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The Impact of Backspin Release Modes on Basketball Spin Axis Alignment

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Abstract

Background: Ball backspin is created during a basketball's final release. The complex nature of the hand-ball interaction at the moment of release can result in spin axis (SA) misalignment, which decreases shooting accuracy.
Aims: This study is the first to analyze distinct backspin modes, such as hand orientation, twist, and push location, and how each mode contributes to overall SA misalignment.
Methods: Three-dimensional ball backspin, hand orientation, hand position, and ball twist before release were measured for 20 male basketball athletes. The multiple linear regression test analyzed SA misalignment about the vertical axis (e_y) and side SA misalignment (e_z).
Results: The multiple linear regression for SA misalignment about the vertical axis (e_y) found that the orientation of the fingers and twist modes were equally important while the push location was insignificant (f2 = 1.9, R2 = 0.63, F = 17.0, p < 0.001). For side SA misalignment (e_z), all three modes contributed to ez misalignment (f2 = 3.3, R2 = 0.77, F = 18.1, p < 0.001), with both the orientation of the palm and twist modes contributing equally and the vertical push location having a smaller contribution.
Conclusion: This study demonstrates that five different backspin modes—two for e_y and three for e_z—each have distinct effects and combine to produce the final SA alignment after the ball is released. Knowing how each mode contributes to the final SA misalignment will allow coaches to identify necessary changes in individual players' shooting techniques to improve their release and increase accuracy.

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INTRODUCTION

In the continuing pursuit to improve shooting performance in basketball researchers continue to explore many different approaches, such as technological advances (Olteanu et al., 2023; Wei et al., 2022), visual cues (Klostermann, 2019; Oudejans et al., 2002; Vickers et al., 2017), and cognitive factors (Fazel et al., 2018; Mascret et al., 2022). A reason for the broad array of approaches is that shooting a basketball is a highly complex sequence of tasks that integrates three phases. First selecting a release strategy, then joint coordination, and then the final execution of the release as the ball leaves the hand. The release strategy selection encompasses identifying the desired combination of the basketball's release angle and speed (Silverberg & Tran, 2024; Tran & Silverberg, 2008). Previous studies have shown that the solution to the release strategy is not unique and explored how athletes select release strategies within the release speed-angle space to maximize performance (Nakano et al., 2020; Slegers, 2022a). This first phase is a decision on how to shoot the ball, while the next two execute the shot.

Many studies have attempted to identify specific joint coordination patterns (Amirnordin et al., 2024; Coves et al., 2020; Irawan & Prastiwi, 2022) and muscle synergies (Matsunaga & Oshikawa, 2022; Matsunaga & Oshikawa, 2023) associated with successful shooters during the second phase. However, there has been little consensus regarding an ideal joint coordination pattern or shooting form to ensure success (Okazaki et al., 2015). Some challenges that exist to finding one ideal shooting form are different techniques, such as high and low releases (de Oliveira et al., 2008; Giancamilli et al., 2022) and effects from fatigue (Rupčić, et al., 2020; Schmitzhaus et al., 2022) which may lead to

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different shooting motions based on the scenario. The absence of any one ideal shooting motion is reinforced by earlier studies that have shown that rather than repeating a learned motion, good shooters choose a desired release and use joint variability along the proximal-distal chain to minimize release error during the shooting motion (Bartlett et al., 2007; Mullineaux & Uhl, 2010).

The final release of the basketball, as the shooting hand pushes the ball towards its final angle and speed, plays a significant role in overall shooting performance. Sevrez and Bourdin (2015) and Slegers et al. (2021) found links between distal joint proprioception and shooting performance. As further evidence of the importance of the final hand-ball interaction, Jiang et al. (2022) found high levels of proprioceptive sensitivity on the index and middle finger of the leading hand in basketball players. In contrast to the specific hand-ball interaction, Slegers and Love (2022) were the first to measure basketball backspin alignment and variability and use it as an indicator of the quality of the release. They illustrated the importance of spin axis alignment by showing that improving alignment and reducing spin variability improved lateral accuracy. The significance is the resulting spin axis alignment is a better predictor of lateral shooting performance than the joint motion leading up to the release. Although the resulting ball spin alignment was a useful measure of release quality and lateral shooting performance, a limitation of the study was that it did not address how different types of hand motion contributed to the final spin axis. A gap remains between the ball spin axis alignment theory and how to integrate different hand-ball interactions into working practice for coaches and athletes.

