Changes in a Starting Pitcher’s Performance Characteristics Across the Duration of a Major League Baseball Game

David Whiteside, Douglas N. Martini, Ronald F. Zernicke, and Grant C. Goulet

Purpose: With a view to informing in-game decision making as it relates to strategy and pitcher health, this study examined changes in pitching-performance characteristics across 9 innings of Major League Baseball (MLB) games. Methods: 129 starting MLB pitchers met the inclusion criteria for this study. Pitch type, speed, ball movement, release location, and strike-zone data—collected using the MLB’s ball-tracking system, PITCHf/x—were obtained for 1,514,304 pitches thrown from 2008 to 2014. Results: Compared with the 1st inning, the proportion of hard pitches thrown decreased significantly until the 7th inning, while the proportions of breaking and off-speed pitches increased. Significant decreases in pitch speed, increases in vertical movement, and decreases in release height emerged no later than the 5th inning, and the largest differences in all variables were generally recorded between the 1st inning and the late innings (7–9). Pitchers were most effective during the 2nd inning and significantly worse in innings 4 and 6. Conclusion: These data revealed that several aspects of a starting pitcher’s pitching characteristics exhibited changes from baseline as early as the 2nd or 3rd inning of an MLB game, but this pattern did not reflect the changes in his effectiveness. Therefore, these alterations do not appear to provide reasonable justification for relieving a starting pitcher, although future work must address their relevance to injury. From an offensive standpoint, batters in the MLB should anticipate significantly more hard pitches during the early innings but more breaking and off-speed pitches, with decreasing speed, as the game progresses.

Keywords: analytics, biomechanics, PITCHf/x, injury, velocity

In the view of former Major League Baseball (MLB) all-star Jerry Remy, “A good starting pitcher is one of the most valuable commodities in baseball.”1 This is unsurprising, considering that 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. Starting pitchers in the MLB will generally pitch in the first several (MLB average 5.8) innings2 before being replaced by relief pitchers, who assume pitching duties for the remainder of the game. However, bouts of pitching are particularly taxing on the upper extremity and have been shown to induce mechanical and musculoskeletal adaptations,3–5 which could potentially influence pitching success and/or injury risk. Profiling pitching performance across the course of a game may elucidate pitching trends and equip coaching staff with knowledge that can be used to exploit tactical advantages and/or protect pitchers’ health.

Numerous studies have investigated pitching mechanics across stages of development,6 skill levels,7 and pitch types.8 In contrast, scientific investigations detailing in situ kinematics and/or pitching outcomes, not to mention how these may change over the course of a professional game, are scarce. Injury-focused studies have simulated games to investigate changes in kinetics and kinematics of the pitching motion, some reporting ball speed to significantly decrease between the first and last innings5,9,10 and others reporting no change in ball speed across a game.11,12 However, it is difficult to generalize these findings to performance contexts, as success is also dependent on factors such as accuracy, release location, and break (ie, ball movement).13,14 Moreover, these experiments have not appraised professional pitchers in situ, so it remains unclear whether performance changes during MLB games and, if so, the precise inning in which a change first manifests. Understanding if and how these parameters change during the course of a game would allow coaching staff and athletes to devise team strategies (eg, player matchups and pitch anticipation) accordingly.

With respect to strategy, during his tenure as manager of the Washington Nationals, Jim Riggleman described the hardest part of his job as deciding when to remove a starting pitcher from the game.15 Assuming that adequate performance is maintained throughout the game, the decision to remove a pitcher is primarily (and somewhat controversially) impelled by pitch counts.16 However, Detroit Tigers pitching coach Jeff Jones has expressed that more subjective factors such as mechanics, effectiveness, projected effectiveness, and fatigue can also motivate the decision to relieve the starting pitcher (J. Jones, personal communication). Adding another voice, during his World Series–winning season with the Florida Marlins, manager Jack McKeon stated, “I don’t think anybody has the right formula [for knowing when to remove the starting pitcher]—it doesn’t exist.”17 Consequently, there is scope for objective data to potentially enhance the understanding of these factors and allow coaching staff to adopt an evidence-based approach when deciding to replace a pitcher.

To that point, the association between upper-extremity kinetics and ball speed18 mandates that alterations in the latter have a mechanical source. Therefore, changes in pitching parameters could be indicative of specific mechanical alterations. Given that alterations in throwing mechanics are postulated to be a precursor to upper-extremity pain and/or injury,19,20 objective data may
be a useful resource for sports-medicine staff. More explicitly, it has been recommended that pitchers avoid pitching when fatigue develops\(^21,22\) and that parameters such as pitch counts, pitch types, ball velocity, and/or ball location may be useful for detecting this juncture.\(^21-23\) In this sense, determining how pitching parameters change over the course of a game may provide sports-medicine staff with information that could potentially prevent injury.

