Ball flight kinematics, release variability and in-season performance in elite baseball pitching

D. Whiteside1, R. S. McGinnis1,2, J. M. Deneweth1, R. F. Zernicke1,3,4, G. C. Goulet1

1School of Kinesiology, University of Michigan, Ann Arbor, Michigan, USA, 2Department of Mechanical Engineering, University of Michigan, Ann Arbor, Michigan, USA, 3Department of Biomedical Engineering, University of Michigan, Ann Arbor, Michigan, USA, 4Department of Orthopaedic Surgery, University of Michigan, Ann Arbor, Michigan, USA

Corresponding author: David Whiteside, PhD, School of Kinesiology, University of Michigan, 401 Washtenaw Avenue, Ann Arbor, MI 48109, USA, Tel: 734 647 1669, Fax: (734) 763 6283, E-mail: dwhiteside@tennis.com.au

Accepted for publication 31 January 2015

The purpose of this study was to quantify ball flight kinematics (ball speed, spin rate, spin axis orientation, seam orientation) and release location variability in the four most common pitch types in baseball and relate them to in-season pitching performance. Nine NCAA Division I pitchers threw four pitching variations (fastball, changeup, curveball, and slider) while a radar gun measured ball speed and a 600-Hz video camera recorded the ball trajectory. Marks on the ball were digitized to measure ball flight kinematics and release location. Ball speed was highest in the fastball, though spin rate was similar in the fastball and breaking pitches. Two distinct spin axis orientations were noted: one characterizing the fastball and changeup, and another, the curveball and slider. The horizontal release location was significantly more variable than the vertical release location. In-season pitching success was not correlated to any of the measured variables. These findings are instructive for inferring appropriate hand mechanics and spin types in each of the four pitches. Coaches should also be aware that ball flight kinematics might not directly relate to pitching success at the collegiate level. Therefore, talent identification and pitching evaluations should encompass other (e.g., cognitive, psychological, and physiological) factors.

Pitching – along with hitting – is one of the two fundamental components of baseball. While the literature is replete with investigations into the kinematics and kinetics of the pitching motion, comprehensive in situ assessments of ball flight have been rare. Previous investigations of ball flight kinematics, though informative, have been largely restricted to controlled laboratory conditions (i.e., wind tunnels and “pitching machines”; Watts & Ferrer, 1987; Alaways & Hubbard, 2001; Nathan, 2008; Alam et al., 2011). More practically, since its installation in 2006, a three-dimensional ball-tracking system (PITCHf/x) in Major League Baseball (MLB) has allowed researchers to examine the trajectories of professional pitches (Nathan, 2007; Nathan, 2012). However, this system does not provide direct measurements of spin rates, spin axes, seam information, and release locations. In other projectile sports, this information has been garnered in situ and interfaced with biomechanical data to provide a more comprehensive understanding of football kicking (Whiteside et al., 2010; Alcock et al., 2012), cricket bowling (Chin et al., 2009), and the tennis serve (Reid et al., 2013; Sakurai et al., 2013). It follows that quantifying ball flight kinematics in baseball pitching may enhance understanding of the skill and prove informative for practitioners.

Pitchers are generally able to execute a variety of different pitches. Ball tracking data collected during the 2014 MLB season showed that the four predominant pitches – in order of frequency thrown – were the fastball, slider, changeup, and curveball (FanGraphs, 2015). In the four-seam fastball, pitchers are anecdotally thought to impart near-perfect backspin to the ball (such that it rotates over its four seams). Scientific investigations have challenged this theory by showing that the fastball’s spin axis is tilted 26–33° from the horizontal in professional and collegiate pitchers (Jinji & Sakurai, 2006; Jinji et al., 2011; Nagami et al., 2011), indicating predominant, but imperfect, backspin. The curveball was long considered the opposite (a four-seam topspin pitch), until the work of Jinji and Sakurai (2006) reveal that pitchers actually impart a combination of rifle-spin and topspin to the ball. In both pitches, the ball’s deviation (or “break”) can be attributed to the Magnus force that acts orthogonal to the ball’s resultant linear and angular velocity vectors (Bahill & Baldwin, 2007), with vertical lift producing a flatter trajectory in the fastball, and predominantly downward lift causing the curveball to “dip” (and deviate laterally). To the authors’ knowledge, rotational kinematics in the slider and changeup have not been directly quantified. Therefore, although kinetic
differences in the pitching motion have been established across these pitch types (Fleisig et al., 2006) and provide an expectation for disparities in ball flight, the magnitude and nature of these differences are unclear. Extending ball flight analyses to the slider and changeup would provide a greater understanding of how pitchers manipulate the ball and provide implications for pitcher development and talent identification.