This study aims to identify how three specific modes of hand-ball interaction contribute to the final basketball spin axis alignment: hand orientation on the ball, twisting the ball into position, and the pushing finger location. Each hand-ball interaction mode is measured during the moments before release and compared to the final spin axis alignment for 20 male professional basketball players. The different modes will be hypothesized to combine to produce an effective spin. The final spin axis alignment can be predicted using the three hand-ball interaction modes as explanatory variables. Knowledge of how individual hand modes contribute to spin alignment is valuable to coaches and players as they try to achieve specific ball spin outcomes by changing specific elements of the hand-ball interaction and translating the theory of spin axis alignment into working practice.

METHOD

Research Design

A linear multiple regression power analysis was performed using G*Power Version 3.1.9.7 (Faul et al., 2009) to determine the required sample size to achieve an effect size of $f^2 = 0.67$. The effect size was chosen since it was consistent with R^2 values of 0.4 found in similar studies for longitudinal accuracy, lateral accuracy, and ball path curvature in basketball (Slegers et al., 2021; Slegers, 2022b). Using an effect size of 0.67, $\alpha = 0.05$, power $(1-\beta) = 0.90$, and two tails, the projected sample size for three predictors was 19. Therefore, a larger sample size of n=20 was chosen.

Participants were asked to attempt 20 jump shots on a regulation-height basket (3.05 m) from a distance of 7.2 m (professional three-point line). All attempts were straight at the basket from the top of the key, directly facing the backboard, without a defender or any time restriction. Each shot was recorded from 1.5 m directly behind the shooter and at a height of 2.5 m using a tripod-mounted 1080p HD digital video camera at 120 frames per second, with a shutter speed of 1/720 seconds. Like Slegers and Love (2022), a regulation basketball with 26 equally spaced 8 mm diameter white markers was used to track the ball spin. Processing the digital video and the identification of the centroid for each attempt was done manually using Tracker 5.1.5 software (Open-Source Physics Java framework).

Participants

Twenty professional right-handed male basketball athletes (n = 20) from the 2022 Professional Canadian Invitational in Toronto, Canada, were used in this study (age = 25.9 ± 3.5 yrs, height = 195 ± 8 cm). Each participant played for a team in the NCAA, U SPORTS, or Canadian Collegiate Athletic Association (CCA) and had recently completed their years of participation eligibility. All participants had been actively involved in sponsored competitive basketball within six months of the study. Each participant gave voluntary consent for inclusion in the study, which the local ethics committee approved.

Spin Axis Alignment

Shooting hand interaction with the ball as a basketball is released generates a three-dimensional backspin of the ball. The basketball spins about a fixed axis, called the spin axis (SA), which can have a unity magnitude without loss of generality. Due to its resemblance to Euler's Theorem, the SA is often equivalently referred to as the Euler axis, and if the left end is at the origin, the right end of the axis has coordinates [e_x, e_y, e_z] as shown in Fig. 1, with the constraint that $e_x^2 + e_y^2 + e_z^2 = 1$. For an ideally aligned backspin, where the SA is horizontal and perpendicular to the shooting plane, the SA can be characterized as [1, 0, 0] and is aligned with the x-axis. Misalignment of the SA results in the right end not lying along the x-axis but being tipped if $\pm e_y$ and/or $\pm e_z$ is nonzero. Two special cases are pure e_y ([0, 1, 0]), where the ball spins like a top, and pure e_z ([0,0,1]), or side spin, where the right side moves up, and the left side moves down. As found by Slegers and Love (2022), the average spin axis for right-handed players is e_y = -0.22 and e_z = -0.17, or slightly tipped down and toward the target, with shot-to-shot variability of the SA being positively correlated with lateral error.

In this study, the SA is estimated using the same procedure outlined in Slegers and Love (2022), where three markers are tracked as they rotate from the moment of last contact until 16 ms before the ball obscures any one marker. The displacement of the markers is used to find the optimal quaternion (Yang, 2012) and rotation matrix representing the displacement, from which the ball's SA can be recovered (Shuster, 1993)

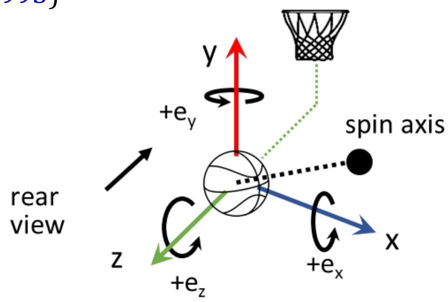

Figure 1. Backspin Coordinate Axes Definition Viewed from behind the Shooter and Facing the target

