Original Research

Comparison of In-Game Trunk and Upper Extremity Kinematics Between Fastballs, Breaking Balls, and Changeups in NCAA Division I Collegiate Baseball Pitchers

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Background: Previous biomechanical analyses of baseball pitching report similar kinematics between pitch types. However, prior studies were conducted in a controlled laboratory environment.

Purpose/Hypothesis: This study aimed to compare in-game trunk and upper extremity kinematics between fastballs, breaking balls, and changeups to determine whether there are kinematic differences that may affect performance as well as to provide new insights into potential risk factors for injury. It was hypothesized that there would be kinematic differences between pitch types.

Study Design: Descriptive laboratory study.

Methods: A retrospective analysis was conducted of markerless motion capture data collected during National Collegiate Athletic Association Division I baseball games. Included were 34 pitchers who pitched at least 3 pitches of each type (fastball, breaking ball, changeup) during competition. A 1-way repeated-measures multivariate analysis of variance (MANOVA) was used to test differences between pitch types, and Bonferroni post hoc tests were used to test pairwise comparisons.

Results: The MANOVA revealed a significant effect of pitch type ($P < .001$), and follow-up univariate tests found a significant main effect of pitch type for 12 of the 15 kinematic variables analyzed. Post hoc Bonferroni tests revealed that maximum shoulder external rotation was significantly greater during fastballs than breaking balls. At foot contact, significantly less shoulder external rotation was seen during changeups compared with fastballs and breaking balls. At the time of ball release, changeups had significantly less trunk lean and less trunk flexion than fastballs and breaking balls, and fastballs had a significantly smaller arm slot angle than breaking balls and changeups.

Conclusion: Collegiate baseball pitchers displayed numerous kinematic differences between pitch types during competitive play, some of which are known influencers of pitching kinetics.

Clinical Relevance: This study offers a novel perspective regarding kinematic differences between different pitch types during competition. These results are comparable to the findings of laboratory studies and provide valuable insights into potential injury mechanisms.

Keywords: elbow; injury risk; performance; pitch type; shoulder

Baseball is one of the most popular collegiate sports in the United States, where >11,000 athletes play the sport at the National Collegiate Athletic Association (NCAA) Division I level.[24] Baseball pitching is an integral aspect of the game, where the dynamic and repetitive nature of pitching culminates in large amounts of stress on the upper extremity.[14] Consequently, pitchers experience high rates of shoulder and elbow injuries[4] that can decrease performance[32] and affect a pitcher's ability to successfully return to sport.[3] Therefore, the biomechanics of baseball pitching have been thoroughly studied over recent decades to identify factors that could affect injury risk and performance outcomes.[5,7,14,28]

The Orthopaedic Journal of Sports Medicine, 12(12), 23259671241298309
DOI: 10.1177/23259671241298309

One factor that has been identified to influence performance and injury risk alike is pitch type.[9,10,13,15] Kinematic differences between pitch types, specifically at the trunk and upper extremity, can affect performance. Not only can kinematic differences show the batter which pitch type will be thrown, but differences could also potentially affect kinetic loading on the elbow.[1,10,13,30] Interestingly, biomechanical analyses comparing different pitch types have reported similar kinematics in collegiate baseball pitchers.[13,15] However, these investigations were limited to a controlled laboratory environment. Laboratory baseball pitching studies cannot replicate an in-game environment, as pitchers must often wear minimal clothing and pitch with motion capture markers[28] or electromagnetic sensors adhered to their skin.[25] Additionally, in a laboratory setting, it is difficult to recreate a game's competitive nature and the emotional factors that may influence pitching mechanics[10]; thus, limitations exist when applying laboratory analyses of pitch types to in-game environments.[6]

With recent advancements in markerless motion capture, it is now possible to capture kinematics during competitive baseball games.[18,23] In-game data may provide additional insight into factors contributing to the likelihood of injuries and overall performance and provide ecologically valid research designs for baseball biomechanics.[6] In fact, a recent study of NCAA Division I collegiate pitchers by Giordano et al[18] found that using an in-game markerless motion capture system resulted in biomechanical data with higher pitch velocities than typically reported in laboratory studies, showing that in-game markerless motion capture provides unique insights into pitching biomechanics that are not found in traditional laboratory studies.

In this study, we aimed to compare in-game trunk and upper extremity kinematics between fastballs, breaking balls, and changeups to determine whether there are kinematic differences that could affect performance and provide new insights into potential injury risk factors. It was hypothesized that there would be kinematic differences between pitch types.

