Shoulder kinematics during pitching: Comparing the slide step and traditional stretch deliveries

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ABSTRACT

Although studies have investigated the traditional stretch delivery, there is little biomechanical data describing the slide step delivery in baseball pitchers. Thus, the purpose of this study was to compare shoulder kinematics across the traditional stretch and slide step deliveries. To collect kinematic data from thirty-seven high school baseball pitchers, electromagnetic sensors recording at 140 Hz were affixed to various body segments. The average of those data from the three fastest pitches passing through the strike-zone were analyzed for each delivery. At the instances of front foot contact and ball release, no differences were observed between the two deliveries. At the instant of maximum shoulder external rotation, differences were observed between the two deliveries with regard to plane of elevation ($t(72) = 4.19, p < .001$), elevation ($t(72) = −3.38, p < .001$), and axial rotation ($t(72) = 2.49, p = .015$). The mechanical differences observed between the two delivery styles may have the potential to impact both performance and injury. Also, based on these results there may be a tradeoff between injury risk and performance. Thus, further study is warranted in an effort to identify the interrelationships between injury risk, performance, and pitching kinematics when throwing from the stretch position.

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1. Introduction

Baseball pitchers have been shown to have exceedingly high injury rates, with these injuries commonly occurring at young ages (Bonza, Fields, & Yard, 2009; Fleisig, Chu, Weber, & Andrews, 2009; Han, Kim, Lim, Park, & Oh, 2009). A number of factors have been described as underlying causes of these injuries, from the repeated forces and torques experienced by the shoulder and elbow throughout the pitch cycle (Adams, 1991; Fleisig, Andrews, Dillman, & Escamilla, 1995; Sabick, Torry, Lawton, & Hawkins, 2004), to improper sequencing of segmental movements throughout the pitching motion (Aguinaldo, Buttermore, & Chambers, 2007; Aguinaldo & Chambers, 2009). Because of these factors, much literature describing the biomechanics of baseball pitching has focused on the idea of proper pitching mechanics in an effort to reduce injury (Davis et al., 2009; Dun, Loftice, Fleisig, Kingsley, & Andrews, 2008; Fleisig, Barrentine, Escamilla, & Andrews, 1996; Fleisig, Barrentine, Zheng, Escamilla, & Andrews, 1999; Olsen, Fleisig, Dun, Loftice, & Andrews, 2006; Sabick et al., 2004; Sabick, Kim, Torry, & Hawkins, 2005; Trakis et al., 2008; Werner, Gill, Murray, Cook, & Hawkins, 2001).

Unfortunately, the aforementioned analyses have focused on the wind-up delivery. To date, only five studies have been identified that analyzed the stretch delivery (Dun, Kingsley, Fleisig, Loftice, & Andrews, 2008; Fortenbaugh & Butcher-Mokha, 2007; Oliver & Keeley, 2010a, 2010b). This disparity in the analysis of the stretch delivery has resulted in a lack of data describing the pitching mechanics associated with the stretch. Also, within the stretch delivery there are two commonly utilized forms; the traditional stretch and the slide step deliveries. To briefly describe the traditional stretch delivery the pitcher begins with their back foot parallel to the pitching rubber and trunk orthogonal to the direction of the pitch. The pitcher then lifts the stride leg vertically, strides toward home plate, separates the hands, and abducts the arms prior to the stride foot contacting the ground. Although the slide step delivery is similar to the traditional stretch delivery initially, the height to which the stride leg is lifted is greatly reduced in an effort to deliver the pitch in less time and reduce the risk of a base runner advancing via the stolen base. An example sketching of these delivery styles is provided in Fig. 1.

Although it is thought among coaches that the kinematics associated with the execution of the traditional stretch delivery and the slide step delivery should be consistent, it is not currently known whether they indeed are. Thus, the purpose of this study was to compare shoulder kinematics in baseball pitchers who utilize both the traditional stretch delivery and the slide step delivery. It was hypothesized that there would be differences in the kinematic position of the shoulder at various instances throughout the pitch cycle.