Backspin Release Modes

A limitation in prior SA studies is that only the net backspin result was considered. New to this study is the analysis of how different modes of hand-ball interaction individually contribute to the net result. Three types of hand-ball interaction modes called orientation, twist, and position (A, B, and C, modes respectively) are considered in this study and visualized in Fig. 2. The top row of Fig. 2 illustrates how each mode functions for e_y spin for a right-handed shooter. Mode A-Y occurs when the shooting (right) hand is tipped counter-clockwise. In this scenario, if the ball rolls off the hand normally, the SA will be tipped up or have $+e_y$. Mode B-Y occurs as the shooting (right) hand starts on the right side and twists to the ball's center at release, causing an $-e_y$ twist. Mode C-Y occurs if the shooting (right) hand is on the right side of the ball. A forward push on the right side results in a $+e_y$ spin. All three modes are illustrated for typical right-handed occurrences. However, the signs on e_y may switch depending on the actual interaction. The bottom row of Fig. 2 shows the three analogous e_z modes.

The spin modes are measured by identifying 18 points: six from the moment of release, six after release, and six before the release, as shown in Fig. 3. The release frame is chosen as the penultimate image frame with the index, middle, and ring finger in contact with the ball (Fig. 3*a*.) Using the release frame, the tip and knuckle of the index, middle, and ring fingers are selected. The final push occurs using either one of the three fingers individually or a combination of the index, middle, middle, and ring fingers and varies from player to player. Each participant in this study was classified by their final push type and was assigned a push classification of 1, 1.5, 2, 2.5, or 3 based on whether they pushed with their index, index-middle, middle, middle-ring, or ring finger. The push center of pressure (x_{cp}, y_{cp}) is defined as the pushing fingertip location for classifications 1, 2, and 3, the average of the index and middle fingertips for 1.5, and the average of the middle and ring fingertips for 2.5. Coordinates x_{cp} and y_{cp} are measured from the ball center and normalized using the ball radius. The push orientation, θ_{cp}, is the angle from knuckle to fingertip, made by the pushing finger angle, with θ_{cp} positive for fingertips to the right of the knuckle. The center of pressure location (x_{cp}, y_{cp}) is used to quantify modes C-Y and C-Z, while the push orientation, θ_{cp}, is used to classify modes A-Y.