METHODS

This study was a retrospective analysis of in-game markerless motion capture data collected during NCAA Division I baseball games. The protocol for this study received institutional review board approval. To be included in this study, pitchers had to throw at least 3 in-game pitches of each pitch type (fastballs, breaking balls, and changeups). A total of 34 pitchers (height, 1.89 ± 0.07 m; weight, 93.6 ± 9.8 kg) met the inclusion criteria and were included for analysis.

Data Collection

To minimize the potential effect of fatigue on pitching mechanics, each pitcher's first appearance in a competitive season where data were available for 3 pitches of each pitch type was used for analysis. Subsequently, the 3 pitches of each pitch type for each pitcher were grouped by pitch type and then averaged and used for analysis. Pitch type was manually tagged using a Trackman V3 Game Tracking unit. Due to inherent difficulties in correctly classifying pitch types without prior input from the pitchers, pitches were grouped into 3 categories.[11] For this analysis, 4-seam fastballs, 2-seam fastballs, and cutters were classified as fastballs; sliders and curveballs were classified as breaking balls; and changeups and splitters were classified as changeups. Pitch velocity was recorded by the Trackman system.

All pitches were recorded during competitive games using an 8-camera KinaTrax markerless motion capture system sampling at 300 Hz. Proprietary deep learning and artificial intelligence algorithms were used to track anatomic location and estimate joint centers as well as to identify typical events associated with baseball pitching (ie, at foot contact, maximum shoulder external rotation, and ball release).[17] The following 15 kinematic variables were analyzed: peak shoulder rotational velocity, peak trunk rotational velocity, and peak elbow extension velocity; shoulder abduction at foot contact, shoulder horizontal abduction at foot contact, shoulder external rotation at foot contact, and elbow flexion at food contact; maximum shoulder rotation and elbow flexion at the time of maximum shoulder external rotation; and shoulder abduction at ball release, trunk flexion at ball release, trunk lean at ball release, elbow flexion at ball release, elbow pronation/supination at ball release, and arm slot at ball release. Arm slot was defined as the angle between the global vertical vector and the vector connecting the shoulder and the hand, where 0° is directly perpendicular to the ground and 90° is parallel to the ground. Kinematic variables and event definitions were calculated within Visual 3D (C-Motion Inc) using protocols proprietary to KinaTrax. Custom Python scripts were used to pair ball metrics data with kinematics and to extract dependent variables of interest.

Statistical Analysis

The average of 3 pitches of each player's pitch type was used to create a single representative pitch for each pitch

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Final revision submitted April 9, 2024; accepted May 21, 2024.
The authors have declared that there are no conflicts of interest in the authorship and publication of this contribution. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.
Ethical approval for this study was obtained from the Auburn University Human Research Protection Program (reference No. 23-218 EX 2304).

TABLE 1
Trunk and Upper Extremity Kinematic Variables According to Pitch Type[a]

	Pitch Type				
Variable	Fastball	Changeup	Breaking Ball	P	ES
Pitch velocity, mph (kph)	91 ± 2 (147 ± 3)	83 ± 3 (134 ± 5)	80 ± 4 (129 ± 6)		
Kinematics by pitching event, deg					
At foot contact					
Shoulder abduction	86 ± 12[b]	85 ± 13	85 ± 13[c]	.028[d]	0.109
Shoulder horizontal abduction	–39 ± 12	–39 ± 11	–39 ± 11	.923	0.002
Shoulder external rotation	31 ± 22[e]	25 ± 26[b,c]	30 ± 24[e]	.007[d]	**0.157**
Elbow flexion	109 ± 19[e]	105 ± 18[c]	107 ± 20	<.001[d]	**0.237**
At maximum shoulder external rotation					
Shoulder rotation	182 ± 10[b]	181 ± 11	180 ± 10[c]	.006[d]	**0.157**
Elbow flexion	77 ± 8	77 ± 8	77 ± 9	.75	0.011
At ball release					
Shoulder abduction	99 ± 5[e]	100 ± 5[c]	99 ± 6	.012[d]	0.135
Trunk flexion	–37 ± 8[e]	–34 ± 7[b,c]	–37 ± 7[e]	<.001[d]	**0.417**
Trunk lean	–16 ± 9[e]	–12 ± 8[b,c]	–15 ± 10[e]	<.001[d]	**0.461**
Elbow flexion	20 ± 5	20 ± 5[b]	19 ± 4[e]	.011[d]	0.139
Elbow pronation/supination	86 ± 14[b]	85 ± 15[b]	77 ± 15[c,e]	<.001[d]	**0.324**
Arm slot	59 ± 10[b,e]	62 ± 8[c]	61 ± 10[c]	<.001[d]	**0.236**
Peak rotational velocities, deg/s					
Shoulder rotational velocity	4428 ± 478	4403 ± 468	4485 ± 520	.459	0.028
Trunk rotational velocity	1110 ± 74[b,e]	1075 ± 69[c]	1072 ± 80[c]	<.001[d]	**0.342**
Elbow extension velocity	2428 ± 316[e]	2329 ± 314[b,c]	2409 ± 314[e]	.001[d]	**0.217**

