

The Association of Baseball Pitch Delivery and Kinematic Sequence on Stresses at the Shoulder and Elbow Joints

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Abstract

Although there is a commonly held belief within the baseball community that delivery from the stretch confers more stress at the elbow and shoulder joints than delivery from the windup, there remains little evidence in the literature investigating this hypothesis. This study aimed to help address this gap in the literature by studying both intra-pitcher kinematic sequence variability, and intra-pitcher joint torque variability when throwing from the windup vs. the stretch. We hypothesized that 1) each pitchers' kinematic sequence would remain similar whether throwing from the windup or stretch, and 2) Kinematic sequence would influence peak arm torque more than delivery method. This cross-sectional 3D biomechanical study included 88 pitches thrown by ten (6 collegiate, 4 high school) pitchers with a mean age of 17.60 ± 2.63 years. Pitch velocity, throwing shoulder/elbow torques and the kinematic sequence of each pitch utilizing segmental peak angular velocities were captured. No statistically significant differences in ball velocity ($p = 0.17$), peak shoulder external rotation torque ($p = 0.80$), shoulder extension torque ($p = 0.97$), or elbow valgus torque ($p = 0.83$) were found between delivery approaches. Three primary kinematic sequences were identified. Shoulder external rotation torque [$F(53,2) = 10.992$, $\eta^2 = .293$, $p < 0.00$], shoulder extension torque [$F(53,2) = 15.517$, $\eta^2 = .369$, $p < 0.00$] and elbow valgus torque [$F(53,2) = 9.994$, $\eta^2 = .274$, $p < 0.00$] did vary significantly across these three kinematic sequence patterns. Our data suggest that the kinematic sequence influences shoulder and elbow torque more than the delivery approach. Instructing ideal kinematic sequence may be more influential for injury avoidance than delivery method.

Key words: Windup; stretch; pitching biomechanics; shoulder torque; elbow torque.

Introduction

Studies of the throwing motion describe the most efficient movement pattern for maximizing performance and preventing injury based on simulated modelled movements (Calabrese, 2013; Putnam, 1993). The timing of peak angular velocity of the pelvis, trunk, arm, forearm and hand, referred to as the "kinematic sequence", is one method of assessing a pitcher's movement pattern. The most efficient movement pattern for the baseball pitcher has been reported as a kinematic sequence precisely moving proximal-to-distal, thus maximizing the efficiency of energy transfer through the kinetic chain (Atwater, 1979; Fleisig et al., 1995; Putnam, 1993). Baseball pitchers throw to batters using two primary pitch delivery approaches: the traditional windup and the stretch. It has been conventionally

theorized that the traditional windup utilizes the full kinetic chain better than the stretch delivery (Dunn et al., 2008). This theory suggests that pitching from the stretch may place extra force on the shoulder or elbow. We know of two studies investigating the biomechanics of the stretch delivery and only one reporting comparison to the windup delivery (Dunn et al., 2008; Keeley et al., 2012). One study of professional pitchers reported that torques at the shoulder (88.9 Nm vs 88.0 Nm) and elbow (86.6 Nm vs. 87.5 Nm) are not significantly different between delivery approaches (Dunn et al., 2008). The second study found differences in shoulder elevation height (100.7° vs 95.1°) at maximum shoulder external rotation during the traditional windup, implicating potential increased injury risk with throws using less lead leg lift (Keeley et al., 2012). It has not been determined whether the same kinematic sequence is used for both approaches or if one approach creates greater vulnerability for injury to the throwing arm.