![Fig. 1. Illustration of the front leg kick associated with the traditional stretch delivery (A) and slide step delivery (B).](image-url)
2. Methods

2.1. Participants

Thirty-seven high school male baseball pitchers with a mean age, height, and mass of 16.8 ± 1.4 yrs., 174.9 ± 8.3 cm, and 79.3 ± 8.1 kg, respectively volunteered to participate in the current study. All participants had recently finished their competitive spring baseball seasons, and were deemed appropriately conditioned for competition. All participants in the current study were identified as being varsity level starting pitchers by their respective coaches. Additional criterion for subject selection included multiple years (up through the current season) of pitching experience using both delivery methods (slide step/high leg kick) and freedom from injury throughout their recently completed competitive baseball season. Throwing arm dominance was not a factor contributing to subject selection or exclusion for this study.

2.2. Testing location

All data collection sessions were conducted indoors at the University of Arkansas Health, Physical Education, and Recreation building and were designed to best simulate a competitive setting. All testing protocols used in the current study were approved by the University of Arkansas Institutional Review Board. Prior to their participation, all subjects (and subject parent(s)/guardian(s)) completed informed consent and provided medical and participation history information.

2.3. Equipment sensitivity

To collect data in the current, The MotionMonitor™ electromagnetic tracking system (Innovative Sports Training, Chicago IL) was utilized. This system has been shown to be a valid tool in tracking movements of the humerus, producing trial-by-trial interclass correlation coefficients for axial humerus rotation in both loaded and non-loaded condition in excess of .96 (Ludewig & Cook, 2000). However, with electromagnetic tracking systems, field distortion has been shown to be the cause of error in excess of 5° at a distance of 2 m from an extended range transmitter (Day, Murdoch, & Dumas, 2000). However, increases in instrumental sensitivity have reduced this error to near 10° prior to system calibration and 2° following system calibration (Perie, Tate, Chencg, & Dumas, 2002). Therefore, prior to testing sessions, the current system was calibrated using previously established techniques (Day, Dumas, & Murdoch, 1998; Day et al., 2000; Perie et al., 2002). Following calibration, pilot data collected prior to testing participants indicated that the magnitude of error in determining the position and orientation of the electromagnetic sensors within the calibrated world axes system was less than .02 m and 3° respectively.

2.4. Subject preparation

Subjects reported for testing prior to participating in any resistance training or vigorous activity. At the testing facility, subjects were prepared as shown in Fig. 2 so that kinematic data could be collected using the aforementioned electromagnetic tracking system. During the set-up, subjects had a series of six electromagnetic sensors attached at the following locations: (1) the medial aspect of the torso at C7; (2) medial aspect of the pelvis at S1 (Myers, Laudner, Pasquale, Bradley, & Lephart, 2005); (3) the distal/posterior aspect of the throwing humerus; (4) the distal/posterior aspect of the throwing forearm; (5) the distal/posterior aspect of the non-throwing humerus; and (6) the distal/posterior aspect of the non-throwing forearm (Oliver & Keeley, 2010a, 2010b). Sensors were affixed to the skin using double sided tape and secured using flexible hypoallergenic athletic tape. Following the attachment of the electromagnetic sensors, a seventh sensor was attached to a wooden stylus and used to digitize the palpated position of the bony landmarks described in Table 1 (Myers et al., 2005; Wu et al., 2005). To accurately digitize the selected bony landmarks, subjects stood in the neutral anatomical position during the digitization process.
2.5. Protocol

Following all set-up and sensor affixation, subjects were allotted an unlimited time to perform their own specified pre-competition warm-up routine. During this time, they were asked to spend a small portion of their warm-up throwing from the indoor pitching mound to be used during the test trials. After completing their warm-up and gaining familiarity with the pitching surface, each subject threw a series of maximal effort fastballs for strikes toward a catcher located the regulation distance from the pitching mound (18.44 m). During test trials, pitches were delivered using both the traditional stretch and slide step deliveries in randomized order. For the current study, those data from the three fastest pitches passing through the strike-zone for each delivery method were selected and averaged for detailed analysis. Pitch velocity was recorded using a manufacturer calibrated radar gun (JUGS Sports, Tualatin, OR).

