PILOT: PITCHING STRIDE CHARACTERISTICS ACROSS AN APPERANCE DURING A DIVISION-I COLLEGIATE BASEBALL GAME

Bryson H. Nakamura[1,2], Nicole S. Pham[1], Christopher J. Baker[3], Gunnar Cederberg[4], John J. Ursone[5], and Michael T. Freehill[1,2]

Department of Orthopaedic Surgery, School of Medicine, Stanford University, Stanford, CA[1]
Stanford Baseball Science Core, Stanford University, Stanford, CA[2]
Department of Athletics, Physical Education, and Recreation, Stanford University, Stanford, CA[3]
Department of Olympic Sports Performance, Stanford University, Stanford, CA[4]
Department of Athletic Training, Stanford University, Stanford, CA[5]

Stride phase characteristics have been identified as contributors to pitch velocity. The aim of this study was to determine how in-game pitching stride phase characteristics and pitch velocity changed across a pitching appearance. Five (5) male Division-I pitchers were measured across an appearance during a collegiate baseball game. Five (5) biomechanical characteristics during the stride phase and pitch velocity were assessed. Biomechanical and pitch metrics were collected for each pitch and averaged per inning. Center of Mass Anterior/Posterior Velocity at Foot Contact was observed to significantly increase across time, though pitch velocity did not change across time. This may suggest that pitch velocity could be a trailing indicator of mechanical change. If true, biomechanical data should be leveraged to better identify when pitching biomechanical patterns may be changing during an outing.

KEYWORDS: in-game, markerless, kinematics

INTRODUCTION: Sustaining a pitcher's maximal level of performance within a game is imperative. Pitch velocity has been shown to be a significant predictor of in-game pitching success (Whiteside et al., 2015). Whiteside et al. (2016) conducted an analysis of starting pitcher pitch characteristics in Major League Baseball (MLB), which showed pitch velocity changing and increasing in variability across a game. As pitch characteristics change within a game, it is reasonable to hypothesize that in-game pitching biomechanics may change as well.

Escamilla et al. (2007) conducted a study where pitchers completed a simulated game in the lab. Findings suggested that only ball velocity and forward trunk tilt were different in the final inning in comparison to the first two innings. However, this study was completed in a lab during a simulated game and it remains unknown if this translates to live competition.

Pitching stride phase characteristics have been shown to be related to pitch velocity. Manzi et al. (2021) showed that pitch velocity increased 0.9 m/s for every 10% increase in stride length as a percent of body height. Braking and resultant ground reaction forces (McNally et al., 2015), knee extension angle, and knee extension velocity (Dowling et a., 2022) of the lead leg at foot contact were shown to be related to pitch velocity. Collectively, these are factors of the lead leg block phenomenon, which is important in arresting the linear center of mass momentum and translating it into rotational energy up the kinetic chain (Lin et al., 2003).

Though published work exists surrounding how pitch characteristics may change across a game, there is limited research suggesting how pitching biomechanics may change across time, especially within a live game. However, it is also accepted that as pitching workloads increase during an appearance, the risk for elbow or shoulder pain increase (Lyman et al., 2001). Thus, determining a balance between sustaining maximal performance and mitigating injury risk during a pitching appearance is imperative. The aim of this study was to determine how in-game pitching stride phase characteristics and pitch velocity changed across a pitching appearance. It was hypothesized that as pitchers accumulate workload, stride characteristics would change in concert with changes in pitch velocity.

