y = \sqrt{(\frac{1}{2}(D_r - D_b))^2 - x^2} \tag{9}$$

where x is the anteroposterior distance between center of the ring and the arrival position of the ball.

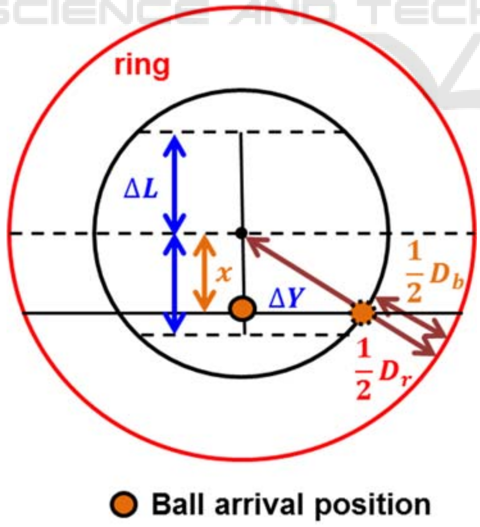

Figure 1: Calculation of successful region of arrival position of the ball.

2.4.4 Margin for Error for Release Angle and Release Speed

The margin for error for the release angle at the selected release speed and the margin for error for the release speed at the selected release angle were calculated at mean release height, horizontal distance from the ring center, and spin rate. In particular, the margin for error for the release angle and release speed at the mean release speed and release angle of each player were calculated and compared with the release speed and release angle that maximize the margin for error to evaluate the selection of the release parameters.

2.4.5 Influence of Spin Rate on the Successful Shot Possibility

The influence of the spin rate on the successful combination of the release angle and the release speed for the 3P shot was investigated by simulating the ball trajectory with an increased spin rate and the corresponding lift and drag coefficients for one subject. The original spin rate for this subject was 109 rotations per minute (RPM) and was altered to 145 RPM which was equal to the highest spin rate of all players.

2.4.6 Statistics

A Pearson correlation coefficient was used to establish relationships between the success rate and the horizontal distance from the ring center, release angles, speed, and margins for errors. The level of significance was set at $P < 0.05$.

3 RESULTS

3.1 Successful Shot Percentages and the Arrival Position of the Ball

The number of shots made and the mean and SD of the distance from the ring center for FT and 3P shots for all participants are listed in Table 1 and Table 2. The successful shot percentages were lower for 3P than FT shots and there were differences in the percentages between the players. A significant correlation between the successful shot percentage and the SD of the anteroposterior distance of arrival position of the ball from the ring center for 50 FT shots in FT (r = -0.68, p < 0.05) was observed but not for 3P shots. For instance, for 3P shots, player 4 whose shot percentage was the lowest among all players had larger mean anteroposterior and mediolateral distances from the ring center but the SDs were not the largest among all players.

Table 1: Percentages of shots made for each player and arrival positions in FT shots.

FT	# of shots made	Distance from ring center for 50 shots [cm]			
		Anteroposterior		Mediolateral	
ID		Mean	SD	Mean	SD
1	47	2.3	7.4	1.3	5.3
2	45	0.2	7.8	4.2	6.1
3	44	11.4	9.2	2.8	5.0
4	42	5.7	9.4	3.9	6.4
5	32	12.5	12.0	-1.3	6.9
6	46	6.1	11.1	1.3	5.8
7	41	4.3	8.7	-2.4	6.1
8	42	-0.1	9.0	-2.2	6.2
9	46	7.6	7.6	-1.7	7.4
10	39	5.2	9.7	0.9	8.4
Mean	42 (84%)	5.5	9.2	0.7	6.4
SD	4.5	4.2	1.5	2.5	1.0

Table 2: Percentages of shots made for each player and arrival positions in 3P shots.

3P	# of shots made	Distance from ring center for 50 shots [cm]			
		Anteroposterior		Mediolateral	
ID		Mean	SD	Mean	SD
1	36	4.2	7.8	3.1	10.5
2	33	-1.9	9.1	0.1	9.2
3	36	6.7	11.7	3.8	6.4
4	17	18.9	11.4	7.7	10.7
5	27	7.1	9.3	-1.4	12.1
6	34	7.4	12.7	-3.1	10.4
7	26	4.0	10.1	-5.4	9.9
8	31	-2.2	10.0	-2.9	8.1
9	36	5.7	11.1	1.0	9.1
10	35	1.9	9.4	2.6	8.7
Mean	31 (62%)	5.2	10.3	0.6	9.5
SD	6.2	5.9	1.5	3.9	1.6