During the traditional windup delivery, the pitcher's starting position on the mound begins facing the batter and is followed by a body rotation in order to position the lead shoulder towards home plate. The pitcher then executes a lead leg lift motion that creates momentum towards home plate, driving the mass of the lead leg forward until it contacts the ground into the stride position (Figure 1). This momentum is transferred through the shoulder and elbow joints and distally to the forearm, hand, and fingertips (Atwater, 1979; Dunn et al., 2008; Fleisig et al., 1996; Seroyer et al., 2010). In contrast, during the stretch baseball delivery, the pitcher's starting position on the mound is to stand with the pitcher's lead shoulder facing the batter (Figure 1). Typically, the leg lift during the stretch delivery is smaller than during the traditional windup delivery, which is thought to result in less momentum (Calabrese, 2013). However, not every pitcher alters the degree of leg lift when throwing from the stretch. In competitive baseball, throwing from the stretch is performed to quicken the pitch delivery time with the hopes of limiting the threat of base runners from stealing bases (Dunn et al., 2008). It is believed among pitchers and coaches that the stretch delivery may inhibit the full efficacy of the energy transfer throughout the kinetic chain by limiting the amount of energy contribution from the lower half of the body (Keeley et al., 2012). Therefore, pitching from the stretch position may result in a greater reliance on shoulder and elbow musculature, as compared to the traditional windup pitch, which is thought to rely more on leg and pelvis musculature to progressively transfer velocity to the hand (Dunn et al.,

2008, Keeley et al., 2012). Understanding the stresses placed on the throwing limb's shoulder and elbow joints during the different pitch deliveries may help better define return to play pitch progressions after surgery.

Many coaches instruct young pitchers to throw from the stretch to facilitate learning basic throwing mechanics. In this reasoning, using the stretch delivery for instruction theoretically allows for direct focus on the kinematic sequence from stride to ball release without the additional movement prior to the balance point position. Understanding how the kinematic sequence varies with pitch delivery approach (and with stresses placed on the throwing arm) may offer information useful in pitching instruction and in the development of injury prevention programs.

Intra-pitcher comparisons of pitch delivery between the windup and stretch approaches offer opportunities to study shoulder and elbow joint stresses and to analyze whether pitchers perform the kinematic sequence consistently despite the role of the lead leg prior to stride. The primary objective of this study was to investigate the kinematic sequences as well as elbow and shoulder torques between the two pitching approaches using high-speed 3D motion capture analysis. Specifically, we set out to investigate two hypotheses: 1) Intra-pitcher comparison of kinematic sequence patterns performed during the windup will be similar to those performed from the stretch and 2) Kinematic sequence patterns influence shoulder and elbow torques more than the type of delivery method.

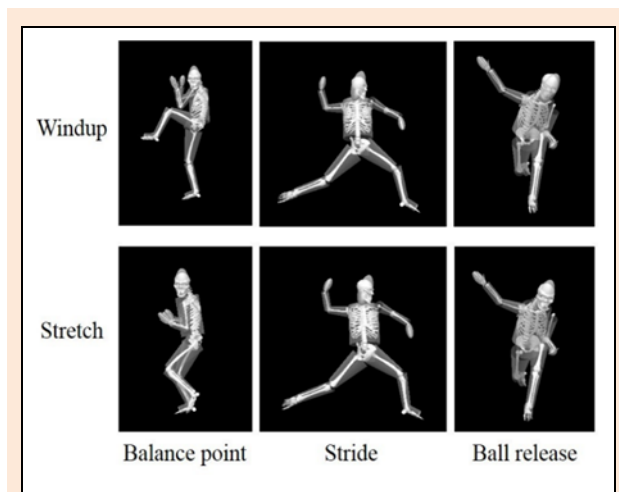


Figure 1. Skeletal model illustration comparing the delivery approaches, windup (top row) and stretch – slide step approach (bottom row).

Methods

Participants

Inclusion criteria were as follows: 14+ years of age, actively pitching in a competitive baseball organization, no

history of injury within the past 3 months, no report of pain at the time of study. This retrospective study was conducted using a convenience sample. Data from 62 baseball pitchers was reviewed to identify and include all pitchers who, during previous testing, threw pitches from both the windup and stretch delivery. Additional criteria for these analyses included that all pitchers reported that they routinely have in-game roles as starters or relievers pitching 3+ innings per outing. All included high school pitchers played in travel club leagues as well as school teams, suggesting similar level of competitive play. Ten (6 collegiate, 4 high school) pitchers met this study criteria (Table 1). The Institutional Review Board approved this 3D biomechanical research study. All subjects provided informed consent to participate in this cross-sectional study of the biomechanics of the baseball pitch.