In addition to the conventional ball kinematics: speed, spin rate, and orientation of the spin axis; the ball’s trajectory is influenced by orientation of the seams (Kensrud & Smith, 2010). Indeed, numerous coaching texts emphasize the importance of orienting the seams expediently in each pitch (Stallings, 2000; Keller, 2009; Johnson, 2013). It is, therefore, perplexing as to why seam measurements have never been undertaken in situ, though methodological difficulties may provide a possible explanation. The ability to release the ball from a consistent location in space, regardless of pitch type, is an equally prevalent aspect of the coaching syllabus when developing pitchers (McFarland, 2003; Maher, 2011). This may be an attempt to limit the advance anticipatory cues available to the batter and could also relate to the fact that variability in pitching mechanics has been shown to decrease in higher levels of competition (Fleisig et al., 2009). However, the functional role of variability has been established in various projectile skills (Button et al., 2003; Horan et al., 2011; Wagner et al., 2012; Whiteside et al., 2014) – and motor abundance effectively precludes a perfectly repeatable pitching action – therefore, even elite pitchers are expected to exhibit some degree of variability. Likewise, the temporal composition of the pitching action has been shown to exhibit within-individual variability in collegiate pitchers (Urbin et al., 2012). Moreover, it has already been established that other projectile movements are not characterized by perfectly repeatable release locations (Dupuy et al., 2000; Kudo et al., 2000; Button et al., 2003), setting a similar expectation for pitching. Quantifying the nature of this variability – and relating the seam orientation and spin axis in different pitches – would improve the current scientific framework for developing pitching ability.

Since 2006, MLB has employed a ball-tracking system, PITCHf/x, to record ball trajectories of pitches. Professional teams have used these data to scout opponents and evaluate their own pitching staff, confirming that there are direct applications for ball flight data in professional baseball. There appears scope to supplement PITCHf/x data with direct measures of rotational characteristics that would provide coaches with additional information to identify, evaluate, and develop successful pitchers. Further, despite the emphasis placed on pitching mechanics in practice, it is unclear how ball kinematics relate to pitching success. Quantifying this relation may help to answer the question of what constitutes a successful pitcher. With a view to addressing these concepts, the aims of this study were to (a) measure ball flight kinematics (ball speed, spin rate, spin axis orientation, seam orientation relative to the spin axis, and release location); and (b) relate these kinematics to pitching success over a single NCAA Division I season. It was hypothesized that (a) ball speed and four-seam rotation would be greatest in the fastball; (b) spin rate would be greatest in the breaking (curveball and slider) pitches; and (c) release location variability and game success would be negatively correlated.

Methods

Subjects

Prior to subject recruitment, the University’s Institutional Review Board approved the methodologies and cohort. Nine pitchers (mean age: 20.69 ± 1.52 years; height: 1.93 ± 0.06 m; mass: 95.66 ± 7.11 kg) from the same NCAA Division I baseball team were subsequently recruited to participate in the study. All pitchers employed a standard overarm action and none utilized a sidearm or “submarine” technique. All players provided informed consent, reported no injury, and were cleared to participate in the protocol by the team’s athletic trainer and pitching coach.