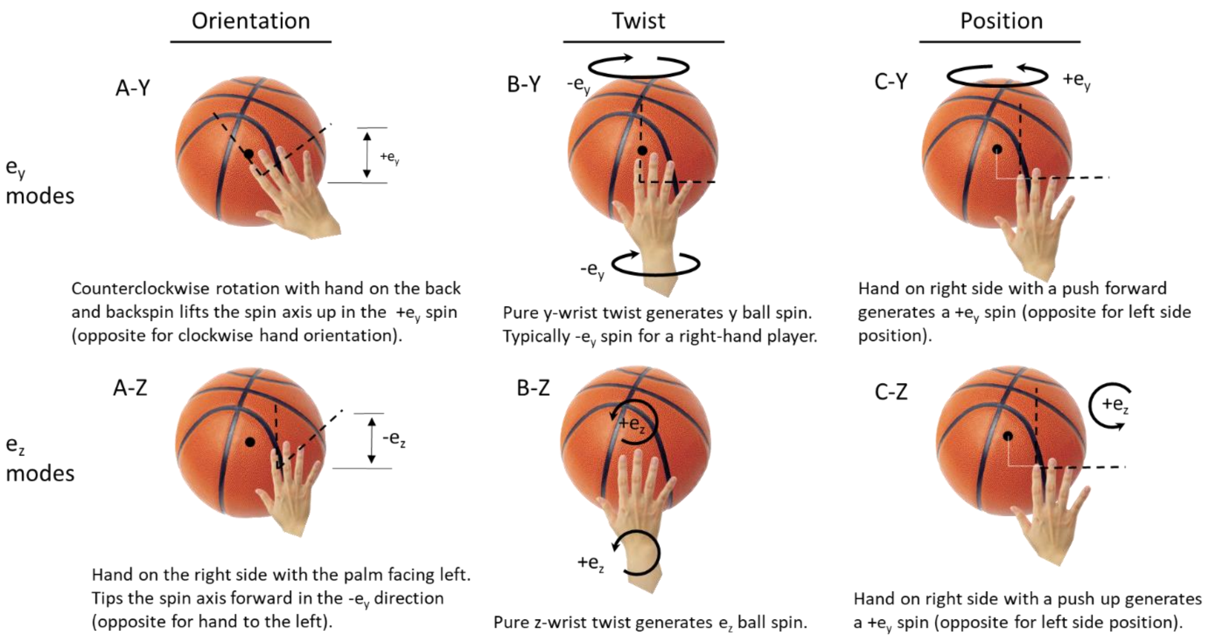

Figure 2. Identification of Backspin Modes. (Top) Visualizations of e_y Modes for a Right-handed Shooter. (Bottom) Analogous Visualizations of e_z Modes for a Right-handed Shooter

Modes B-Y and B-Z are generated as the hand twists into position before release and are called pre-spin. Similar to how the SA and spin rate are found from the evolution of three markers after release (Fig. 3b) using the method outlined in Slegers and Love (2022), the pre-spin axis (pre-SA) and rate (ω^*) is measured using six frames (8^{th} to 3^{rd} frames) before the release (Fig. 3c.) From the pre-SA [e_x^*, e_y^*, e_z^*], the y and z pre-spin angular rates are found by multiplying the pre-SA components and the rate so to that $\omega_y = \omega^* e_y^*$ and $\omega_z = \omega^* e_z^*$.

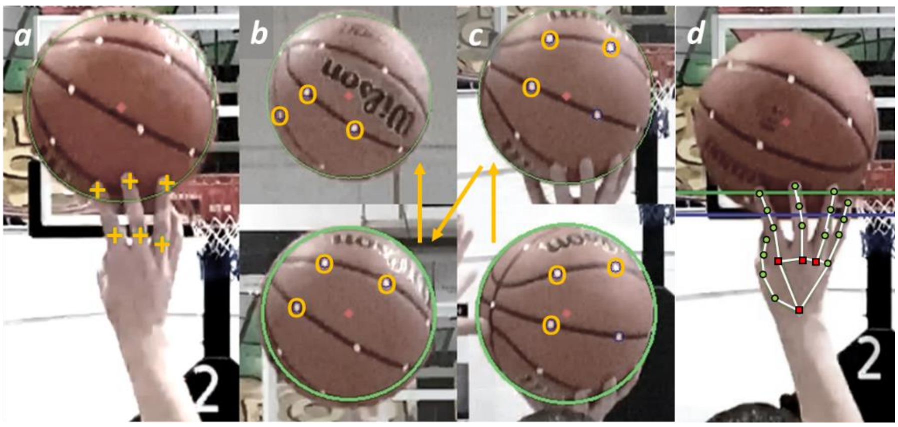

Figure 3. Backspin Release Modes. (*a*) Finger and Knuckle Identification at Release. (*b*) SA Alignment Tracking the Evolution of Three Markers after the Release. (*c*) Pre-spin by Tracking the Evolution of Three Markers before the Release. (d) Palm Orientation using MediaPipe Hands

Mode A-Z requires the orientation of the palm or back of the hand. Two-dimensional selection of landmarks, such as in Fig. 3*a*, is insufficient to identify the orientation of the palm, so MediaPipe Hands, which employs machine learning, is used to infer 21 3D landmarks of a hand (Fig. 3d) from a single frame. The back of the hand is considered rigid and defined by four landmarks: the index, middle, and ring finger metacarpophalangeal, and wrist (red squares in Fig. 3d.) The global orientation of the palm is defined as a *j*-*i*-*k* body-fixed rotation sequence by the angles ϕ_{palm}, θ_{palm}, and ψ_{palm}, of which the palm twist, ϕ_{palm}, about the j-axis is mode A-Z shown in Fig 2. If each of the back of the hand landmarks is transformed from the global to the back-of-hand frame by a 3x3 direction cosine matrix **R**, the z-components must necessarily be zero. These four equations can be put in the form $\mathbf{Ax} = \mathbf{0}$, where **A** is a 4x3 matrix containing each landmark's x, y, and z coordinates as rows, **and x** is a 3x1 column vector containing the elements of the third row of **R**. The best fit least squares solution for **x** that achieves the $min\|\mathbf{Ax}\|_2^2$ subject to the direction cosine constraint that $\|\mathbf{x}\|_2 = 1$ is well known and found using the singular value decomposition (SVD) of **A** where the solution is the right-singular vector of **A** corresponding to the smallest singular value. From the best estimate of **x** (third row of **R**), the palm twist, ϕ_{palm}, can be found using the definition of the direction cosine elements.