[a]Data are presented as mean ± 1 SD. For reference, trunk lean is also known as lateral trunk tilt, and elbow pronation/supination is the pronation/supination of the forearm. A negative value for shoulder horizontal abduction denotes shoulder horizontal abduction, a negative value for trunk flexion denotes trunk flexion, and a negative value for trunk lean denotes lateral trunk tilt towards the pitcher's glove side. Boldface values denote large effect sizes (partial $\eta^2 \geq 0.14$). ES, effect size.
[b]Significant pairwise comparison with breaking ball.
[c]Significant pairwise comparison with fastball.
[d]Significant follow-up univariate test after Benjamini-Hochberg corrections ($P < .05$).
[e]Significant pairwise comparison with changeup.

type. A 1-way repeated-measures multivariate analysis of variance (MANOVA) was used to test for differences between pitch types. Mahalanobis distance values were calculated across the 15 dependent variables, and multivariate normality was supported by examining a *Q-Q* plot of these values. The Mauchley test of sphericity showed that the assumption of sphericity was maintained (Mauchly $W > 0.7$ for all kinematic variables). Follow-up univariate testing determined main effects for each kinematic variable. Univariate P values were then ranked in ascending order, and sequential Benjamini-Hochberg corrections[2] were applied to the univariate P values to help control the risk of a type I error. If a significant main effect was found from a univariate test, Bonferroni post hoc tests were used to identify significant pairwise comparisons between pitch types. Statistical significance was set to .05. Effect size was calculated using partial η^2, with 0.01 to <0.06 denoting small effect size, 0.06 to <0.14 denoting moderate effect size, and ≥0.14 denoting large effect size. Statistical analysis was performed in SPSS Version 29 (IBM Corp).

RESULTS

The MANOVA resulted in statically significant differences between pitch types ($F_{30,104} = 6.730$; $P < .001$; Wilk $\lambda = 0.116$). Follow-up univariate tests revealed a significant main effect of pitch type on 12 of the 15 kinematic variables (Table 1). Post hoc tests resulted in specific differences among the pitch types. Descriptive kinematic data and the results from the follow-up univariate tests and post hoc comparisons are provided in Table 1.

DISCUSSION

Contrary to the findings of previous laboratory studies,[13,15] collegiate pitchers displayed numerous in-game kinematic differences between pitch types. Significant differences were observed in 12 of the 15 kinematic variables analyzed in this study, and these differences may affect performance and provide new insights into potential injury risk mechanisms.

Kinematics by Pitching Event

At Foot Contact. Changeups had significantly less shoulder external rotation than fastballs and breaking balls at the time of foot contact. Although these differences fell within the range of previously reported values of within-pitcher variability[12] (mean within-subject differences of 5.4° and 4.2°, respectively), these results had a large effect size and were not observed in previous laboratory biomechanical analyses of pitch types.[10,13] Consistent kinematics between pitch types may aid in deceiving the batter by hiding the pitch type being thrown; thus, a difference of this magnitude this early in the pitching cycle could affect pitcher performance by showing the batter that a changeup will be thrown.[10,13] However, the pitcher's trunk may obstruct the batter's view of the pitcher's shoulder rotation, so it is unknown whether hitters would be able to distinguish this difference.

At foot contact, fastballs had significantly greater shoulder abduction than breaking balls. Shoulder abduction angle at foot contact has been shown to affect pitching variability in a laboratory study[19]; however, the magnitude of this difference was relatively small (mean within-subject difference of 1.6°). It is unknown whether this change between pitch types would alter performance or whether it could be a mechanism that affects injury risk. Interestingly, fastballs had significantly greater elbow flexion than changeups at foot contact, which was not found in a previous laboratory analysis.[13] However, later in the pitching sequence, there was no difference in elbow flexion between pitch types by the time of maximum shoulder external rotation.