2.6. Post processing

Throwing kinematics for right handed subjects were calculated using the standards and conventions for reporting joint motion recommended by the International Shoulder Group of the International Society of Biomechanics (Wu et al., 2002, 2005). Briefly, raw data describing sensor orientation and position were transformed to locally based coordinate systems for each of the respective body

Table 1

<table>
<thead>
<tr>
<th>Bony landmarks</th>
<th>Bony process palpated and digitized</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thorax</strong></td>
<td></td>
</tr>
<tr>
<td>Seventh cervical vertebra (C7)</td>
<td>Most dorsal aspect of the spinous process</td>
</tr>
<tr>
<td>Eighth thoracic vertebra (T8)</td>
<td>Most dorsal aspect of the spinous process</td>
</tr>
<tr>
<td>Suprasternal notch</td>
<td>Most cranial aspect of the sternum</td>
</tr>
<tr>
<td><strong>Humerus (throwing and non-throwing)</strong></td>
<td></td>
</tr>
<tr>
<td>Medial epicondyle</td>
<td>Most distal/lateral aspect of the condyle</td>
</tr>
<tr>
<td>Lateral epicondyle</td>
<td>Most distal/lateral aspect of the condyle</td>
</tr>
<tr>
<td>Center of glenohumeral rotation</td>
<td>Estimated*</td>
</tr>
<tr>
<td><strong>Forearm (throwing and non-throwing)</strong></td>
<td></td>
</tr>
<tr>
<td>Radial styloid process</td>
<td>Most distal/lateral aspect of the radial styloid</td>
</tr>
<tr>
<td>Ulnar styloid process</td>
<td>Most distal/medial aspect of the ulnar styloid</td>
</tr>
</tbody>
</table>

* Note – The center of glenohumeral rotation (and subsequently the joint itself) was not digitized. It was estimated using a least squares algorithm for the point moving least during series of short rotational movements (Myers et al., 2005).
segments. Euler angle decomposition sequences were used to describe both the position and orientation of the torso relative to the global coordinate system (Wu et al., 2002, 2005). The use of these rotational sequences allowed the data to be described in a manner that most closely represented the clinical definitions for the movements reported (Myers et al., 2005). Angle decomposition sequencing for the torso, shoulder, and elbow, as well as definitions of the movements they describe are shown in Table 2. Throwing kinematics for left handed subjects were calculated using the same conventions; however, the world z axis was mirrored so that all movements could be calculated, analyzed, and described from a right hand point of view (Wu et al., 2002, 2005).

### Table 2
Sequence of angle decompositions used to describe torso, humerus, and forearm orientation throughout the pitching motion.

<table>
<thead>
<tr>
<th>Segment</th>
<th>Axis of rotation</th>
<th>Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torso</td>
<td>Z</td>
<td>Flexion (−)/extension (+)</td>
</tr>
<tr>
<td></td>
<td>X'</td>
<td>Left lateral tilt (−)/Right lateral tilt (+)</td>
</tr>
<tr>
<td></td>
<td>Y'</td>
<td>Right axial rotation (+)/left axial rotation (−)</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Y</td>
<td>Plane of elevation (0° is abduction; 90° is flexion)</td>
</tr>
<tr>
<td></td>
<td>X'</td>
<td>Elevation</td>
</tr>
<tr>
<td></td>
<td>Y'</td>
<td>Internal Rotation (+)/external rotation (−)</td>
</tr>
<tr>
<td>Elbow</td>
<td>Z</td>
<td>Flexion (+)/hyperextension (−)</td>
</tr>
<tr>
<td></td>
<td>X'</td>
<td>Carrying angle</td>
</tr>
<tr>
<td></td>
<td>Y'</td>
<td>Pronation (+)/supination (−)</td>
</tr>
</tbody>
</table>

Note – Prime (′) and double prime (′′) notations represent previously rotated axes due to rotation of the local coordinate system resulting in all axes within that system being rotated (i.e. rotation about the X-axis, also results in rotation of both the Y-axis and Z-axis producing a new axis system of X′, Y′, and Z′. Subsequent rotations will then be about these axes).