Design and procedures

A Vicon™ (Vicon Motion Systems Ltd, Oxford, Oxfordshire, UK) 20 T-series MX cameras motion capture system collecting at 360 HZ, identified and tracked 62 reflective markers (14 mm) placed on anatomic landmarks and segment regions to create a 15-segment model of each pitcher. Each pitcher was provided time to perform their individualized warm up routine. Pitches were thrown from a standard turf baseball mound at a distance of 18.44 m from home plate into a stationary strike zone target, to minimize variability. The players were requested to throw between 5-10 pitches of each of their routine pitch types resulting in an average of 35 pitches thrown per person. Pitchers were asked to throw 5-10 fastballs from both the windup and stretch. A Stalker ATS 5.0 radar gun (Stalker Radar, Plano, TX, USA) was utilized to measure pitch velocity, and pitch location was recorded based on a standard six-box strike zone of the target. A target 5 of the fastest and most accurate fastball pitches were selected as representative of each pitcher's windup and stretch deliveries. For final study inclusion, a pitcher's data set needed a minimum of 4 fastball pitches in the strike zone for the windup delivery and a minimum of 4 fastball pitches in the strike zone for the stretch delivery. If a pitcher had more than 5 in strike zone fastball pitches for a delivery type, the fastest pitches were selected to allow for a maximum of 5 pitches per delivery type. The above pitch criteria lead to a final sample size of 88 total pitches from the 10 pitchers.

The biomechanical software, Visual 3D™ (Version 5, C-Motion Research Biomechanics, Inc., Germantown, MD, USA), was used for the analysis of data obtained in the motion capture lab. The lab used the following coordinate system: the direction of the pitch was represented by the X-axis, the vertical direction by the Z-axis, and the cross product of the X- and Z-axes by the Y-axis (Scarborough et al., 2018). A 6 degree-of-freedom model was used for biomechanical calculations. Following common

Table 1. Pitcher characteristics. Data are average values (standard deviation).

	Age (yrs.)	Height (m)	Weight (kg)	Windup Fastball pitch speed	Stretch Fastball pitch speed
High school	15.00 (± 0.82)	1.73 (± 0.10)	68.04 (± 13.09)	30.24 (± 4.45)	29.06 (± 4.92)
College	19.33 (± 1.75)	1.79 (± 0.05)	80.34 (± 8.64)	34.30 (± 2.04)	34.29 (± 1.55)
Total	17.60 (± 2.63)	1.77 (± 0.08)	75.42 (± 11.79)	32.68 (± 3.65)	32.19 (± 4.08)

placement protocol, the reflective markers were placed on each pitcher's skin directly over anatomical landmarks to complete the 15 body segment model (Scarborough et al., 2018). Shoulder and elbow joint centers were defined based upon the recommendations of the International Biomechanics Society (Wu et al., 2005). Linear regression following Meskers et al. (1997) protocol was used to estimate the shoulder and elbow joint centers. The definition of Upper Body Segments followed the International Society of Biomechanics definitions (Meskers et al., 1997).

Measures

All biomechanical variables were calculated within Visual 3D™. The peak value of each segment's angular velocity (degrees per second) was calculated relative to the laboratory coordinate system using the resultant magnitude (Scarborough et al., 2018). Time events comparing windup and stretch delivery differences were calculated based on calculations for time of balance point and stride. Balance point was defined as when the first greatest value of hip flexion occurred. The time of stride occurred when the lead foot was first flat on the mound. Stride length was defined as the distance between both ankle joint centers in the lab axis X plane at the time of stride and displayed as percent of pitcher's height.