Analysis plan

Statistical analysis was performed in Matlab v9.2.0 R2017a (Mathworks Inc., Natick MA, USA). All reported values are found using the means from 20 shot attempts for each participant, and therefore, differences in means are inter-individual values. Descriptive statistics are presented as inter-individual means ± standard deviations (SD) for SA (e_y and e_z), push location (x_{cp} and y_{cp}), θ_{cp}, ϕ_{palm}, and pre-spin (ω_y and ω_z). Multiple linear regressions are presented for both e_y and e_z. Analysis of each multiple linear regression is presented with the F-statistic, adjusted R^2, and Cohen's f^2 global effect size and interpreted as $f^2 \geq 0.02$, $f^2 \geq 0.15$, and $f^2 \geq 0.35$ representing small, medium, and large effect sizes, respectively. The multiple linear regression model reduction is achieved by eliminating all slope regression coefficients, β, with statistical significance p < 0.05, then performing a partial F-test between the higher and reduced order model to verify the reduced model is adequate. In all cases, statistical significance was set at 0.05.

To assess the reliability of the digitization of the finger and marker locations, a test-retest reliability analysis was performed using 20 attempts of one participant for e_y, e_z, push location (x_{cp} and y_{cp}), θ_{cp}, and pre-spin (ω_y and ω_z). The reliability coefficient and SD of test-retest differences were 0.996 and 0.008 for e_y, 0.998 and 0.007 for e_z, 0.815 and 0.021 for x_{cp}, 0.897 and 0.018 for y_{cp}, 0.801 and 2.2 for θ_{cp}, 0.941 and 0.0543 for ω_y, and 0.988 and 0.02 for ω_y.

RESULTS AND DISCUSSION

Results:

Table 1 presents descriptive statistics as inter-individual means ± SD and ranges for the SA alignment, push location normalized by the ball radius, shooting finger orientation θ_{cp}, palm orientation ϕ_{palm}, and the shooting pre-spin rates. Results from a multiple linear regression between the response variable e_y and four independent explanatory variables, ω_y, θ_{cp}, x_{cp}, and y_{cp}, are provided on the left side of table 2. Since only two explanatory variable coefficients (ω_y and θ_{cp}) have p < 0.05, a reduced order multiple linear regression with only those two explanatory variables is provided on the right side of table 2. a partial F-test using an F-statistic from the ratio of the extra sum of squared residuals in the reduced model to the full model results in an F-statistic of 0.39 (p = 0.69). Therefore, there is no evidence that the models for e_y differ when x_{cp} and y_{cp} are excluded. A scatter plot of the predicted e_y values using the reduced model is shown at the top of Fig. 4.

The left side of table 3 summarizes a multiple linear regression between the response variable e_z and the four independent explanatory variables, ω_z, ϕ_{palm}, x_{cp}, and y_{cp}. The reduced order multiple linear regression with only the three explanatory variables having p < 0.05 (ω_z, ϕ_{palm}, and y_{cp}) is provided on the right side of table 3. A partial F-test results in an F-statistic of 0.68 (p = 0.52). Therefore, there is no evidence that the models for e_z differ when x_{cp} is excluded. A scatter plot of the predicted e_y values using the reduced model is shown at the bottom of fig. 4.

Table 1. Descriptive Statistics for SA and Backspin Modes (n=20)

	Mean	SD	Range
e_y	-0.15	0.31	0.51 – -0.53
e_z	-0.06	0.21	0.38 – -0.47
x_{cp} (ball r)	0.17	0.18	0.48 – -0.20
y_{cp} (ball r)	-0.73	0.08	-0.60 – -0.90
θ_{cp} (deg)	-3.6	12.8	15.4 – -24.5
ϕ_{palm} (deg)	7.3	2.6	13.9 – -3.9
ω_y (Hz)	-0.53	0.40	0.26 – -1.31
ω_z (Hz)	-0.37	0.54	0.10 – -0.88

Table 2. Effect of Backspin Release Modes on e_y SA Alignment (n=20)