#### 2.7. Statistical analyses

Data were analyzed in the current study using the statistical analysis package SAS 9.1 for Windows (SAS Institute Inc., Cary, NC). For both delivery methods, mean and standard deviation for shoulder kinematics were calculated at foot contact, maximum shoulder external rotation, ball release, and maximum shoulder internal rotation. After the calculations of the measures of central tendency were completed, a series of descriptive statistics were utilized to identify the nature of the distribution for each parameter. To determine the nature of the distribution, the Kolmogorov–Smirnov Goodness-of-Fit statistic was calculated to test for normality. Once the data were deemed to be normally distributed paired sample t tests were conducted to test for mean differences. For any data not meeting the normality assumption of the paired sample t test, nonparametric analyses were conducted using the Wilcoxon t test. In the current study, an intra-subject design was employed in which pitch delivery method was the independent variable. For the current study, because three dependent variables were analyzed at each of the selected instances of the pitch cycle, the level of significance was adjusted using a standard Bonferroni adjustment and set at \( p = .05/3 \) or \( p \leq .0168 \).

#### 3. Results

##### 3.1. Descriptive statistics and normality

Pitch velocity averaged 34.06 ± 2.36 m/s (76.2 ± 5.3 mph) for the traditional stretch and 33.30 ± 2.10 m/s (74.5 ± 4.7 mph) for the slide step delivery. Results of descriptive analyses are shown for both delivery techniques in Table 3. All variables at foot contact, shoulder maximum external rotation, and release met parametric t test model assumptions, as did elevation at maximum internal
rotation. However, the data describing both shoulder plane of elevation and axial rotation at the instant of shoulder maximum internal rotation violated the normality assumption and were further analyzed using the Wilcoxon test for nonparametric distributions.

### 3.2. Comparison of group means

The values reported for pitch velocity were not determined to be statistically different. With regard to both shoulder plane of elevation and shoulder elevation at the instances of foot contact, release, and maximum shoulder internal rotation, no differences were observed between the two delivery styles. In contrast, at the instant of shoulder maximum external rotation all three shoulder angles were different between the delivery styles. These results are displayed in Fig. 3 (plane of elevation), Fig. 4 (elevation), and Fig. 5 (shoulder axial rotation). These results indicated that the throwing humerus in a position of greater horizontal abduction and elevation, and a position of lesser external rotation for the traditional stretch delivery. However, based on the calculated coefficient of determination for each

#### Table 3

Mean (± standard deviation) for shoulder kinematics at selected instances during both the traditional leg kick and slide step deliveries.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Traditional delivery Mean (SD)</th>
<th>Slide step delivery Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Foot contact</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plane of elevation (°)</td>
<td>-24.4 (±9.3)</td>
<td>-26.7 (±11.9)</td>
</tr>
<tr>
<td>Elevation (°)</td>
<td>-95.8 (±12.7)</td>
<td>-98.4 (±13.3)</td>
</tr>
<tr>
<td>Axial rotation (°)</td>
<td>-98.5 (±21.7)</td>
<td>-104.5 (±16.2)</td>
</tr>
<tr>
<td><strong>Maximum Shoulder external rotation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plane of elevation (°)</td>
<td>4.3 (±3.1)</td>
<td>1.1 (±3.4)</td>
</tr>
<tr>
<td>Elevation (°)</td>
<td>-100.7 (±7.9)</td>
<td>-95.1 (±6.5)</td>
</tr>
<tr>
<td>Axial rotation (°)</td>
<td>-157.7 (±14.3)</td>
<td>-165.1 (±11.1)</td>
</tr>
<tr>
<td><strong>Release</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plane of elevation (°)</td>
<td>11.2 (±5.5)</td>
<td>12.4 (±8.3)</td>
</tr>
<tr>
<td>Elevation (°)</td>
<td>-102.3 (±10.7)</td>
<td>-98.9 (±10.9)</td>
</tr>
<tr>
<td>Axial rotation (°)</td>
<td>-52.2 (±26.7)</td>
<td>-46.8 (±22.7)</td>
</tr>
<tr>
<td><strong>Maximum shoulder internal rotation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plane of elevation (°)</td>
<td>42.7 (±10.7) *</td>
<td>44.68 (±10.6) *</td>
</tr>
<tr>
<td>Elevation (°)</td>
<td>-77.0 (±25.9)</td>
<td>-83.1 (±23.6)</td>
</tr>
<tr>
<td>Axial rotation (°)</td>
<td>23.5 (±12.5) *</td>
<td>31.1 (±15.2)</td>
</tr>
</tbody>
</table>