Kinematic sequences (KS) were defined based on the system using the proximal-to-distal sequence (PDS) as the foundation of ideally coordinated movements utilized in a baseball pitch as previously described (Scarborough et al., 2018). The example naming of the PDS KS is 12345: 1-pelvis, 2-trunk, 3-arm, 4-forearm and 5-hand. Peak angular velocities at each of these body segments were recorded and the time points of these maximum velocities were used to characterize individual KS patterns for each pitch. Specific KS patterns were identified for all 88 pitches included from the 10 pitchers and it was noted that none of the pitches fit the ideal sequence PDS pattern

(12345). Of the 88 pitches, 11 different KS's were identified and the 3 most frequently performed KS's were selected for comparison and analyzed. The 3 top KS patterns resulted in a total of 57 pitch trials across all players and across both pitch delivery types. The pattern closest to the true PDS was one where the forearm and hand peak at same time (12344), which we therefore called the Proximal-to-distal KS (Figure 2). There was a total of 14 pitch trials in the PDS group. To conceptually differentiate the three kinematic sequences, the second and third most frequently performed KS patterns were named based on the body segment location where the sequence first deviated from the ideal PDS: Altered Distal arm segment KS (12354) group - forearm segment velocity peaking prior to the hand. The Altered Distal arm segment KS pattern group was the largest and included a total 28 pitches. The Altered Proximal arm segment KS (12453) group - peak arm segment velocity switches order with that of the hand. Fifteen pitches were identified as the Altered Proximal arm segment KS pattern.

Statistical analysis

The averages of the peak shoulder force, peak shoulder external rotation torque, peak shoulder extension torque and peak elbow valgus torque across the 4-5 pitches for each delivery type were calculated for analysis (total of 88 pitches). Paired analysis comparison was performed using a paired t-test analyses to compare ball velocity, stride length, shoulder external rotation, shoulder extension torque, and elbow valgus torque between the wind-up and stretch delivery. The number of different KSs performed between each delivery were compared using Wilcoxon Rank order analyses (all 88 pitches). A multivariate analyses of variance analyses using pitch speed as a covariate (MANCOVA) was performed to compare shoulder external rotation and extension torques and elbow torques across the three primary KSs identified (57 pitches). Post hoc

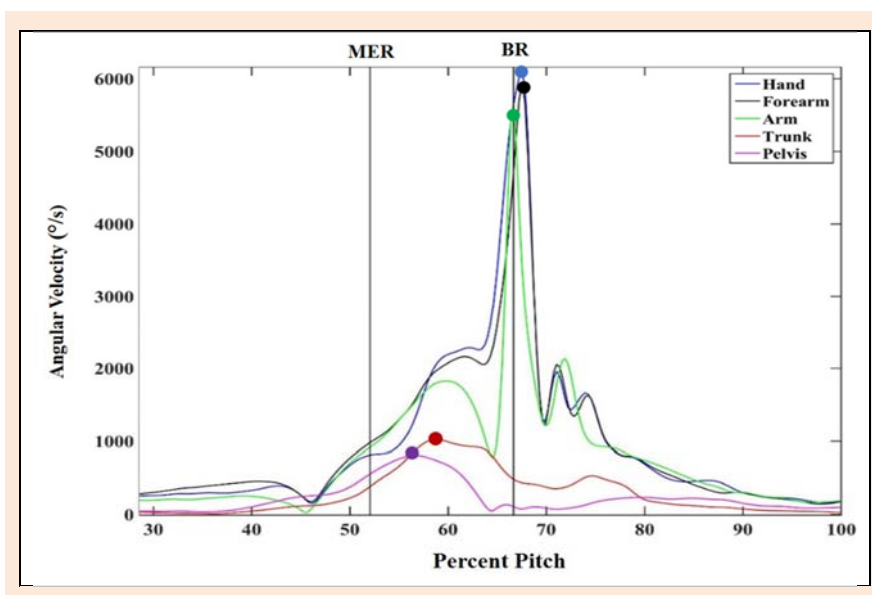


Figure 2. Kinematic sequence illustrating the angular velocity of the pelvis, trunk, arm, forearm and hand segments during one pitch. The pattern of peak angular velocities demonstrates a simultaneous occurrence of the forearm and the hand segments as described in this study as a representative of one of 2 possible PDS patterns. The vertical line MER represents the time of maximum shoulder external rotation and the vertical line BR represents the time of ball release.

comparisons across the 3 kinematic sequence patterns were performed using the Least Significant Difference (LSD) pairwise analyses. Two-way ANOVA analyses were conducted to examine the interaction effect of pitch delivery and kinematic sequence on each of the torque values. All analyses were performed using SPSS statistical package (Version 24) and considered statistically significant if $p < 0.05$.