	Full model		Reduced Model	
Independent variable	**Coefficient (β^y_{var})**	**CI 95%**	**Coefficient (β^y_{var})**	**CI 95%**
ω_y (Hz)	0.366 (0.113) **	0.124 – 0.607	0.373 (0.108) **	0.143 – 0.600
θ_{cp} (deg)	-0.017 (0.004) ***	-0.025 – -0.008	-0.016 (0.003) ***	-0.023 – -0.009
x_{cp} (ball r)	-0.125 (0.274)	-0.709 – 0.459	-	-
y_{cp} (ball r)	0.510 (0.630)	-0.837 – 1.85	-	-
Intercept	0.378 (0.473)	-0.631 – 1.39	-0.005 (0.072)	-0.157 – 0.148
f^2	= 2.1		= 1.9	
F	= 8.1**		= 17.0***	
Adjusted R^2	= 0.60		= 0.63	

* p < .05, ** p < 0.01, *** p < 0.001

Note: Coefficients are partial regression slopes with standard errors in parentheses.

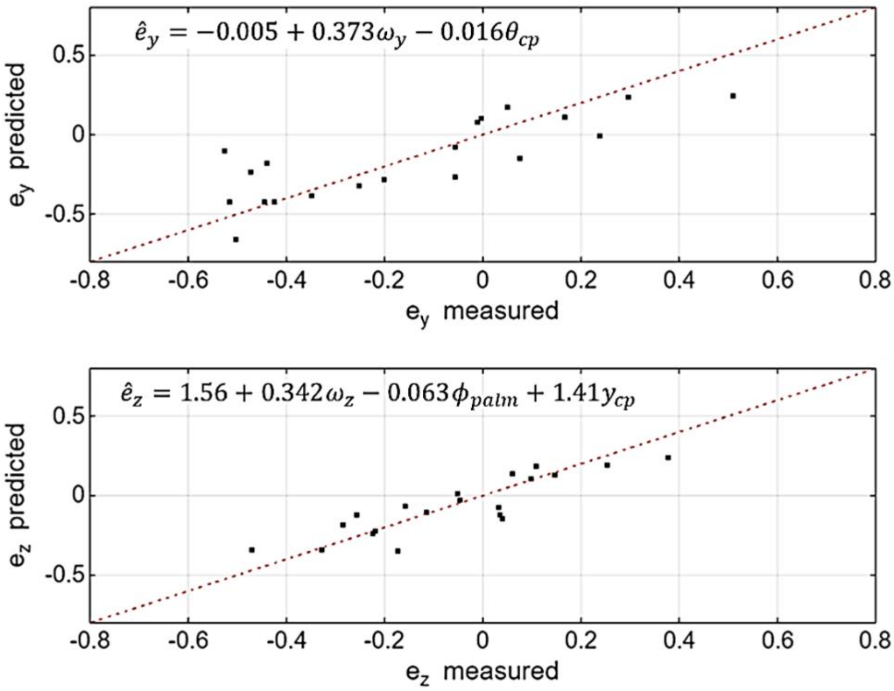

Figure 4. Comparison of the multiple linear regression models for SA alignment. (*Top*) Predicted e_y versus measured e_y. (*Bottom*) Predicted e_z versus measured e_z.

Table 3. The Effect of Backspin Release Modes on e_z SA alignment (n=20)

	Full model		Reduced Model	
Independent variable	**Coefficient (β^z_{var})**	**CI 95%**	**Coefficient (β^z_{var})**	**CI 95%**
ω_z (Hz)	0.355 (0.089)**	0.164 – 0.546	0.342 (0.087)**	0.157 – 0.526
ϕ_{palm} (deg)	-0.064 (0.011)***	-0.088 – -0.040	-0.063 (0.011)***	-0.086 – -0.039
x_{cp} (ball r)	0.123 (0.150)	-0.196 – 0.442	-	-
y_{cp} (ball r)	1.35 (0.405)**	0.483 – 2.21	1.41 (0.400)***	0.562 – 2.24
Intercept	1.51 (0.339)***	0.790 – 2.23	1.56 (0.332)***	0.859 – 2.27
f^2	= 3.6		= 3.3	
F	= 13.5***		= 18.1***	
Adjusted R^2	= 0.72		= 0.73	

* p < .05, ** p < 0.01, *** p < 0.001
Note: Coefficients are partial regression slopes with standard errors in parentheses.