Protocol

Testing was performed at the team’s indoor practice facility. All pitches were thrown from the same permanent pitching mound and directed toward a catcher. The location of the pitching rubber, relative to home plate (vertical displacement: 0.25 m; horizontal displacement: 18.44 m), conformed to NCAA baseball regulations. Upon arrival to the facility, the pitchers dressed in their standard practice apparel, cleats, and a Lycra suit housing miniature inertial sensors (part of a separate study). During their typical pre-match warm-up, and throughout the protocol, each athlete was asked whether he felt that the suit constrained any aspect of his pitching motion, and no athlete reported that to be the case. Having affirmed his readiness, the pitcher was asked to assume his starting posture on the pitching rubber. The location of his trail foot was then marked with chalk on the pitching rubber; he was asked to use this marking to replicate his starting position in each pitch. The team’s coaching and medical staff permitted each pitcher to throw a maximum of 20 pitches for the purposes of this study. Each athlete performed four repetitions of four different pitching variations (four-seam fastball, changeup, curveball, and slider), completing a total of 16 pitches. Appreciating that different variations of each pitch exist, pitchers were instructed to throw traditional four-seam fastballs and breaking pitches, as they were familiar with these. Variation across pitchers made it more difficult to standardize the changeup and, in an effort to replicate game performance, each pitcher was
permitted to throw his preferred changeup (circle, straight, or palm). The typical grip types used in each of these six types of pitches are depicted in Supporting Information Fig. S1. All pitches were thrown from a wind-up, in a randomized sequence that was determined prior to testing using a MATLAB (Mathworks, Natick, Massachusetts, USA) script. The pitchers were instructed to perform the pitches at a tempo representative of that to which they would adhere during a game.

All pitchers used the same type of baseball (Rawlings, St. Louis, Missouri, USA), which was sanctioned for use in the Big Ten Conference. Prior to testing, the ball was marked with dots using a black fine point permanent marker. A piece of string was used to mark one circle of dots extending around the circumference of the ball, along the four-seam plane. The remaining dots were marked arbitrarily. A high-speed video camera (AOS Technologies, Baden Daettwil, Switzerland) was placed approximately 1.5 m behind the pitching rubber, adjusted to the height of each pitcher’s release location during his warm-up and electronically leveled (Fig. 1). The camera collected 600 frames per second, using an exposure time of 1/2500 s, and yielded 640 × 480 resolution videos for subsequent analysis. A radar gun (Stalker Radar, Plano, Texas, USA) was placed adjacent to the high-speed camera and directed toward home plate to measure the maximal speed of each pitch.

Data analysis

Prior to analysis, footage of the two left-handed pitchers was horizontally inverted, such that the results in this study could be interpreted consistently (and pertain to a right-handed pitcher). The frame of release was determined visually as the first frame in which contact was lost between the fingers and ball. Aside from ball speed, all ball kinematics were calculated using a digitization procedure within a graphical user interface that was created in MATLAB. This digitization procedure was a replica of that described by Jinji and Sakurai (2006) and calculated the magnitude and orientation of the ball’s spin axis (using the markings on the ball). However, a minimum of five post-release frames (opposed to two) were used to calculate these parameters in this study. A single tester completed all digitization procedures. An a priori inter-rater reliability analysis was conducted (using five raters) and yielded the following standard errors of measurement: 0.3 revs/s in the spin rate; < 0.9° in the azimuth/elevation angles; 0.8% in the four-seam rotation index (FSRI); < 0.1 cm in the release location.

Consistent with previous work (Jinji & Sakurai, 2006; Nagami et al., 2011; Sakurai et al., 2013), the orientation of the ball’s angular velocity vector (i.e., spin axis) was reported using elevation (ϕ) and azimuth (θ) angles. These angles are reported relative to a global frame originating at the center of the ball with positive x pointing toward the third base (right), positive y pointing to home plate (forward), and positive z pointing up. The elevation angle denoted the excursion of the angular velocity vector from the horizontal (xy) plane (positive = inclination; negative = declination), while the azimuth angle denoted the angle between the projection of the angular velocity vector on the xy plane and the global x-axis (0° = pointing toward the third base; 90° = pointing toward the home plate; ± 180° = pointing toward the first base). The right-hand rule was used to interpret the nature of the ball’s angular velocity vector (Bahill & Baldwin, 2007) and explanations of its orientation are provided in Table 1.