METHODS: Five (5) male NCAA Division-I pitchers (Age: 20.4±0.7yr; Ht: 1.90±0.02m; Mass: 96.2±8.4kg) were included in this study. All pitchers signed informed consent approved by the University IRB committee. Data were collected across seven (7) games during the 2022 NCAA Season then filtered using the following inclusion criteria: 1) recorded at least one (1) appearance in a collegiate, regular season game and 2) pitched a minimum of four (4) complete innings.
Ball tracking data were collected with the TrackMan In-Stadium V3 (Vedbæk, Denmark) system. Pitch-type classifications were used to group similar pitch types together. Only Fastball classified pitches (Four-Seam Fastball, Sinkers, and Cutters) were included in the analysis to remove pitch velocity variability from breaking balls and change-ups.
Videos of pitching events were collected during each game using an in-stadium, eight (8) camera KinaTrax Markerless Motion Capture System (Boca Raton, FL). Videos were then rendered and processed using KinaTrax computer vision software to derive joint-center tracking data (Pitching Model v6.3.9). Pitching stride kinematics were calculated from C-Motion Visual 3D software (Boyds, MD). Stride kinematics assessed were: Max Center of Mass Anterior/Posterior Velocity (CoM A/P Vel Max), Center of Mass Anterior/Posterior Velocity at Foot Contact (CoM A/P Vel FC; positive: toward home plate), Center of Mass Medial/Lateral Velocity at Foot Contact (CoM M/L Vel FC; positive: Arm-Side/Closed Stride), Stride Length as a percentage of Body Height, and Step Width (positive: lead leg closed with respect to the rear foot). Foot Contact was determined when the resultant velocity of the lead leg ankle joint center reduced to less than 0.1m/s. Ball tracking data and Markerless Motion Capture data were then time-synchronized for each event. For the inning by inning analysis, biomechanical and pitch characteristic data were averaged per inning per individual pitcher.
Multivariable quadratic linear regression models were used to examine the effects of the number of pitches or innings on various stride biomechanical variables, adjusting for individual pitchers and the interaction effect. Model residuals were visually evaluated for normality and homoscedasticity. Variance inflation factors (VIFs) were also evaluated to check for multicollinearity, using a cutoff of 10 to identify serious collinearity issues. Model p-values were adjusted to account for multiple comparisons using the Benjamini-Hochberg procedure. All analyses were completed in RStudio version 2022.12.0+353 (Boston, MA) using a two-sided level of significance of 0.05.

RESULTS: CoM A/P Vel FC was observed to significantly increase as both pitches (0.27cm/s, p = 0.045) and innings (3.76 cm/s, p = 0.042) increased during an appearance. Fastball pitch velocities showed no change across the appearance. Table 1 highlights the results from both linear and quadratic regression models across all stride biomechanical variables and pitch velocity.

Table 1: Regression Results of Stride Biomechanical Variables and Pitch Velocity

	CoM A/P Vel Max (cm/s)		**CoM A/P Vel FC (cm/s)**		**CoM M/L Vel FC (cm/s)**	
	Estimate	*p*	*Estimate*	*p*	*Estimate*	*p*
Pitch in Game¹	-0.13	0.184	0.27*	0.045	-0.10	0.525
Pitch in Game²	0.00	0.131	0.00*	0.045	0.00	0.325
Inning in Game¹	-1.22	0.352	3.76*	0.042	-1.73	0.397
Inning in Game²	0.16	0.320	-0.41	0.053	0.27	0.292
	Stride Length (%BH)		**Step Width (cm)**		**Pitch Velocity (km/h)**	
Pitch in Game¹	0.03	0.086	0.06	0.168	0.01	0.767
Pitch in Game²	0.00	0.740	0.00	0.210	0.00	0.775
Inning in Game¹	0.40	0.064	0.52	0.350	0.31	0.564
Inning in Game²	-0.02	0.363	-0.04	0.509	-0.02	0.611