Discussion:

Implications

The descriptive statistics in table 1 illustrate some common tendencies of right-handed shooters (left-handed shooters are similar but the signs would be flipped except for y_{cp}.) First, for three-point attempts in this study, the mean SA is $-e_y$ and $-e_z$, similar to free throws in Slegers and Love (2022). Next, the mean pre-spin is negative for both ω_y and ω_z as the right-hand starts on the right side of the ball and twists into position for the final release. Negative pre-spins are consistent with modes B-Y and B-Z and provide evidence that the initial twisting of the ball likely carries over to the final SA alignment after the release. The vertical location of the push point for all participants is located on the bottom quarter of ball $-0.5 \leq y_{cp} \leq -1.0$ with the mean lateral push point being typically on the right side of the ball ($x_{cp} > 0$), though not exclusively. The pushing finger varies from shooter to shooter, and of the 20 participants, 7, 9, and 4 have push classifications of 1.5, 2, and 2.5, respectively (no 1's or 3's), with the average being 1.93. Contrary to Hung et al. (2017), who used only two participants and concluded that the index finger does the pushing, the results here are more consistent with a combined index and middle finger push as in Jiang et al. (2022). The mean palm orientation points toward the left ($\phi_{palm} > 0$) and is consistent with the right hand being on the right side of the ball. The finger orientation, θ_{cp}, varies significantly from shooter- to shooter with a range of 40 deg, suggesting it may be a significant contributor to inter-individual variation in SA alignment.

Backspin release modes A-Y, B-Y, and C-Y can be assessed through the multiple regression model for e_y in table 2. The coefficient β^y_θ= -0.016 (p < 0.001), indicates that the orientation mode A-Y has a significant role in e_y SA alignment and that e_y decreases with finger orientation θ_{cp}. Based on the sign convention, e_y increases as the fingers tip toward the left, as shown in Fig. 2. The coefficient β^y_ω= 0.373 (p < 0.01) indicates that the twist mode B-Y also has a significant role in e_y SA alignment and that e_y increases with y-axis pre-spin ω_y, which carries over to the final SA alignment after release. Comparing the regression coefficients and study SDs for θ_{cp} and ω_y, illustrates that the model predicts shooter-to-shooter variation in θ_{cp} and ω_y contribute nearly equally to the study's SD in e_y. This suggests that backspin modes A-Y and B-Y are equally important in determining e_y SA alignment. Table 2 also suggests that mean e_y is neither affected by the push location x_{cp} nor y_{cp} and that backspin mode C-Y may not be important for mean SA alignment. A challenge in measuring backspin mode C-Y is that while the location x_{cp} can be measured with a 2D image, the push direction cannot. Qualitatively, some participants with a large positive x_{cp} who were expected to have a $+e_y$ as shown in Fig. 2, were also observed to swipe their hand to the left, creating a $-e_y$ instead. The swiping of the hand to the left or right may be more significant than the position of the push but was not measured in this study.

The multiple regression model for e_z presented in Table 3 is used to assess the backspin release modes A-Z, B-Z, and C-Z. The coefficient β^z_ϕ= -0.063 (p < 0.001) indicates that the palm orientation mode A-Z has a significant role in e_z SA alignment and that e_z decreases as ϕ_{palm} increases (ϕ_{palm} > 0 corresponds to palm directed more toward the left.) This is consistent with the image for mode A-Z in Fig. 2 where the SA is in the plane of the palm. The coefficient β_{ω}^{z}= 0. 342 ($p < 0.01$) indicates that the twist mode B-Z also has a significant role in e_z SA alignment as e_z increases with z-axis pre-spin ω_z, and carries over to the final SA alignment after release, similar to how ω_y and e_y interact in mode B-Y. The similarity in the magnitude of β_{ω}^{y} and β_{ω}^{z} also suggests that the mechanism between the carryover of pre-spin to SA alignment for both e_y and e_z may be the same and that reducing any pre-spin may lead to improved SA alignment.

Mode C-Z interacts with e_z through y_{cp}, and the coefficient β_{y}^{z} = 1.41 ($p < 0.001$), with any contribution from x_{cp} being insignificant. This suggests that as the push location moves lower on the ball, it contributes more to the -e_z spin. A comparison of the e_z regression coefficients and the shooter-to-shooter SDs for ϕ_{palm}, ω_z, and y_{cp} illustrates that the model predicts modes A-Z and B-Z contribute nearly equally to the study's SD in e_z, and mode C-Z to be approximately half of the other two. This suggests that backspin modes A-Z and B-Z are equally important in determining e_z SA alignment, while C-Z plays a minor role.