Results

There was no statistical difference in ball velocity between the windup ($\bar{x} = 32.68 \pm 3.65$ m/s) and stretch delivery ($\bar{x} = 32.19 \pm 4.08$ m/s), $p = 0.17$. Stride length measures from the windup ($\bar{x} = 83.93$ %HT ± 0.08) and stretch ($\bar{x} = 83.43$ %HT ± 0.08) deliveries were not statistically different, $p = 0.48$.

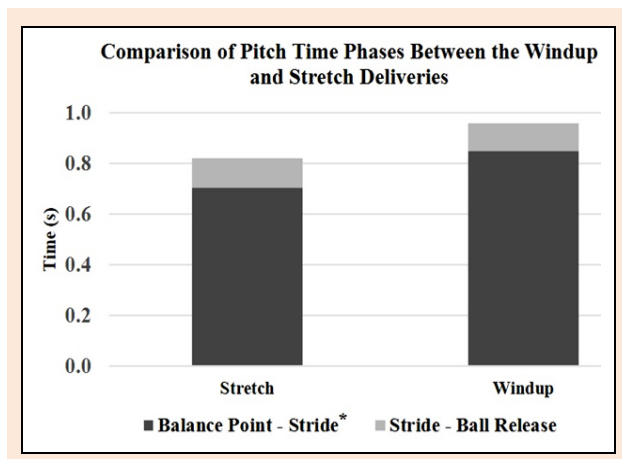


Figure 3. Comparison of time phases from 1) Balance Point to Stride* and 2) Stride to Ball Release. * Reached statistical significance, $p < 0.05$.

Comparison of 2 pitch phase times between the stretch and the windup approaches

Based on the 88 pitches, pitchers demonstrated a quicker time from balance point to stride when performing pitches from the stretch ($\bar{x} = 0.704 \pm 0.205$) compared to throwing using the windup approach ($\bar{x} = 0.851 \pm 0.127$ s), reaching a statistical significant difference (95% CI, 0.0068 to 0.2885), $t(9) = 2.360$, $p = 0.04$. There was no statistical difference between pitch approaches for the time from stride to ball release, $p = 0.25$ (Figure 3).

Elbow Valgus and Shoulder torques between the stretch and the windup approaches

Across all 88 pitches, comparison of valgus elbow torques

between the windup and the stretch approaches did not reach statistical significance, $p = 0.83$ (Table 2). There were no statistically significant differences in peak shoulder external rotation ($p = 0.80$) or extension torques ($p = 0.97$) between pitches thrown from the stretch compared to those of the windup approach (Table 2).

Table 2. Comparison of the peak shoulder and elbow torques (Nm) across the 10 pitchers for both throws from the windup and stretch delivery.

Torques	Wind-up (SD)	Stretch (SD)
Elbow Valgus	59.42 (± 14.75)	59.22 (± 14.53)
Shoulder Extension	73.04 (± 22.81)	72.99 (± 22.02)
Shoulder External Rotation	63.39 (± 16.59)	63.11 (± 16.25)

Comparison of shoulder and elbow torques across kinematic sequence patterns

Shoulder external rotation torque was statistically different across the 3 KS patterns, $[F(53,2) = 10.992, \eta^2 = 0.293, p < 0.00]$. The greatest shoulder external rotation torques were performed by the Altered Proximal KS pattern group and the lowest values were performed by the PDS group of KS patterns (Table 3). The post hoc analyses revealed that all KS comparisons reached a significance level of < 0.00 except for a non-significant difference between the PDS and Altered Distal KS patterns, $p = 0.24$. Similarly, the shoulder extension torques demonstrated statistically different values across all KS patterns, $[F(53,2) = 15.517, \eta^2 = .369, p < 0.00]$. The Altered Proximal KS group exhibited the largest shoulder extension torques and the PDS group demonstrated the lowest values. The post hoc analyses of shoulder extension torques were statistical different among all KS groups at a significance of $p \leq 0.00$ except for a non-significant difference between the PDS and Altered Distal KS patterns, $p = 0.11$. The elbow valgus torques also varied significantly across these three primary different KS patterns $[F(53,2) = 9.994, \eta^2 = .274, p < 0.00]$ except for a non-significant difference between the PDS and Altered Distal KS patterns, $p = 0.28$ (Figure 4).