Knowledge of changes in a starting pitcher’s performance during the course of a game could plausibly be used to govern team strategy and decision making to enhance team performance and reduce a pitcher’s injury risk. With a view to informing these processes, the objective of this study was to investigate changes in starting pitchers’ pitch selection and pitching outcomes over the course of a professional baseball game. We hypothesized that degradations in effectiveness (as measured by fielding-independent pitching [FIP]), ball speed, movement, and accuracy (zone percentage) would emerge around the fifth inning of a game (ie, just during the course of a game could plausibly be used to govern processes, the objective of this study was to investigate changes in starting pitchers’ pitch selection and pitching outcomes over the course of a professional baseball games. We hypothesized that degradations in effectiveness (as measured by fielding-independent pitching [FIP]), ball speed, movement, and accuracy (zone percentage) would emerge around the fifth inning of a game (ie, just before the starting pitcher is generally removed). Similarly, pitch selection was expected to change, with off-speed pitches thrown in the later innings, although release location was not expected to change during a game.

**Methods**

**Subjects**

This study was granted approval by the institutional ethics board. We initially identified 1508 pitchers that pitched in the MLB from the 2008 to 2014 seasons. To isolate a homogeneous population of “true” starting pitchers, this population was delimited to 129 pitchers (age 27.90 ± 4.33 y, seasons sampled 4.93 ± 1.90, starts sampled 122.80 ± 62.18, innings sampled 757.66 ± 409.17; each pitcher’s age was calculated as his median age during the sampled period from which his data were obtained) who had accumulated at least 200 regular-season innings as a starting pitcher and not more than 9 innings in relief roles during this period. This delimitation procedure was conducted using search functions on the FanGraphs Web site.\(^24\)

**Experimental Design**

This was a descriptive cohort study that analyzed in-game recordings of pitch trajectories during the 2008 to 2014 MLB seasons. Specifically, recordings of the pitch type, magnitudes of ball speed and movement, release location, and whether the ball passed through strike zone were obtained and subsequently compared across the 9 innings to determine how pitching characteristics change across an MLB game.

**Methodology**

Each pitcher’s date of birth, throwing hand, and MLB identification number were garnered manually from his MLB.com player page. This information was then cross-checked against FanGraphs’ player pages, from which each pitcher’s FanGraphs ID was also acquired. Demographical, statistical, and PITCHf/x data were subsequently harvested from 3 Web sites using a MATLAB script (Mathworks, Natick, MA). By iterating the 129 FanGraphs IDs into a uniform resource locator, FanGraphs’ game logs were parsed to identify the dates of regular-season games that the pitcher had started in the 2008 to 2014 seasons, as well as the number of innings pitched during each of those games. Subsequent data harvesting was then delimited to these dates, such that data were only obtained from regular-season games in which the pitcher started.

Statistical information (ie, home runs, walks, hits by pitches, and strikeouts) was extracted from the Baseball Savant Web site\(^25\) by iterating the script for each MLB identification number and starting game date and then cross-checked with records on the FanGraphs Web site to ensure validity. Pitching parameters (ie, pitch type, pitch speed, horizontal release location, vertical release location, horizontal movement, vertical movement, and percentage of pitches in the strike zone) were “scraped” from player cards on the Brooks Baseball Web site\(^6\) using the iteration procedure described previously. These parameters were obtained directly from the PITCHf/x database that is made publicly available by MLB Advance Media. However, Brooks Baseball provides an alternative pitch-classification system that involves manual classification of each pitch (Pitch Info LLC, Chicago, IL) and is, therefore, preferential to the automated MLB Advance Media algorithm. Each pitch is classified into 1 of 10 types: fastball, sinker, cutter, slider, curveball, screwball, knuckleball, changeup, splitter, or slow curve. Pitch selection was expressed using the ratios of each pitch type that a pitcher threw in each inning. Pitch speed was the exit speed of the ball from the hand. The release location and movement values were reported relative to the right-handed reference frame originating at home plate (y-axis pointing to pitching mound, z-axis pointing up, x-axis orthogonal). Horizontal release and movement values were inverted for left-handed pitchers to permit statistical analyses and interpretation (all values pertain to a right-handed pitcher). Vertical and horizontal ball movements were the z and x displacements of the ball, respectively, when it left the pitcher’s hand. Vertical and horizontal ball movements were the z and x displacements of the ball between the time it left the pitcher’s hand and the time it crossed home plate. Zone percentage represented the percentage of pitches that were thrown in the strike zone.

