# VARIATIONS IN PITCHING PERFORMANCE DURING A MAJOR LEAGUE BASEBALL GAME: WHAT CAN WE LEARN FROM BALL TRACKING DATA?

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The aim of this study was to identify changes in pitching characteristics during nine innings of professional (MLB) baseball. Ball tracking data were obtained for 1,514,304 pitches thrown by 129 pitchers during the 2008–2014 MLB seasons and compared across the nine innings using linear mixed model analyses. Earlier innings contained significantly more hard (i.e., fast-type) pitches. A significant decrease in pitch speed and release height emerged before the sixth inning. These data revealed that aspects of a starting pitcher's performance significantly change as early as the second or third inning of an MLB game, although these do not influence his effectiveness. Coaches may use these data to inform their decision to relieve a starting pitcher and/or direct in-game strategies to exploit trends in pitcher performance.

**KEY WORDS:** analytics, sport, PITCHf/x, MLB, biomechanics, injury.

**INTRODUCTION:** In baseball, the starting pitcher is tasked with limiting the opposition's run scoring for most of the game and is, therefore, a crucial factor in achieving a win. However, bouts of pitching are particularly taxing on the upper extremity and have been shown to induce mechanical and musculoskeletal adaptations (Reinhold et al., 2008), which may influence pitching performance. Consequently, profiling pitching performance across the course of a game may be beneficial for developing tactics and/or protecting pitchers' health.

Starting pitchers rarely complete a nine-inning game and are typically replaced between the 5$^{th}$ and 7$^{th}$ inning, at the discretion of the manager. It has been postulated that factors such as pitch counts, pitch types, ball velocity, and/or ball location may be useful for informing when to relieve a pitcher (Lyman et al., 2001; Fortenbaugh, Fleisig & Andrews, 2009; Lyman, Fleisig, Andrews & Osinski, 2002), although there is little empirical guidance in this respect. Further, changes in pitching parameters could be indicative of mechanical alterations, which have been presented as potential precursors to upper extremity pain and/or injury (Scacia & Kibler, 2010; Wilk, Meister & Andrews, 2002). Thus, uncovering trends in pitcher performance during games might enhance managerial decision-making and prevent injury.

There is a distinct lack of peer-reviewed evidence pertaining to *in situ* ball kinematics and/or pitching outcomes in baseball. Quantifying changes in a starting pitcher's performance over the course of a game could have implications for enhancing pitching and batting performance and reducing a pitcher's injury risk. Therefore, the objective of this study was to investigate changes in the starting pitcher's performance characteristics over the course of professional baseball games. It was hypothesized that degradations in effectiveness, ball speed and accuracy (zone percentage) would be recorded during games but that pitch selection and release location would be invariant across all innings.

**METHODS:** This study was exempt from human ethics approval as all data were freely available in the public domain. 129 pitchers who had accumulated at least 200 regular season innings as a starting pitcher, and not more than nine innings in relief roles during the 2008–2014 Major League Baseball (MLB) seasons, were included for analysis in this study.

Demographical, statistical, and ball tracking (PITCHf/x) data were harvested from three websites using a MATLAB script (Mathworks, Natick, MA). Iterating each player's unique player identification number into a uniform resource locator (URL): (1) the dates of regular season starts and innings pitched were harvested from the Fangraphs website (www.fangraphs.com); (2) statistical data (i.e., home runs, walks, hit by pitches, and strikeouts) were extracted from the Baseball Savant website (www.baseballsavant.com), and; (3) pitching parameters [i.e., pitch type, pitch speed, horizontal release location, vertical release location, and zone percentage (percentage of pitches in the strike zone)] were scraped from the Brooks Baseball website (www.brooksbaseball.net).

Statistical data from (2) were used to calculate the fielding independent pitching (FIP) statistic in each inning. Only factors that are entirely within the pitcher's control are admitted into the calculation of FIP (home runs, walks, pitches that hit the batter and strikeouts), and thus provided a criterion measure of the pitcher's effectiveness. The parameters in (3) were derived from the PITCHf/x ball tracking system (Sportvision, Chicago, IL), which is installed in all 30 Major League Baseball stadiums. The system utilizes two 60 Hz cameras mounted in the stadium to track the 3D trajectory of the ball in every pitch.

Data were isolated to a particular inning (1–9) and, to simplify interpretation, pitch types were grouped into three categories: hard pitches (fastball, sinkers, and cutters), breaking pitches (sliders, curveballs, and screwballs), and off-speed pitches (changeups, splitters, and slow curveballs). Linear mixed model analyses were used to compare pitching parameters across the nine innings, with a view to identifying: (1) the inning in which the parameter first changed from baseline (i.e., inning one), and (2) the two innings that displayed the greatest difference from one another. To account for the multiple comparisons being undertaken, a conservative significance level of $P < .001$ was adopted. Given the relatively large sample size, there was a greater probability of detecting significant changes that were not practically meaningful so differences were only presented if *post hoc* analyses revealed both significance (at the $P < .001$ level) and Cohen's *d* effect sizes > 0.5. Statistical procedures were performed in SPSS Statistics 21 (IBM, Armonk, NY, USA) and MATLAB.