Comparison of the kinematic sequences performed during windup compared to stretch pitch delivery

The intra pitcher variation of kinematic sequences performed were consistent between the windup and stretch pitch deliveries. A Wilcoxon Sign-Rank test revealed that the number of kinematic sequences performed during fast-ball wind up pitches did not statistically differ from the number of kinematic sequences performed when throwing from the stretch position, $Z = -0.632, p = 0.53$. The median number of kinematic sequences performed during the windup was 2.0 and 2.5 for the stretch delivery.

Table 3. Comparison of peak elbow and shoulder torques (Nm) across the three kinematic sequence patterns.

KS Pattern	Elbow Valgus	Shoulder External Rotation	Shoulder Extension
12344- Proximal to Distal KS (N=14)	49.79 \pm 13.75	52.63 \pm 14.37	55.99 \pm 15.00
12354- Altered Distal Arm KS (N=28)	54.86 \pm 19.53	59.13 \pm 22.03	68.07 \pm 29.04
12453- Altered Proximal Arm KS (N=15)	65.29 \pm 8.82	70.43 \pm 11.01	87.77 \pm 18.48
Total (N=57)	56.36 \pm 16.75	60.51 \pm 18.84	70.29 \pm 26.06
Differences across kinematic sequences	$p < 0.00$	$p < 0.00$	$p < 0.00$

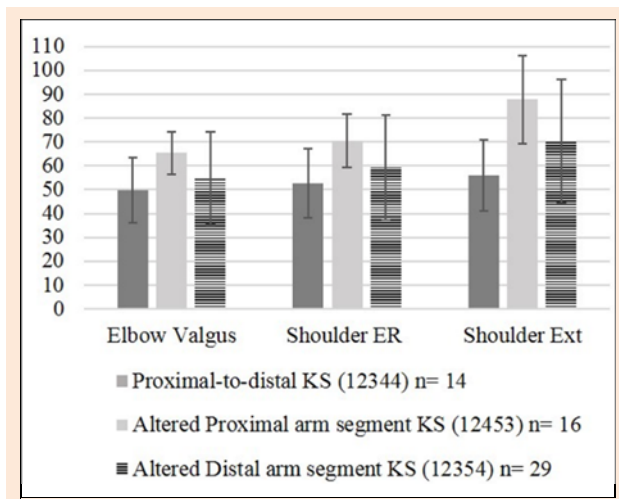


Figure 4. Comparison of elbow valgus, shoulder external rotation (ER) and shoulder extension (Ext) peak torques (N-m) across the three kinematic sequences performed.

There was no statistically significant interaction between the effects of pitch delivery and kinematic sequence on shoulder extension torque ($p = 0.16$), shoulder external rotation torques ($p = 0.71$) and elbow valgus torques ($p = 0.77$).

Discussion

Differences in torques incurred about the shoulder and elbow during fastball pitches were investigated between the windup and stretch deliveries and across different kinematic sequences. The time from balance point to stride was statistically significantly faster among the pitches thrown from the stretch compared to the windup. The additional comparison of the time from stride to ball release was not different between the pitch delivery groups. Therefore, the ‘quickness’ of the pitch from the stretch position compared to the windup position was, as expected, successfully performed by the time of lead leg ground contact (stride). The kinematic sequence is currently defined based on the pelvis segment’s movement initiated after stride. Because of this, it is unlikely that pitchers change their kinematic sequence in an attempt to quicken delivery between stride and ball release. Our findings demonstrate that the 10 pitchers do indeed complete throws from the stretch faster than from the windup and that this is accomplished during the first phase.