Each of these parameters was recorded using the PITCHf/x (Sportvision, Chicago, IL) ball-tracking system, which is installed in all 30 MLB stadiums. The system uses two 60-Hz cameras mounted in the stadium to track the 3-dimensional trajectory of each pitch. Within the bounds of the purported system error (<1.06 km/h and <1.02 cm), the confidence of determining the true mean of the PITCHf/x parameters from the sample of pitches analyzed in this study (mean pitches, per inning, per pitcher = 1304) was 97.23%. Statistical information was used to calculate FIP for each inning according to the formula $FIP = \frac{13HR + 3(BB + HBP) - 2K}{IP}$, where HR was the number of home runs conceded, BB the number of (nonintentional) walks, HBP the number of pitches that hit the batter, K the number of strikeouts, and IP the number of innings pitched.\(^27\) FIP does not consider statistics that involve fielders and isolates statistical outcomes within the pitcher’s control, thereby providing a true measure of his effectiveness. A lower FIP was indicative of better performance.

**Statistical Analysis**

Data were isolated to a particular inning (1–9) during the scraping process. To simplify analyses and interpretation, pitch types were grouped into 3 distinct categories: hard pitches (ie, fastball, sinkers, and cutters), breaking pitches (ie, sliders, curveballs, and screwballs), and off-speed pitches (ie, changeups, splitters, and slow curveballs). No pitcher in this cohort threw a knuckleball over the analyzed period. Grouping pitches also helped to control for the fact that MLB pitchers possess different repertoires. Given that 19 pitchers never pitched into the ninth inning during the sampled period, linear mixed-model analyses were preferred to evaluate
pitching parameters across the 9 innings. Within the models, subjects were selected as a random factor and innings were fixed factors, an autoregressive heterogeneous covariance matrix selected, and a maximum-likelihood-approach adopted. The output of each mixed model was then used to identify the inning in which the parameter first changed from baseline (ie, inning 1) and the 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. Consequently, differences were only presented if post hoc analyses revealed both significance (at the \( P < .001 \) level) and medium to large effect sizes (ie, Cohen \( d > 0.5 \)). Statistical procedures were performed in SPSS Statistics 21 (IBM, Armonk, NY, USA), with the exception of effect sizes, which were computed using MATLAB.

Results

FIP was smallest in the second inning and, comparatively, was significantly greater during innings 4 and 6 (Figure 1). Compared with inning 1, the proportion of hard pitches thrown decreased significantly by the second inning (Figure 1). The proportions of breaking and off-speed pitches increased significantly by innings 2 and 3, respectively. In all 3 pitch-type categories, the largest changes in pitch selection occurred between innings 1 and 6, with the proportion of hard pitches decreasing between these innings and breaking and off-speed pitches increasing.

Hard- and breaking-pitch speeds exhibited significant decreases by the third inning. Off-speed-pitch speed did not experience a significant drop until the fifth inning. The largest decreases in ball speed were recorded between innings 1 and 7 in hard and breaking pitches and between innings 1 and 5 in off-speed pitches (Figure 2).
Although zone percentage displayed a decreasing trend in all 3 pitch-type categories, only hard pitches displayed a significant decrease from baseline (first emerging at inning 7). The largest differences were both recorded as decreases in zone percentage, between innings 3 and 9 in both hard and breaking pitches. Zone percentage did not differ significantly between innings in off-speed pitches. Horizontal release locations did not significantly differ across innings. The vertical release locations of hard and off-speed pitches exhibited significant decreases by the second and third innings, respectively. The largest decrease in release height occurred between innings 1 and 9 in hard pitches and between innings 1 and 6 in off-speed pitches. The release height of breaking pitches did not significantly differ between innings.

Horizontal ball movement did not exhibit any significant differences between innings. Significantly more vertical (ie, downward) movement was recorded by the second inning in hard pitches, with the largest increase observed between innings 1 and 7 (Figure 3). Inning had no significant effect on vertical-plane ball movement in breaking or off-speed pitches.

**Discussion**

This study examined changes in pitcher effectiveness (FIP), pitch selection, pitch speed, pitch movement, release location, and zone percentage over the course of professional baseball games. Somewhat contrary to expectations, pitcher effectiveness did not significantly diminish across the 9 innings. Rather, the only significant differences in FIP were recorded between the second inning (where effectiveness was greatest) and innings 4 and 6. Significant changes in pitch selection, pitch speed, vertical movement, and
release height were evident as early as the second or third innings. The largest changes from baseline generally occurred during the later innings (6–9) and support the notion of replacing the starting pitcher around the sixth inning. However, coaching staff should be aware that specific changes occur earlier than this.