3.2 Comparison of the Selected Release Parameters and the Theoretical Optimal Combination

For FT shots, significant correlations between the success rate and the release height ($r = 0.82$, $p < 0.05$) and release speed ($r = -0.64$, $p < 0.05$) were observed. The release angle and its variability, and the variability in the release speed did not have significant correlation with the success rate. Moreover, players with a larger margin for error for the release speed at his mean release angle had a higher success rate ($r = 0.64$, $p < 0.05$). For player 9 with a higher FT success rate (92%), the mean release angle (50.4°) was higher than the minimum-speed angle (47.6°), and the mean release speed (6.90 m/s) was close to the release speed that maximizes the margin for error for the release angle (6.86 m/s) (Figs.2 and 3). For player 5 with the lowest FT success rate (64%), the mean release angle (46.6°) was lower than the minimum-speed angle (49.6°), and the mean release speed (6.97 m/s) was close to the release speed that maximizes the margin for error for the release angle (6.93 m/s) (Figs.2 and 3).

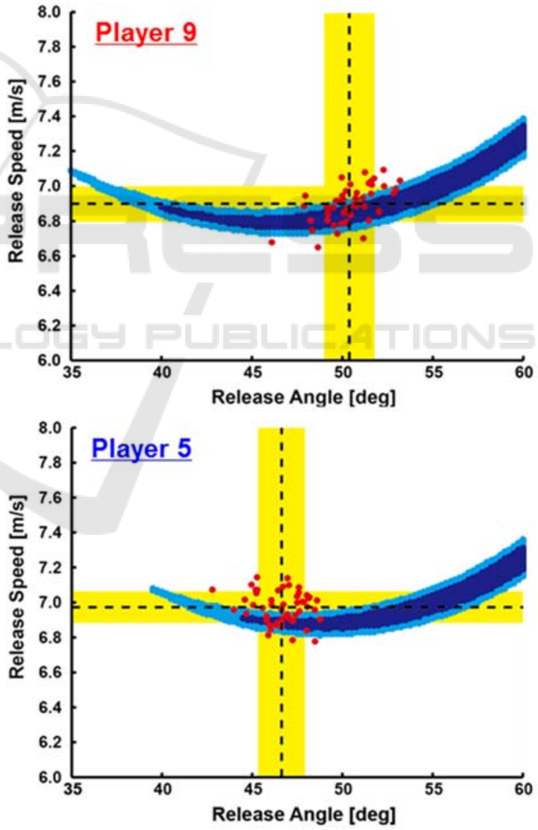

Figure 2: Theoretical successful combination of the release angle and release speed (dark blue: swish, light blue: swish±50 mm) and the experimental data (red) for player 9, whose successful rate was high (top), and for player 5, whose successful rate was the lowest (bottom) in FT shots.

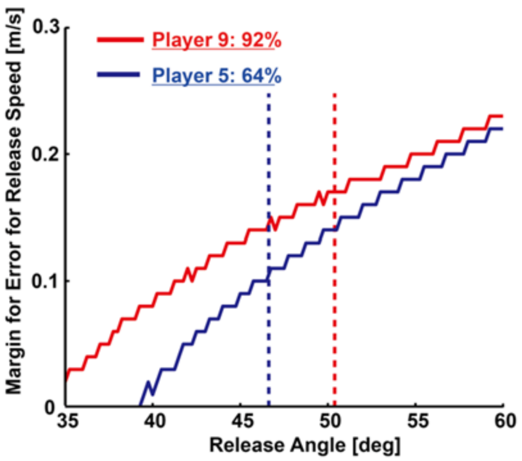

Figure 3: Margin for error for the release speed for player 9 (red) and player 5 (blue) in FT shots. The dashed lines show the mean release angle for each player and the solid lines show the computed margin for error for the release speed at the selected release angle.

For 3P shots, no significant correlation was observed for the release parameters and those variabilities, and success rate. No significant correlations between the margins for error for the release speed and the release angle, and success rate were observed. However, considering the combined margin for error for both the release speed and release angle were computed (margin for error for the speed × margin for error for the angle), a significant correlation ($r = 0.70$, $p < 0.05$) was observed. For player 1 with the highest success rate for 3P shots (72%), the mean release angle (46.1°) was close to the minimum-speed angle (47.0°), and the mean release speed (8.61 m/s) was close to the release speed that maximizes the margin for error for the release angle (8.62 m/s). For player 4 with the lowest success rate for FT shots (34%), the mean release angle (50.4°) was higher than the minimum-speed angle (48.4°), and the mean release speed (8.75 m/s) was also higher than the release speed that maximizes the margin for error for the release angle (8.63 m/s). For player 4, the actual combination of release parameters was different than the theoretical successful combination (Figs 4 and 5).