Previous investigations have found association of injury to high shoulder external rotation and shoulder extension torques (Fleisig et al., 1995, Sabick et al., 2004) as well as large elbow torques (Aguinaldo and Chambers, 2009, Anz et al., 2010). Our study findings among collegiate and high school pitchers revealed no significant difference between the shoulder torques thrown from the stretch and windup deliveries. This is a similar finding to a previous study of professional pitchers which reported no differences in shoulder or elbow torques (Dunn et al. 2008). The study by Keeley DW et al among high school students throwing from the stretch and from the modified stretch (slide step) did not measure shoulder or elbow torques. However, they reported that throws from the stretch

resulted in greater throwing “shoulder plane of elevation and axial rotation” at the time of maximum shoulder external rotation compared to the slide-step delivery at the instance of maximum external shoulder rotation (Keeley et al., 2012).

Our findings supported our first hypothesis that the pitchers use similar kinematic sequences during the two pitch approaches. All pitchers used similar number and type of kinematic sequences whether they threw from the windup or stretch position. They maintained similar ball velocity despite the alteration to lower body kinematics at the start of the delivery. This likely is due to the fact that, after the point of stride, the pelvis rotates about the fixed lead leg initiating the kinematic sequence chain of motion regardless of how the lead leg moved the body into that position prior to stride. Our sample of pitchers maintained consistent stride length despite the pitch delivery approach used, which allowed for consistency in the data comparison. In our laboratory setting, the turf mound allowed for a consistent landing location for pitchers. Our findings are limited to this controlled setting and we recognize that during games, environmental factors which influence the pitching mound should be considered.

Across the 88 trials, there were no differences in these biomechanical measures when comparing between the pitch delivery approaches (windup versus stretch). However, the data revealed statistically significant differences across 3 of the most frequently performed kinematic sequence patterns for shoulder external rotation and extension torques as well as elbow valgus torque. Our second hypothesis was supported as we found significant differences of each of the biomechanical measures across the kinematic sequence patterns and no differences between the 2 pitch delivery approaches. Morehouse and Cooper describe the optimal pitch pattern through demonstration that the most efficient transfer of energy occurs when the more distal segments delay movement until the more proximal body segments reach their peak angular velocities (Morehouse and Cooper, 1950). The proper use of this kinematic sequence, which includes the coordinated efforts of the lower extremity and core musculature, reduces the demand of kinetic contributions of the shoulder joint (Seroyer et al., 2010). A past study reported that, when there is a 20% decrease in kinetic energy generated from hip and trunk, a compensatory 34% increase in rotational velocity at the shoulder is observed (Kibler, 1998). These concepts support the importance of striving for performance of the PDS kinematic sequence.

The sample of pitchers studied demonstrated consistency of kinematic sequences performance between both windup and stretch approaches. This supports their representation in the study as experienced baseball pitchers in their level of play groups to meet participation objectives in the study. The 10 pitchers in our study accomplished similar fastball velocity across both pitch approaches, demonstrating each was experienced in using both approaches. Ball velocity consistency between pitch deliveries is in contradistinction to a previous study performed among 28 professional pitchers which reported a small but statistically significant greater ball velocity during fastball pitches thrown from the windup compared to the stretch

approach (Dunn et al., 2008). The scarce number of studies comparing throws from the stretch compared to the windup limit the ability to make further comparisons to past literature.

This study has some limitations. First, the use of our high-speed motion capture system while set at the upper end of industry norm (360 HZ), may potentially miss high speed movements. We acknowledge that our sample size, while reaching statistical significance, is relatively low and thus careful consideration should be made in extrapolating findings to all pitchers. This study is an introduction for the use of the kinematic sequence as a tool to compare movement patterns.

Conclusion

Our study findings suggest that the specific KS pattern employed during pitch delivery is more influential to the torques on the shoulder and elbow than the pitch delivery approach. Therefore, concerns for instructing youth on throwing from the stretch versus the windup likely are not as important as instruction of the proximal-to-distal kinematic sequence pattern. The results of this study have implications for strategies regarding both injury prevention and rehabilitation at all levels.

Acknowledgements

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Key points

- Our findings demonstrate that baseball pitchers utilize a similar kinematic sequence whether throwing from the windup or the stretch.
- The specific kinematic sequence pattern employed during pitch delivery is more influential to the torques on the shoulder and elbow than the pitch delivery approach.
- Instructing ideal kinematic sequence may do more to avoid injury than avoiding a particular delivery method.

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