In contrast to our hypothesis, a pitcher’s effectiveness during the first inning was not significantly different from that recorded in any of the ensuing innings. Rather, the average pitcher was most effective during the second inning. The most likely explanation for this is that the pitcher typically faces batters farther down the batting order (who are generally poorer batters) during the second inning. Compared with the second inning, the pitcher’s effectiveness was significantly worse during the fourth and sixth innings. Since a commensurate trend was not recorded in any of the measured ball kinematics, the pitching metrics measured in this study do not appear to explain this disparity. Instead, this increase in FIP may, again, simply relate to the fact that batters at the top of the order generally return for their second and third at-bats during these innings—a hypothesis that future work should look to confirm. However, these batters may have been favored by the fact that they were facing slower pitches in the strike zone during the fourth and sixth innings. Ultimately, managers, pitchers, and batters should be aware that the fourth and sixth innings may be the most precarious for the pitcher—a fact that could provide tactical justification for relieving the starting pitcher in certain game scenarios.

Starting pitchers in this study displayed a trend for throwing fewer hard pitches and more breaking and off-speed pitches as games progressed, which is most likely related to the concept of “establishing” (ie, becoming comfortable and confident throwing) the fastball.
during the early innings of a game. Toronto Blue Jays starting pitcher Marcus Strosman explains the rationale for this approach:

Once you establish your fastball early it opens up so many more opportunities later in the game to get people out. That’s the biggest thing: Not throwing all five pitches to the first batter. It’s being able to really establish your fastball and go from there.

Thus, changes in pitch selection are most likely motivated by strategic factors. Notwithstanding, these data are informative for manipulating in-game matchups. For example, probability dictates that the batter should predominantly anticipate hard pitches early in the game but increasing numbers of breaking and off-speed pitches, thrown with less speed, during the pitcher’s second and third time through the batting order. The zone percentages recorded in this study also suggest that the batter should be expecting fewer hard and breaking balls in the strike zone during the late innings (7–9). It is possible that this is change is deliberate, as batters facing a starting pitcher in the final innings are most likely trying to prevent a loss and adopting an aggressive strategy—encouraging the pitcher to throw fewer pitches into their hitting zone. Nevertheless, these data encourage batters to err on the side of balls during these innings. Those high-risk, high-reward batting tactics may also partly explain why effectiveness became hugely variable in the late innings. Not limited to these examples, the current findings may help coaching staff and players exploit pitcher or batter matchups to their advantage.

Significant changes in pitch speed, vertical movement, and vertical release location were evident by the fifth inning, with the largest differences from baseline primarily occurring during innings 6 and 7. For managers who consider alterations in mechanics and speed to be appropriate reasons for removing a pitcher, these findings advocate replacing the starting pitcher no later than the fifth or sixth inning of a game—before the largest differences emerge—which is consistent with current MLB practice. However, pitch selection, speed, release height, and vertical-plane movement all exhibited changes from baseline as early as the third inning. Considering the fact that the pitcher’s effectiveness had not diminished at this point in time, these data imply that it would be too zealous to relieve the starting pitcher when significant changes first emerge (since starting pitchers would be removed during, or before, the third inning). Moreover, it is also critical to acknowledge the possibility that these changes may be deliberate tactical adjustments on the pitcher’s behalf—something that future research may wish to consider. Thus, among the parameters analyzed in this study, there may not be a preeminent indicator that informs the decision to relieve a starting pitcher. Indeed, the growing percentile tails in Figures 1 to 3 denote that trends in these parameters became more variable in the later innings and imply that it becomes more difficult to predict performance trends later in a game. Therefore, based on the available evidence, it seems most judicious for coaching staff to consider pitching characteristics in conjunction with other information (eg, pitcher-specific performance, feedback, or injury history), rather than any single factor in isolation. What is clear from these data is that the pattern of acute changes in pitch selection, speed, release height, vertical-plane movement, and zone percentage did not correspond to the significant changes in FIP and, therefore, does not necessarily justify removing a starting pitcher based on the premise that his effectiveness will be compromised by these changes.