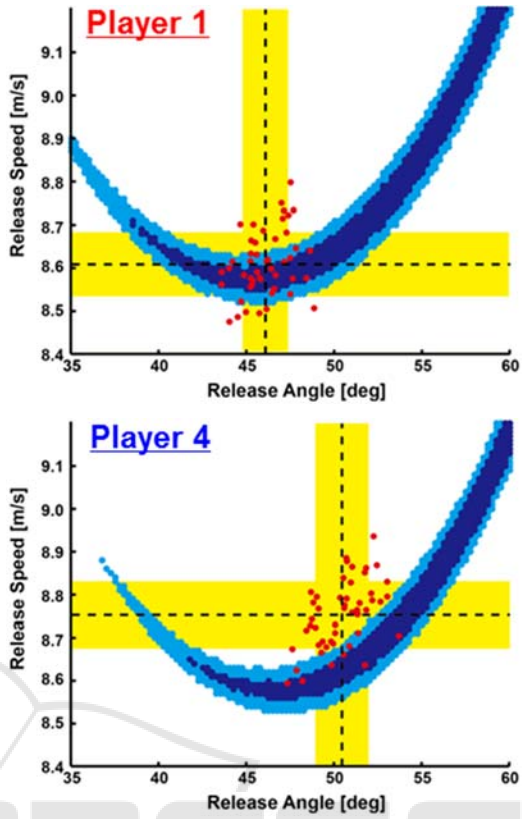

Figure 4: Theoretical successful combination of the release angle and release speed (dark blue: swish, light blue: swish±50 mm) and the experimental data (red) for player 1, whose successful rate was one of the highest (top), and for player 4, whose successful rate was the lowest (bottom) in 3P shots.

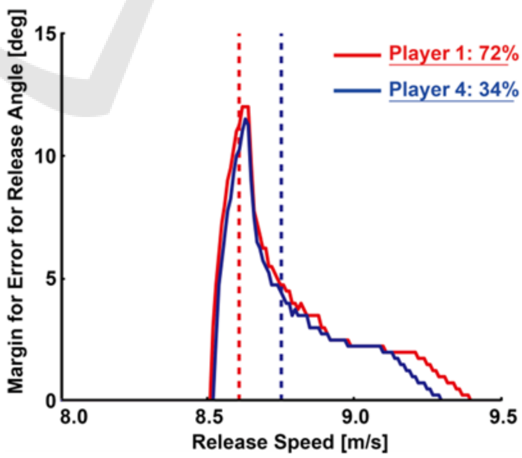

Figure 5: Margins for error for the release angle for player 1 (red) and player 4 (blue). The dashed lines show the mean release speed for each player, and solid lines show the computed margin of error for the release angle at the selected release speed.

3.3 Influence of Spin Rate on the Theoretical Optimal Combination

Noticeable changes in the successful combination of release angle and speed were observed when the ball trajectories were simulated with different spin rate (Figs. 6 and 7). For the selected release angles, the corresponding release speeds resulting in successful trajectories were lower for the higher spin rate condition. Also, the region of release speed resulting in successful shot was greater when the spin rate was higher.

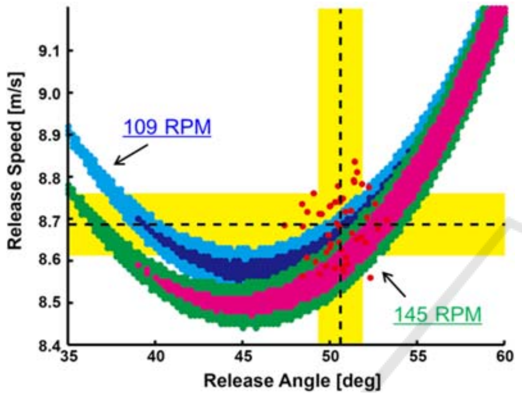

Figure 6: Theoretical successful combination of the release angle and release speed with different spin rate (dark blue and light blue: original spin rate 109 RPM, green and pink: increased spin rate 145 RPM).

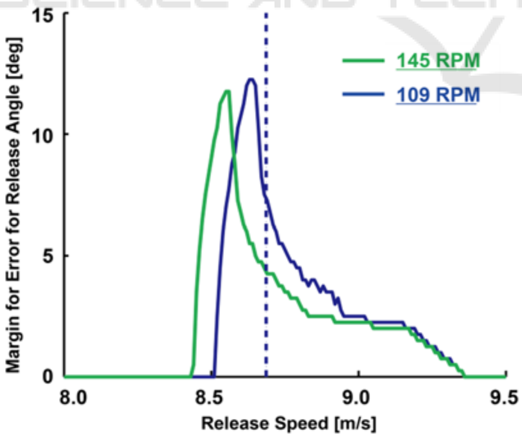

Figure 7: Margins for error for the release angle simulated at original spin rate (blue) and increased spin rate (green) for 3P shot.