Novel to this study, the orientation of the spin axis, relative to the four-seam plane of the ball, was also reported (referred to as “four-seam rotation index”; FSRI). For this calculation, the axis normal to the four-seam plane of the ball \( \mathbf{B} \) was first defined by taking the cross product between the position vectors defining the location of two marks on the ball’s four-seam plane relative to the ball center. The projection of the spin axis \( \mathbf{\omega} \) onto the x-axis of the ball’s coordinate system \( \mathbf{B} \) is denoted as \( \mathbf{\bar{\omega}} \) and defined per

\[
\mathbf{\bar{\omega}} = \frac{\mathbf{B} \times \mathbf{\omega}}{||\mathbf{B}||}
\]  

Fig. 1. Camera and radar gun placement.
The acute angle between $\bar{o}_p$ and $\bar{o}$ was then used to
determine FSRI, as a percentage value, according to
\[
FSRI = \frac{90 - \arccos \left( \frac{\bar{o}_p \cdot \bar{o}}{|\bar{o}_p| |\bar{o}|} \right)}{90} \times 100 \qquad [2]
\]
where a value of 100 represented perfect four-seam
rotation (i.e., that the ball was spinning around an axis
normal to the four-seam plane: an ideal four-seam fast-
ball), while a value of 0 represented perpendicularity
between the ball’s angular velocity vector and Ball, (i.e.,
that the ball was spinning about an axis lying in the
four-seam plane). Ultimately, this variable provided an
indication of how close the rotation axis was to the
normal of the four-seam plane.

The $xz$ coordinates of the center of the ball at release
were initially calculated in pixels, relative to an origin in
the bottom left of the frame. The known diameter of the
ball (0.036 m) was then divided by the diameter of the
ball in pixels to determine the scale of the plane of view
and convert the ball’s release coordinates to centimeters.

The spatial variability of the release location in each
pitch type was then computed using bivariate variable
error (Hancock et al., 1995). The standard deviations of
ball release location in the horizontal (left-right) and
vertical directions were also calculated for each player
using all of his (grouped) pitches. Likewise, 95% confi-
dence covariance ellipses were computed from each
pitcher’s release coordinates, the area of which provided
a singular quantity of the two-dimensional (i.e., approxi-
mate batter’s perspective) spatial variability of his
release location across his 16 pitches.

Data collection was completed 2 months prior to the
2014 NCAA baseball season. After the season had been
completed, each pitcher’s fielding independent pitching
statistic (FIP) was obtained from team management.
Fielding independent pitching was chosen as the crite-
ron measure of pitching performance as it eliminates
plate appearance outcomes that involve defensive factors
(which are beyond the pitcher’s control). More explic-
tively, it only reflects the factors of performance that the
pitcher – and only the pitcher – has complete control
over: home runs, walks, hit by pitches, and strikes. The
equation used to calculate FIP in this study assigned a
weighting to each of these pitching variables and was
akin to that developed by Clay Dreslough (2000; origi-

nally referred to as defense-independent component
earned run average or DICE):
\[
FIP = \frac{13 \times HR + 3 \times (BB + HBP) - 2 \times K}{IP} \qquad [3]
\]
where $HR$ was the number of home runs conceded
during the season, $BB$ the number of walks, $HBP$ the
number of pitches that hit the batter, $K$ the number of
strikeouts, and $IP$ the number of innings pitched.
Although the addition of a constant is customarily used
to translate FIP onto a more “reader friendly” scale that
is akin to earned run average, this was not required in
this study as FIP was only examined using correlations,
which are not affected by changes of scale. A lower FIP
value is more indicative of success than a higher value.