At Maximum Shoulder External Rotation. Fastballs had significantly more shoulder external rotation than breaking balls at the time of maximum shoulder external rotation. This result was not observed in previous laboratory analyses.[10,13] Maximum shoulder external rotation is a key contributor to ball velocity[22,29] and pitching consistency.[19] The increased external rotation observed in fastballs could result from pitchers attempting to throw fastballs at maximal or near-maximal velocity. Increased maximum external rotation may affect injury risk by placing the glenohumeral joint at an increased risk of shoulder impingement and an increased risk of a superior labral anterior-posterior tear via the peel-back mechanism.[7,20,30] Interestingly, conflicting literature exists on the influence of maximum external rotation on elbow varus torque. Increased maximum external rotation may increase injury risk by subjecting the medial elbow to increased elbow varus torque[1]; however, a more recent study found that increased maximum external rotation led to decreased elbow varus torque.[26] Thus, the combination of added injury risk at the shoulder, along with the potential changes in kinetics at the elbow that are associated with increased maximum external rotation, suggests that kinematic differences at the shoulder that were observed may influence injury risk and provide a need for additional research.

At Ball Release. Numerous kinematic differences were seen between pitch types at ball release. Changeups had significantly less trunk flexion and less trunk lean than both fastballs and breaking balls, consistent with findings from laboratory analyses.[10,13] Similar to the difference in shoulder external rotation at foot contact, these variations may affect performance by showing the batter that a changeup will be thrown.[13]

Similarly, the differences observed in arm slot at ball release between pitch types may also affect performance, as a study by Whiteside et al[31] discovered that a consistent release point was associated with pitching success in Major League Baseball players. Trunk lean, shoulder abduction, and elbow flexion all contribute to and affect arm slot, as arm slot is defined as the angle between the global vertical vector and the vector connecting the shoulder and hand. Fastballs had a significantly higher arm slot than both changeups and breaking balls. Although arm slot has not been reported in previous laboratory analyses of pitch types, a previous study in collegiate pitchers found significant differences in the variables that compose arm slot (trunk lean, shoulder abduction, and elbow flexion at ball release) between pitch types.[13]

Another kinematic difference at the time of ball release was that breaking balls had significantly greater forearm supination than both fastballs and curveballs. This result is consistent with a previous laboratory study and was expected given that breaking balls (ie, sliders and curveballs) often require increased supination to impart the desired spin that makes a breaking ball effective.[15]

Peak Rotational Velocities

Significant differences were found in peak rotational velocities between pitch types. Fastballs had greater peak trunk rotational velocity than changeups and breaking balls, and changeups had significantly slower peak elbow extension velocity than fastballs and breaking balls. These results are consistent with findings from a previous laboratory study[13] and are further supported by additional literature that suggests that peak rotational velocities significantly contribute to pitch velocity.[21] However, there were no differences in shoulder internal rotation velocities between pitch types, contrary to past studies that found the changeup to have significantly slower shoulder internal rotation velocities than fastballs, sliders, and curveballs.[10,13] It is possible that the inherent difference between laboratory and in-game environments is responsible for this conflicting finding.[6]

Altogether, this study provides a unique insight into how pitching biomechanics change between pitch types in an in-game environment. This study provides an additional rationale for further investigation of in-game pitching biomechanics, as additional research is needed to determine whether the kinematic differences observed in this study could affect kinetic variables known to influence injury risk, such as elbow varus torque.[1]

Limitations

The primary limitation of this study is the markerless motion capture system's lack of validation against the gold standard, marker-based motion capture. Although the markerless system has been shown to provide valid gait kinematics[27] and has undergone private, internal validation for baseball pitching, a validation of the in-game markerless motion capture system against marker-based motion capture is not possible. Although there have been recent validations of other markerless motion capture systems, these validations have been limited to laboratory settings.[8,16] Additionally, this study was unable to differentiate between pitch types with similar movement patterns, such as sliders and curveballs, as it is inherently difficult to correctly classify similar pitch types in an in-game setting. Finally, this study included only Division I collegiate baseball pitchers; thus, the results of this study may not be generalizable to other populations, such as youth, high school, or professional pitchers.

CONCLUSION

The current study identified the kinematic differences between pitch types during a competitive collegiate baseball game. This study determined that collegiate pitchers have numerous in-game trunk and upper extremity kinematic differences between pitch types. Some of the differences observed, such as changes in trunk kinematics, were consistent with previous laboratory analyses of pitch types. However, other kinematic differences, such as shoulder rotation at foot contact and maximum shoulder external rotation, had not been previously identified. This study provides insight into differences between pitch types that were used in-game, which are comparable to the findings of laboratory-based studies and provide valuable insight into potential injury mechanisms.

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