*Note* – indicates that the assumption of distributional normality was not met.

![Fig. 3](image_url) Results of mean difference testing for plane of elevation angle throughout the pitch cycle. Plane of elevation differed significantly between the two delivery styles on at the instant of maximum shoulder external rotation ($t(72) = 4.19, p < .001, r^2 = .32$).
of the differences, only 14% (axial rotation), 24% (elevation), and 32% (plane of elevation) of the observed variability in shoulder kinematics can be accounted for by delivery technique.

Results of the nonparametric Wilcoxon t test analyses at the instant of shoulder maximum internal rotation indicated that only the angle of axial rotation was different between the two delivery styles ($W(37) = 447.00, p < .001, r^2 = .24$). This result showed that the throwing humerus was in a position of greater internal rotation for the slide step delivery.

4. Discussion

As previously stated, there are two commonly utilized versions of the stretch delivery in baseball; the traditional stretch and the slide step. It was the purpose of this study to quantify pitching mechanics utilized when performing both deliveries. An additional purpose was to analyze the differences in shoulder kinematics between the two deliveries. It was hypothesized that there would be differences in shoulder kinematics at various instances throughout the pitch cycle between the two deliveries.

4.1. Impact on performance

Based on the results of this study, it appears that coaches are correct in their thoughts that, while not exact, shoulder kinematics of the slide step and traditional stretch deliveries are similar. Although
the research hypothesis of this study was correct and differences in shoulder kinematics were observed between the two deliveries, the magnitudes of those differences were small. These findings are important in that it appears adequately trained pitchers can benefit in two primary areas when utilizing the slide step delivery.

First, it is thought that the fastball is the most important pitch in the game of baseball and the ability to consistently maximize fastball velocity is vital to a pitcher’s success (Stodden, Fleisig, McLean, & Andrews, 2005). In the current study, no difference was observed in pitch velocity between the two delivery styles. This finding indicates pitchers are able to utilize the slide step delivery without sacrificing vital pitch velocity. Second, the differences observed in shoulder kinematics were small enough that they may be unperceivable without the use of highly complex equipment. Because of this, pitchers can reduce the likelihood of the stolen base by decreasing the time needed to deliver the pitch by utilizing the slide step delivery. Based on the findings of this study, it appears that pitchers are able to achieve this advantage without the batter gaining information about pitch velocity or location due to noticeable mechanical alterations.

4.2. Study limitations

To improve the interpretation of the results of this study, it should be discussed that there are limitations associated with the system utilized to collect movement data. Although electromagnetic tracking systems have been shown to be valid tools in describing movements about the shoulder, there is error associated with their output. However, when appropriate calibration and collection techniques are utilized this error can be reduced to acceptable levels. The implementation of these techniques in this study allowed the error rates to be reduced to levels similar to those in previous work (Day et al., 1998, 2000; Perie et al., 2002). Although the differences observed in this study were small, they were within the error limits associated with the techniques employed in this study. This indicates that while the kinematics employed by baseball pitchers as they utilize both the slide step and traditional stretch deliveries are not exact, they are quite similar.

5. Conclusion

Regardless of the circumstances, pitchers are always striving to gain an advantage over their opponent. The results of this study reveal this may be possible by utilizing the slide step delivery when pitching from the stretch position. By utilizing the slide step delivery, pitchers appear to be able to decrease the risk of the stolen base while maintain pitch velocity. Also, because the differences between the two deliveries are small, it appears pitchers are able to achieve this without providing the batter with increased information regarding pitch velocity or location.

References