**Variables of interest**

The variables of interest were primarily measures of ball
flight kinematics: (a) resultant ball velocity; (b) magni-
tude and (c) orientation of the ball’s angular velocity
vector; and (d) four-seam rotation of the ball. Addition-
ally, the following release parameters were measured
using the 16 pitches: (e) individual pitcher standard
deviations of horizontal and vertical release locations;
and (f) 95% confidence ellipse area of release location.
Finally, each player’s FIP during the 2014 NCAA season
was used to gauge in-game pitching success.

**Statistical procedures**

Differences in ball kinematics across pitches were evalu-
ated using six linear mixed-model analyses, with pitcher
as the subject and pitch type as the repeated measure.
This approach was preferable to a one-way analysis of
variance with repeated measures as the covariance struc-
tures did not possess compound symmetry in several of
the variables (Ugrinowitsch et al., 2004). The individual
pitcher variability (i.e., each pitcher’s standard devia-
tions) in the vertical and horizontal release locations was
assessed using a paired $t$-test. To account for the multiple
comparisons being undertaken, the significance level
was sequentially adjusted in these tests according to the
procedure described by Holm (1979). The $P$-values were
sufficiently small that no rejections were required until
the final test, and all significance was reported using a

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**Table 1. Interpretations of the ball’s spin axis using the elevation and azimuth angles**

<table>
<thead>
<tr>
<th>Azimuth (°)</th>
<th>Elevation (°)</th>
<th>Description of spin axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Spin axis coincident with horizontal and pointing toward third base</td>
</tr>
<tr>
<td>± 180</td>
<td>0</td>
<td>Spin axis coincident with horizontal and pointing toward first base</td>
</tr>
<tr>
<td>0</td>
<td>± 90</td>
<td>Spin axis coincident with vertical: Pointing up = “leftward sidespin”; Pointing down = “rightward sidespin”</td>
</tr>
<tr>
<td>± 90</td>
<td>0</td>
<td>Spin axis coincident with horizontal and the line between home plate and second base: Pointing to: home plate = “leftward rifle spin”; second base = “rightward rifle spin”</td>
</tr>
</tbody>
</table>

---
were, on average, 53.6° (CI: 36.2 – 70.9°; \( P < 0.001 \)) and 80.0° (CI: 34.8 – 125.2°; \( P = 0.002 \)) smaller than the curveball, respectively; and 47.8° (CI: 34.9 – 60.6°; \( P < 0.001 \)) and 49.0° (CI: 17.8 – 80.1°; \( P = 0.002 \)) smaller than the slider, respectively. The significant main effect for FSRI was found to relate to significantly greater four-seam rotation in the fastball, compared with the changeup (MD: 51.0; CI: 28.7 – 73.3%; \( P = 0.001 \)). The fastball also displayed a nonsignificant trend toward greater FSRI than the slider.

**Release variability**

Release location variability did not differ across pitch types. When pitches were grouped, the horizontal release location was significantly more variable than the vertical release location (MD: 1.97; CI: 0.87 – 3.06 cm; \( P = 0.003 \); Table 3). The mean release area of the average pitcher, as measured by the 95% confidence ellipses across his 16 pitches, was 324 ± 165 cm².

**Relation between ball flight kinematics (and game success)**

None of the kinematic ball flight variables, nor the release variability, were significantly correlated to FIP (Table 4).

**Discussion**

This study described ball flight kinematics and release variability in NCAA Division I pitchers and related these variables to in-season pitching success. Significant differences in speed, spin rate, spin axis orientation, and FSRI were variously noted between the fastball and off-speed pitches, which may be useful for evaluating and/or developing pitching technique. None of the measured ball flight kinematics were significantly related to pitching success (as measured by fielding independent pitching), suggesting that the pitching strategy is complex and success is dependent on factors other than the mechanics.
Table 3. Individual pitcher release location variability in the horizontal and vertical directions, across all (n=16) of their pitches

<table>
<thead>
<tr>
<th></th>
<th>Horizontal</th>
<th>Vertical</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD</td>
<td>5.72 ± 2.17</td>
<td>3.76 ± 1.52</td>
<td>0.003*</td>
</tr>
</tbody>
</table>

*Significant at the Bonferroni–Holm adjusted level.