4 DISCUSSION

The purpose of this study was to investigate the influences of the selection of release angle, release speed and spin rate and variability on the success rate of jump-shots in basketball by comparing the theoretical and actual release parameters. The greater influence of selection of the release angle and release speed than those variabilities on the success rate during jump shots from different distances was revealed in this study. For FT shots, players with a higher release position, a lower release speed, and a larger margin for error for the release speed had higher success rate. For 3P shots, player with a larger margin for error for the combination of the release speed and angle had higher success rate. However, the variabilities in release speed and angle did not have significant correlations with the success rate. Thus, it can be said that selecting the release parameters that allow greater margin for error was important for increasing the success rate.

For FT shots, players who selected the release angle with larger margin for error for the release speed had higher success rate. It must be noted that this accompanied lower release speed and higher release height, which are assumed to have played a role in minimizing the variability in release speed as reported by Knudson(1993).On the other hand, for shots from a larger distance, it is difficult to maintain a low variability in the release speed since the amplitude is higher. If release angle was increased in addition to the increased release speed, it would negatively affect the variability. Therefore, it is expected that the players with a higher success rate did not simply increase the release angle to increase the margin for error for the release speed, but selected the region that can maximize the margins for error for both release angle and speed. In fact, there was one player who selected high release angle yet had higher success rate (Fig. 8). Though this player selected relatively high release angle, the selection of release speed was adjusted according to the release angle. Also, since the selected combinations of release angle and speed were almost within the successful region, he could achieve high success rate.

Thus, for shots from a larger distance, it is not recommended to increase the release angle to increase the margin for error for the release speed unless the player can keep the variability low with the increased release angle. On the other hand, for shots from a close distance, the variability is not negatively affected by increasing the release angle since the release speed required is smaller. Therefore, it is recommended to increase the release angle to the extent that does not affect the variability. However, it must be noted that the trend in changes in variability depending on the shot distance varies with the levels of players. Also, this study did not assume indirect shots (interaction with the backboard and ring), which can also influence the success rate. In addition, the mean body height of the participants was relatively high, which could contribute to reduce the variability of the shots since smaller release speed and angle are required for the shots with higher release point.

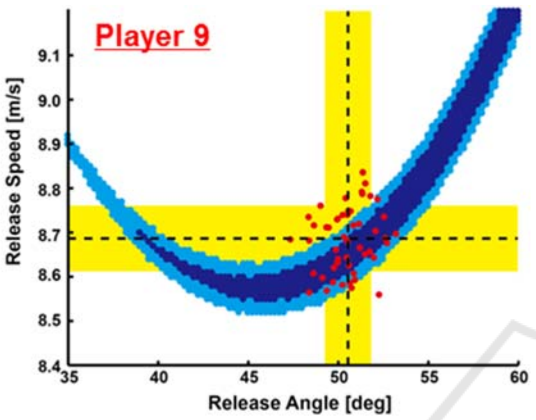

Figure 8: Theoretical successful combination of the release angle and release speed (dark blue: swish, light blue: swish±50 mm) and the experimental data (red) for player 9, whose successful rate was one of the highest.

The spin rate also had a significant effect on the successful combination of the release speed and angle. At the higher spin rate, the required speed at the selected release angle was reduced (Fig. 6). Also, the release speed that maximizes the margin for error for release angle was lower for the increased spin rate. It is assumed that by increasing the spin rate, the ball experienced greater lift force, which resulted in the trajectory with higher arch even when the ball was released at lower release speed. Thus, in addition to the reported positive influence of back spin at the interaction with the backboard and ring (Hamilton and Reinschmidt, 1997; Silverberg et al., 2003; Okubo and Hubbard, 2006; Tran and Silverberg, 2008), our results added an insight that the trajectory is altered by the spin rate during the ball is in air. When a player is relatively shorter it is difficult to increase the release height as taller players do. In that case, increasing the spin rate can be another option for them to decrease the release speed with respect to the same release angles.

5 CONCLUSIONS

The results of this study permit us to make the following recommendations for increasing the success rate in jump-shots: (1) The player should increase the release height to decrease the required release speed and variability in the closer shots possibly by increasing their jump height or altering their arm angle. (2) The player should increase the release angle for shots from a closer distance since it increases the margin for error for the release speed. (3) The player should not increase the release angle higher than necessary if it negatively affects the variability of release speed especially in longer shots such as the three-point shot. (4) Increasing spin rate will help maintain the successful release speeds lower for a given release angle and thereby maintaining the variability in release speed low.

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