**RESULTS:** Mean FIP values were between 3.76 and 4.44 and did not differ significantly between any innings. Compared with inning one (pitch proportions: hard = 72%; breaking = 18%; off-speed = 13%), the proportion of hard pitches decreased significantly by the second inning (Figure 1) while the proportions of breaking and off-speed pitches increased significantly by innings two and three, respectively. In all three pitch type categories, the largest changes in pitch selection occurred between innings one and six; hard pitches decreasing between these innings, while breaking and off-speed pitch proportions increased.

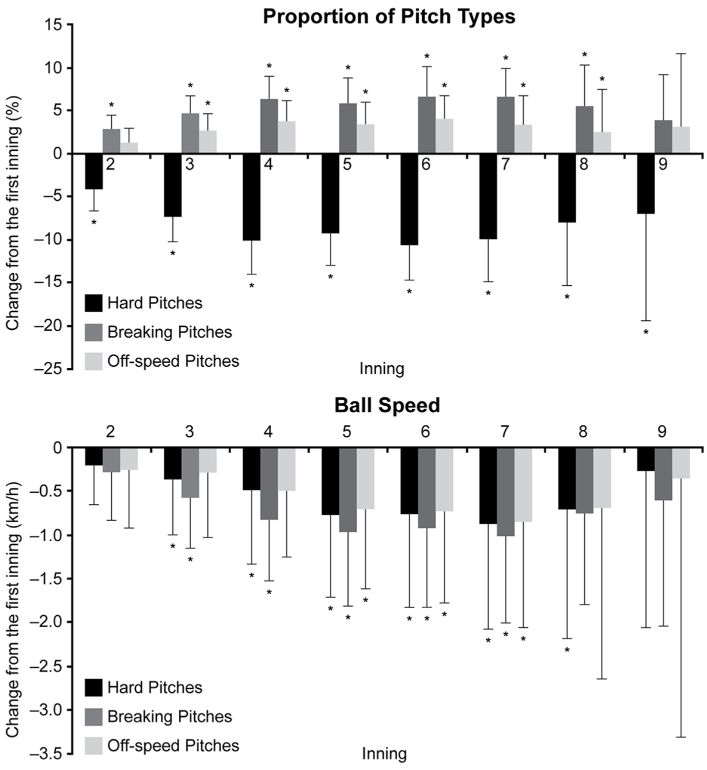


**Figure 1. Changes in pitch selection and pitch speed, relative to the first inning. *Significant**

Hard and breaking pitch speeds exhibited significant decreases by the third inning. Off-speed pitch speed did not fall significantly until the fifth inning. The largest decreases in ball speed occurred between innings one and seven in all three pitch types.

Horizontal release locations did not significantly differ across innings. The vertical release locations of both hard and off-speed pitches exhibited significant decreases by the third inning, although no change from baseline was recorded in breaking pitches. The largest decrease in release height occurred between innings one and nine for hard pitches, innings two and seven for breaking pitches, and innings one and six for off-speed pitches.

Although zone percentage displayed a decreasing trend in all three pitch categories, only hard pitches displayed a significant decrease from baseline (occurring during inning eight). The largest differences recorded were decreases in zone percentage: between innings one and nine in hard pitches and between innings three and nine in breaking pitches. Zone percentage did not differ significantly between innings in off-speed pitches.

**Table 1**
**Statistical description of: (1) The inning in which significant changes from inning 1 first emerged, and (2) The largest differences recorded across innings.**

| Variable | First Significant Change from Inning 1 | | | | Largest Significant Change Across Innings | | | |
|---|---|---|---|---|---|---|---|---|
| | Inning | Mean Diff | 95% CI | *d* | Innings | Mean Diff | 95% CI | *d* |
| ***Proportion (%)*** | | | | | | | | |
| Hard | 2 | –4.13 | (–6.00, –2.26) | 1.60 | 1 vs 6 | –10.62 | (–12.49, –8.76) | 2.62 |
| Breaking | 2 | 2.86 | (1.23, 4.50) | 1.35 | 1 vs 6 | 6.60 | (4.97, 8.23) | 1.77 |
| Off-speed | 3 | 2.67 | (1.37, 3.97) | 1.40 | 1 vs 6 | 4.02 | (2.70, 5.32) | 1.49 |
| ***Speed ($km \cdot h^{-1}$)*** | | | | | | | | |
| Hard | 3 | –0.36 | (–0.63, –0.09) | 0.58 | 1 vs 7 | –0.87 | (–1.14, –0.60) | 0.72 |
| Breaking | 3 | –0.57 | (–0.96, –0.18) | 0.78 | 1 vs 7 | –1.02 | (–1.41, –0.63) | 0.81 |
| Off-speed | 5 | –0.72 | (–1.13, –0.27) | 0.77 | 1 vs 7 | –0.85 | (–1.28, –0.42) | 0.70 |
| ***Vertical Release Location (cm)*** | | | | | | | | |
| Hard | 3 | –1.10 | (–1.68, –0.55) | 1.02 | 1 vs 9 | –2.62 | (–3.20, –2.04) | 0.70 |
| Breaking | | | N/A | | 2 vs 7 | –1.58 | (–2.65, –0.52) | 0.60 |
| Off-speed | 3 | –1.16 | (–2.07, –0.27) | 0.57 | 1 vs 6 | –2.07 | (–2.99, –1.19) | 0.64 |
| ***Zone Percentage (%)*** | | | | | | | | |
| Hard | 8 | –9.40 | (–13.17, –5.63) | 0.54 | 1 vs 9 | –11.66 | (–15.60, –7.71) | 0.54 |
| Breaking | | | N/A | | 3 vs 9 | –12.10 | (–16.53, –7.66) | 0.51 |
| Off-speed | | | N/A | | | | N/A | |