Table 4. Pearson product-moment correlations (r) between ball kinematics and FIP

<table>
<thead>
<tr>
<th></th>
<th>Fastball</th>
<th>Changeup</th>
<th>Curveball</th>
<th>Slider</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>0.652</td>
<td>−0.126</td>
<td>0.483</td>
<td>0.001</td>
</tr>
<tr>
<td>Spin rate</td>
<td>0.341</td>
<td>0.412</td>
<td>−0.185</td>
<td>−0.141</td>
</tr>
<tr>
<td>Elevation</td>
<td>−0.132</td>
<td>−0.776</td>
<td>−0.470</td>
<td>0.621</td>
</tr>
<tr>
<td>Azimuth</td>
<td>0.161</td>
<td>−0.592</td>
<td>−0.602</td>
<td>0.217</td>
</tr>
<tr>
<td>FSRI</td>
<td>0.536</td>
<td>0.141</td>
<td>0.638</td>
<td>−0.058</td>
</tr>
<tr>
<td>Release location variability*</td>
<td>−0.422</td>
<td>−0.330</td>
<td>0.243</td>
<td>−0.378</td>
</tr>
</tbody>
</table>

No correlations were significant at the P < 0.05 level.

*Release variability as indicated by bivariate variable error scores.

FIP, fielding independent pitching statistic.

Fig. 2. Mean ball kinematic measurements in the four pitch types.

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that are predominantly emphasized by coaches. Ultimately, these findings may prove instructive for pitching coaches.

Resultant ball velocity and spin rate

Ball speed was predictably higher in the fastball, compared with the three other pitch types. The mean fastball speed in this study (38.3 ± 2.0 m/s) was similar to that previously reported in pitchers from the top collegiate division in Japan [37.7 ± 1.2 m/s (Nagami et al., 2011)]. However, other studies have reported lower fastball speeds [33.8 ± 1.7 m/s (Jinji & Sakurai, 2006); 34.0 ± 3.1 m/s (Jinji et al., 2011)], which may be an artifact of different methodologies (i.e., digitization procedures as opposed to a radar gun). This may also explain why the curveball speed reported by Jinji and Sakurai (2006) (27.2 ± 1.9 m/s) was lower than this study (32.1 ± 1.5 m/s), although differences in skill level between the cohorts could also be factor as Jinji and Sakurai (2006) did not detail the competition level of their collegiate sample. Ultimately, the discrepancies in ball speed are consistent with expectations, whereby the breaking pitches and changeup are collectively termed “off-speed” pitches as they involve less speed than a fastball.

The spin rate did not differ between the fastball and breaking pitches, contradicting the notion that breaking pitches possess higher spin rates. These findings are consistent with those of Jinji and Sakurai (2006), who reported that the curveball possesses a similar spin rate to the fastball. The paradox between a fastball’s high spin rate and apparent lack of deviation is likely related to the fact that the ball’s backspin provides lift, which counteracts the effect of gravity and produces a trajectory with less curvature than would otherwise occur. Consequently — and contrary to what is instinctively implied by its generally straighter trajectory — the fastball also “breaks” in the sense that its spin causes lift that produces upward deviation from the parabolic trajectory that would otherwise ensue. The larger spin rates also imply that the torque applied to the ball by the fingers in the fastball and breaking pitches was significantly higher than that applied in the changeup. While this may be partially explained by the disparate ball speeds, these spin rates imply that the changeup was unique in that the pitcher did not deliberately apply asymmetrical pressure to the ball when releasing this pitch.