In this study, the absence of any contribution from the lateral push location, x_{cp}, was surprising, specifically since the range among participants was large (0.48 – -0.20), but it may be explained in two ways. First, since the push for a 3-point attempt is mostly forward and not up, the e_z spin from a lateral push is expected to be much smaller than e_y spin which may explain the insignificance of the coefficient β_{x}^{z}. Secondly, x_{cp} is sensitive to the determination of push classification and variations in actual finger forces and the discrete classification used may not accurately represent the actual lateral push location. However, the finding that β_{x}^{y} is not significant in modeling mean e_y doesn't necessarily imply x_{cp} does not contribute to the SA. It remains possible that intra-individual variation in x_{cp} is related to variation in e_y.

Research contribution

The importance of SA alignment and variability to basketball shooting performance has already been established (Slegers & Love, 2022). However, the source of misalignment and the role of different hand-ball interactions were left unanswered. This study demonstrates five different backspin modes: A-Y and B-Y for e_y and A-Z, B-Z, and C-Z for e_z, all combine to produce the final SA alignment after the ball is released.

The existence of these backspin modes provides two important contributions. First, it establishes tools for players and coaches to minimize total SA misalignment. Based on modes A-Y, A-Z, and C-Z, aligning the shooting fingers vertically with the palm centered so that it faces the target (ϕ_{palm} = 0) and pushing closer to the ball's quarter radius than its bottom will yield less misalignment. Minimizing pre-spin modes B-Y and B-Z highlight that getting the hand in position earlier to minimize twisting of the ball near the release is also beneficial for reducing SA misalignment. Secondly, since variability in SA alignment was found to be the most significant contributor to lateral shooting error (Slegers & Love, 2022), understanding the role of each mode provides players and coaches with tools to isolate sources of variability. For example, if a player tries to reduce e_y variability, the results here clarify that modes A-Y and B-Y are equally important. A coach may be able to isolate for the player whether their finger orientation variability (A-Y) or pre-spin ω_y (B-Y) dominates their shooting technique.

Limitations

A limitation of this study is that it only investigates the inter-individual variation of the backspin modes. Intra-individual variations could provide further insight into the relative importance of each backspin mode. For example, while modes A-Y and B-Y for e_y and A-Z and B-Z for e_z were found to have equal importance in predicting SA alignment, it may be that players naturally exhibit more intra-individual variation in specific modes. If such a situation exists, it would have important implications for the relative importance of each backspin mode. In addition, the effects of evading defense and rushing shot attempts were not considered. Adding such factors may affect how each mode interacts with spin axis alignment.

Suggestions

This study recommends further exploration of factors influencing SA alignment, particularly intra-individual variability related to xcp. Developing training interventions focused on controlling pre-spin and finger orientation is also crucial for improving SA alignment. Future research could involve larger sample sizes and more advanced measurement techniques and testing the impact of improved SA alignment on shooting performance in actual games. Additionally, 3D motion analysis could provide deeper insights into the hand and ball movement mechanisms.

CONCLUSION

This study was the first to identify and measure how three specific modes of hand-ball interaction: hand orientation on the ball (mode A), twisting the ball into position (mode B), and the pushing finger location (mode C), each contribute to the final basketball spin axis alignment. It was observed that modes A and B contributed equally to e_y SA misalignment while all three modes A, B, and C contributed to e_z, with mode C only having a minor impact. Combined, the specific role of each mode suggests that the total SA misalignment can be reduced by having correct hand placement with vertical fingers and palms facing the target, along with limited pre-spin of the ball before release. While it was previously known that SA alignment was a useful measure of release quality, an important outcome of this study is the finding that two athletes could combine modes differently to have similar total SA misalignment but for different reasons. In such a scenario, knowing how these individual modes interact to create the total backspin is valuable to coaches and players as they try to achieve specific ball spin outcomes since the remedy may differ based on which modes dominate and their relative contributions.

Further studies should investigate how coaches could integrate knowledge of backspin release modes into training to improve SA alignment. The effectiveness of specific drills and training on how it changes the SA, its variability, and overall shooting performance would provide valuable insight for translating the theory of SA alignment into working practice. Other areas of future research include the effects of lateral movement while evading a defender and increased tempo. Both may alter how the spin modes contribute to the final spin axis alignment, and it may be insightful to coaches if future research can identify if different modes are more sensitive to these effects.

AUTHOR CONTRIBUTION STATEMENT

MC was responsible for the study's conceptualization and design, data collection, and initial drafting of the manuscript. NS contributed to the data analysis, interpretation of the results, and critical revision of the manuscript. NS also served as the corresponding author, handling all correspondence and revisions related to the publication.

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