All significant at the $P < 0.001$ level. *d*: Cohen's *d* effect size. N/A: not significant change recorded.

**DISCUSSION:** This study appraised starting pitchers' effectiveness (FIP), pitch selection, speed, release location, and zone percentage over the course of professional baseball games. Contrary to expectations, pitcher effectiveness did not deteriorate as games progressed. However, significant changes in pitch selection, speed and release height were evident as early as the third inning. The largest changes from baseline occurred during the later innings (6–9) and—if these changes are linked to injury, as has been proposed—advocate replacing the starting pitcher around the sixth inning.

Pitchers in this study displayed a trend for throwing less hard pitches and more breaking and off-speed pitches as games progressed. This was most likely strategic and related to the concept of "establishing" (i.e., becoming confident throwing) the fastball early in the game (Kaat, 2004). These data have tactical implications, whereby probability dictates that the batter should anticipate hard pitches early in the game, but increasing numbers of breaking and off-speed pitches, thrown with less speed, as the game progresses. Likewise, the zone percentages advise the batter to expect less hard and breaking balls in the strike zone during the late (eighth and ninth) innings. Equally then, if the manager solicits hard pitches and/or strikeouts late in the game, these data imply that the starting pitcher should be replaced.

Significant changes in pitch speed and vertical release location were generally evident by the fifth inning, with the largest differences from baseline primarily occurring during innings six and seven. For managers who consider alterations in mechanics and speed suitable justification for relieving the starting pitcher, these findings advocate replacing the starting pitcher no later than the sixth inning of a game—before the largest differences emerge—which is consistent with current MLB practice. However, acute changes in these parameters had no effect on FIP and imply that it is unsuitable to remove a starting pitcher based on the premise that these changes will diminish his effectiveness.

Shoulder strength has been shown to decrease 11–18% over the course of a game (Mullaney, McHugh, Donofrio & Nicholas, 2005) and muscle fatigue may, therefore, account

for the decreases in ball speed recorded in this study. It is unclear whether fatigue could also be responsible for release height changes, although these data confirmed that the kinematic and/or kinetic chain of an MLB pitcher was not perfectly repeatable during a pitching outing (Fleisig, Chu, Weber & Andrews, 2009). This is consistent with evidence showing that pitching induces acute musculoskeletal adaptations (Reinhold et al., 2008). It is also interesting to note that changes manifested as early as the third inning. Thus, while previous research has reported differences in velocity and mechanics when comparing the first and last inning of a pitching outing (Escamilla et al., 2007), the present findings suggest that these changes emerge much earlier in professional pitchers. If mechanical alterations are related to injury as has been proposed, it would be advisable for future work to identify the mechanical source of these changes and evaluate their pathological implications.
Limiting to this study, the parameters of interest were analysed independent of the count (i.e., balls and strikes) and/or whether there were runners on base—factors that future research may wish to consider. Also, these data only pertain to MLB pitchers and should be generalized to other populations with caution.

**CONCLUSION:** These findings revealed that acute changes in the starting pitcher's pitch selection, speed and release location emerged as early as the third inning of an MLB game, although his effectiveness remained similar across all innings. Consequently, it appears too zealous to replace a starting pitcher based on acute changes in his pitching characteristics, alone (since starting pitchers would be relieved in the second inning). Likewise, the assumption that a pitchers' effectiveness diminishes over the course of a game appears incorrect. The largest changes from baseline occurred during innings six to nine, which generally conforms to MLB practices, whereby the starting pitcher is most commonly relieved in the fifth or sixth inning. However, these data did not reveal a quintessential parameter for informing when to relieve the starting pitcher and this decision should likely also be guided by other factors such as pitcher feedback or injury-related performance metric. The trends observed in these data could be used to create more effective hitting and pitching strategies and direct future research.

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