Spin axis orientation and FSRI

The elevation and azimuth angles were indicative of two significantly different spin axes: one representing the fastball and changeup, and another, the breaking balls. The fastball (−14°) and changeup (−32°) were both characterized by an elevation angle declined from the horizontal, while their azimuth angles (fastball: 32°; changeup: 33°) were effectively identical. The fastball values matched previous reports (Jinji & Sakurai, 2006; Jinji et al., 2011; Nagami et al., 2013) and may indicate a spin axis orientation (and release configuration) that is optimum to maximizing ball speed. Similar spin axes in the fastball (see Supporting Information Video S1) and changeup (see Supporting Information Video S2) indicated that that the angular impulse applied by the finger force was in the same direction in both pitches. However, the magnitude of this force was significantly higher in the fastball (as denoted by the spin rates) and indicates a more deliberate impartation of spin to the ball as previously mentioned. The practical significance of this finding is that, unlike in the fastball, pitchers need not emphasize the application of torques (i.e., high-speed dexterous movements of the digits such as “rolling the fingers over the ball”) at release in the changeup. The non-horizontal spin axis also supports the contention that the fastball (and changeup) trajectory involves slight deflection toward the third base (Nagami et al., 2011).

Both the elevation and azimuth angles were significantly larger in the breaking pitches compared with the fastball and changeup. The spin axis in the slider was only rotated 9° from the home plate (toward the third base), and therefore more closely resembled a “gyro ball” with rifle-spin (see Supporting Information Video S3). This finding is of interest as the Magnus force (and ball’s deflection, normal to its path) is known to be zero when the spin axis is aligned with the direction of travel in this way (Cross, 2011). Therefore, the average slider in this study would not have experienced significant deviation in the initial portion of flight. While this seemingly challenges the utility of such a pitch, the ball’s velocity vector gradually declines over the course of its flight as gravity compels it toward the ground. As this occurs, the perpendicularity between the spin axis and velocity vector gradually increases and escalates the Magnus force that is deflecting the ball laterally. These dynamics could potentially contribute to the “late” break that is often cited in the slider (and other breaking pitches), and are likely more difficult for a batter to anticipate than a ball that breaks more consistently, although future scientific scrutiny is necessary in both cases. The hand dynamics in the slider conformed to the findings of Stevenson (1985), whereby pitchers appeared to release their thumb from the ball approximately 1/150 s before digits 1 and 2, which ‘rolled’ down the side of the ball during this period.

The curveball’s spin axis was similar to the slider but rotated further from the direction of travel (23° in the direction of the first base) and more indicative of combined rifle-spin and topspin (see Supporting Information Video S4). The increased topspin component was likely an effort to amplify the downward deviation (i.e., “dip”) that is associated with the curveball. Previous descriptions of the curveball [θ = 27°; φ = 132° (Jinji & Sakurai, 2006)] reported a slightly more balanced
that pitching development should afford attention to pitchers prioritized this aspect of performance. It follows Whiteside et al., 2013), thereby explaining why these et al., 2000; Kudo et al., 2000; Button et al., 2003; to be critical to accuracy in projectile skills (Dupuy may relate to the fact that release height has been shown to be critical to accuracy in projectile skills (Dupuy zontal release location (Dupuy et al., 2000; Kudo et al., 2000; Button et al., 2003; Whiteside et al., 2013), thereby explaining why these pitchers prioritized this aspect of performance. It follows that pitching development should afford attention to variability

Variability of the release location was not dependent on pitch type. However, it should be noted that within-pitch type variability was quantified using only four trials and future research should, therefore, confirm these findings. When all pitch types were grouped, the vertical release location was significantly more consistent than the horizontal release location (P < 0.001). This discrepancy may relate to the fact that release height has been shown to be critical to accuracy in projectile skills (Dupuy et al., 2000; Kudo et al., 2000; Button et al., 2003; Whiteside et al., 2013), thereby explaining why these pitchers prioritized this aspect of performance. It follows that pitching development should afford attention to refining a consistent release height. These findings also provide some insight for the batter, as the small window in release height seemingly possesses less value for discerning pitch type. Since the variability is higher in the horizontal direction, it would seem more astute to search for advance (biomechanical) cues related to this. However, the 95% confidence interval bandwidth denotes that the average pitcher in this study released 95% of his pitches from a horizontal window that was 14.3 cm wide. Therefore, future work may wish to examine whether or not expert batters possess the visual acuity necessary to discern differences of this magnitude from a distance of 18.44 m and, if so, the most beneficial fixation areas.