It has been shown that flexion, internal rotation, and adduction strength at the throwing shoulder decrease 11% to 18% over the course of a game. Cumulative muscle fatigue may, therefore, provide the most plausible explanation for the decreases in ball speed recorded in this study. It is unclear whether this factor could also explain the changes in release height, although these findings confirm that the kinetic and/or kinetic chain of an MLB pitcher is not perfectly repeatable during a pitching outing. This was not unexpected and is consistent with evidence showing that pitching induces acute musculoskeletal adaptations. If mechanical alterations are related to injury as has been proposed, it would be intuitive for future work to identify the mechanical source of these changes and evaluate their pathological implications. It is also interesting to note that changes manifested as early as the third inning. Therefore, although previous research has reported differences in velocity and mechanics when comparing the first and last innings of a pitching outing, the current findings suggest that these changes emerge much earlier in professional pitchers. Moreover, pitch speed, vertical movement, and vertical release location generally appeared to recover to baseline levels during the eighth and ninth innings, especially in breaking and off-speed pitches. For this reason, it appears prudent for future researchers to adopt a more comprehensive repeated-measures approach such as that used by Grantham et al when comparing performance across a game, as simply comparing the first and last innings pitched may conceal relevant information.

A limit to this study is the fact that MLB starting pitchers are replaced before the end of the game during 98.6% of their starts and, therefore, the preponderance of data analyzed in this study pertain to such games. Consequently, late-inning changes that might have otherwise emerged if the pitcher had remained in the game would not be reflected in these data. This may explain why most of the largest changes from baseline were observed during the sixth and seventh innings, as opposed to the ninth (as ninth-inning data most likely represent rare games in which the pitcher was performing extraordinarily). Nevertheless, the volume of data analyzed in the eighth (mean pitches per pitcher = 256) and ninth (mean pitches per pitcher = 64) innings was not trivial. Most important, it must be noted that these data represent a population of pitchers rather than a sample, and, therefore, these data ultimately embody the performance of elite pitchers during MLB games. The parameters of interest were also analyzed independent of the count and/or whether there were runners on base, again soliciting a more granular analysis in future. Without access to the subjects, it was also not possible to garner feedback about injuries and pain that may have affected performance. Since these data only pertain to MLB pitchers, they should be generalized to other (particularly junior) populations with caution. Finally, this study only focused on a selection of pitching metrics, which should not be considered the sole informants of when to relieve a pitcher. Other independent variables (eg, injury history) also deserve research attention and may be optimized as predictors when employed at the individual level.

Practical Applications

- A significant change in pitch selection, speed, movement, and/or release location, alone, appears too stringent a reason for replacing a starting pitcher, as these occur as early as the third inning and do not influence the pitcher’s effectiveness.
- There may not be a preeminent indicator to inform when to relieve a starting pitcher, suggesting that the decision should be informed by a collection of performance metrics (along with the pitcher’s injury history, game score and opposition batting lineup, game schedule, and feedback), rather than any 1 in isolation.
• Batters in the MLB should anticipate significantly more hard pitches during the early innings but more breaking and off-speed pitches, thrown with less speed, as the game progresses.
• With alterations in mechanics considered precursors for injury, sports-medicine staff and future researchers should be aware that changes in pitch speed, release location, and outcome emerge as early as the third inning.
• Pitchers were most effective in the second inning and, comparatively, significantly less effective in the fourth and sixth innings.

Conclusions

These findings revealed that MLB pitchers were most effective during the second inning and significantly less effective during innings 4 and 6. However, this pattern was not reflected in any of the measured pitching metrics, implying that there was no intuitive link between the pitching parameters and pitcher effectiveness. Significant changes in the starting pitcher’s pitch selection, speed, ball movement, and release location emerged before or during the third inning of an MLB game and suggest that acute changes in pitching parameters, alone, do not appear to justify replacing a starting pitcher. Nevertheless, the largest changes from baseline occurred during innings 6 to 9, which is generally supportive of current MLB practices whereby starting pitchers are most commonly replaced in the fifth or sixth inning, although there did not appear to be a quintessential parameter for informing when to relieve a starting pitcher. The trends observed in these data could be used to create more effective hitting and pitching strategies where, for example, batters in the MLB should anticipate significantly more hard pitches during the early innings but more breaking and off-speed pitches, thrown with less speed, as the game progresses. Equally, with alterations in mechanics considered precursors for injury, sports-medicine staff and researchers should be aware that changes in pitch speed, release location, and outcome emerge as early as the third inning.

Acknowledgments

The authors wish to acknowledge the numerous contributors to Brooks sourced. Special thanks are warranted for Dr Dan Brooks and Prof Alan Nathan, both of whom provided particularly helpful technical information regarding PITCIHfx during the composition of this manuscript.

References