Relation between ball flight kinematics and fielding independent pitching

Contrary to expectations, none of the ball flight kinematics, nor the release location variability across pitches, were related to fielding independent pitching. From a coaching perspective, this suggests that mechanics are not the ultimate determinant of pitching success, at least at the collegiate level. This endorses coaching philosophies that stress the importance of tactics and strategy in pitching performance (O’Connell, 2006). Yet, talent identification (or “scouting”) methods in baseball are notorious for focusing on pitching mechanics and outcomes (e.g., speed and deviation; Bodet, n.d). The current findings suggest that mechanics should be considered a single component of the complex pitching strategy and discourage the exclusive appraisal of pitching mechanics and/or outcomes in the talent identification process. It is likely that other attributes [e.g., cognitive: pattern recognition, identifying batters’ tendencies, coping with psychological stressors, decision making (selecting the correct pitch for a given pitch count); physiological/mechanical: withstanding fatigue, adaptability to different batters/conditions] are equally pertinent to the evaluation of overall pitching ability and warrant attention in the scouting process. The link between these attributes and pitching success provides a focal point for future research, and would likely help to inform the development of pitchers.

Limitations

This study examined a relatively small sample size of pitchers and utilized a limited number of pitches (four per pitch type), which presents a limitation to the statistical values reported in this study. Additionally, data in this study were not garnered during competition, thereby providing a limitation for the correlations between ball kinematics and fielding independent pitching. Although previous research provides an expectation for elite
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pitching mechanics to remain stable (Fleisig et al., 2009), and the players were asked to simulate a game scenario when performing, it is impossible to guarantee that their pitches in this study were perfectly representative of how they pitched during the season. It is also worth noting that the protocol was constrained by the pitchers’ medically regimented throwing volumes (i.e., pitch counts), meaning that the pitch count during a game generally comprises more than the four pitches (of each type) that were used to measure kinematics in this study. As such, the complexion of the measured ball flight variables may have been different if more pitches were considered. Spatial variability of the release location was only reported in the horizontal and vertical directions across grouped pitch types, and future work should therefore explore release variability in the anterior-posterior dimension. Likewise, these data must be synthesized with biomechanical data to better determine how pitchers generate specific ball kinematics.

Perspectives

There are distinct differences in the ball flight kinematics of the four main pitch types in baseball. In this study, the fastball did not possess a horizontal spin axis, while the curveball tended to resemble a traditional “slurve,” implying that the fastball with perfect backspin and 12-6 curveball may be theoretical pitches. The sliders’ spin axis was more conducive to lateral deviation in its later flight, potentially contributing to the “late” break that is often cited in this pitch. In a practical sense, these kinematic values are instructive for inferring appropriate hand mechanics and spin types across the different pitches. Of equal importance to coaches is the fact that consistency in the release location – particularly in the vertical direction – appears to be a hallmark of pitching at the collegiate level. However, while pitching mechanics and outcomes provide a focal point for pitching development, the findings of the current study suggest that these factors do not provide the sole determinants of performance during the baseball season. Consequently, pitching development, talent identification, and future research should also attend to other (e.g., cognitive, psychological, and physiological) effectors of pitching performance.

Key words: Aerodynamics, spin, axis, velocity, biomechanics, coaching.

Acknowledgements

The authors thank Kimberley Hill, Ryan Holstad, and Douglas Martini for their assistance with this study. This study was funded by the University of Michigan.

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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher’s web site:

Fig. S1. Typical grips used in common baseball pitches (jpg).

Video S1. Video of a representative four-seam fastball (mp4).

Video S2. Video of a representative changeup (mp4).

Video S3. Video of a representative slider (mp4).

Video S4. Video of a representative curveball (mp4).