*¹Linear regression model; ²Quadratic regression model; *p < 0.05*

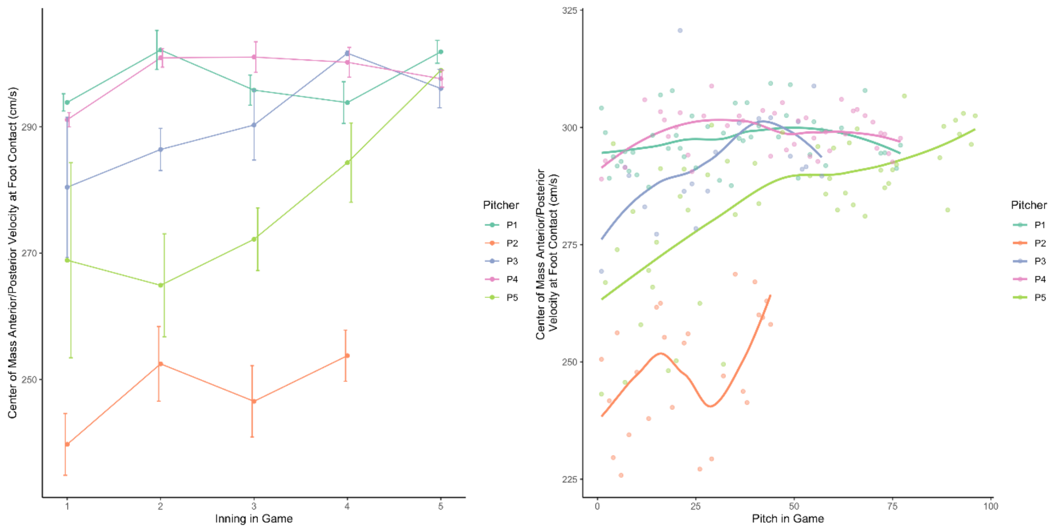

Figure 1a & 1b: Individual Pitcher Trends for CoM A/P Vel FC by Inning & Pitches

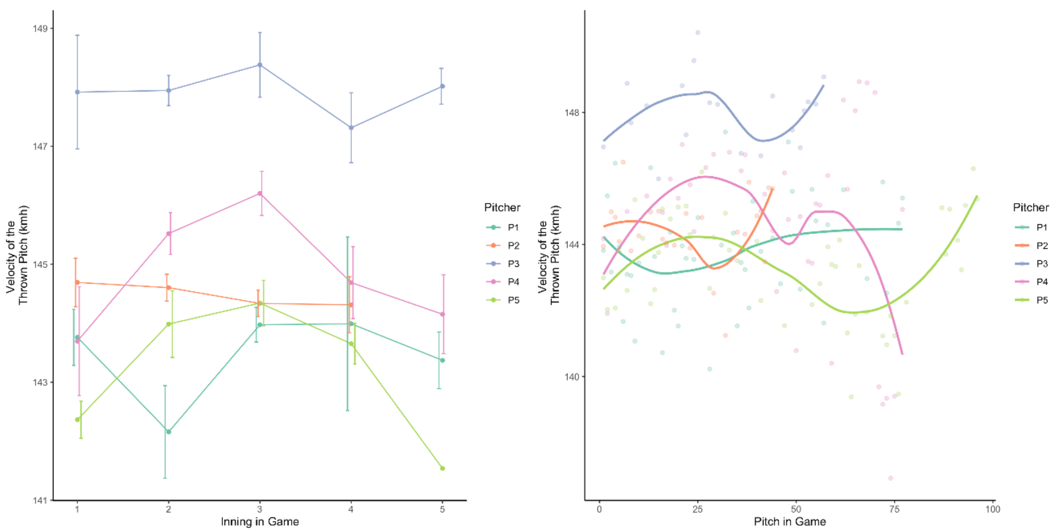

Figure 2a & 2b: Individual Pitcher Trends in Fastball Pitch Velocities by Inning & Pitches

DISCUSSION: The aim of this study was to determine how in-game pitching stride characteristics and pitch velocity changed across a pitching appearance. Previous lab-based work (Escamilla et al., 2007) showed that some biomechanical changes across a simulated game occur. Analysis of the current study's in-game data showed that only CoM A/P Vel FC significantly increased across innings and pitches (Figure 1a & 1b), while pitch velocity did not change (Figure 2a & 2b). The lack of change in stride length corroborates findings by Escamilla et al. (2007) where no significant differences were observed through a simulated game. The corresponding 3.76cm/s increase per inning in CoM A/P Vel FC may indicate a reduction in the capacity for a pitcher to leverage their lead leg block; and thus delay the transition of energy up the kinetic chain. Given that velocity did not change, this increase in CoM A/P Vel FC may be a compensation factor or indicate that compensation may be occurring in the upper extremities to sustain velocity.

Pitch velocity did not significantly change across time. However, when observing individual trends (Figure 2b), subjects P2, P3, and P5 exhibited similar, sinusoidal-like fluctuation in velocity across the differing time scales that is different from what P1 and P4 exhibited. Whiteside et al. (2016) showed that, in aggregate, pitch velocity tended to decrease in the first half of games, while variability increased in the second half of games. The observed trends in P2, P3, and P5 would generally oppose Whiteside et al.'s findings. However, it should be noted that the prior study found no significant differences in velocity when comparing the 1st inning to the 9th inning; likely due to the higher variability in later innings. Nonetheless, this could indicate that differing pitchers could employ different strategies to mitigate or perform through fatigued states later in the game.

Given the preliminary results of this pilot project, caution should be taken if only leveraging pitch velocity as a metric of health and performance during a game. The current study found that CoM A/P Vel FC changed across time while pitch velocity did not. This suggests that biomechanical changes or compensations are being made before a discernable change in pitch velocity is observed; indicating that pitch velocity may be a trailing indicator for fatigue.

Primary limitations of the current study are the duration of each pitcher's in-game appearance and sample size. Length of appearance is directly influenced by the performance needs of the team given the in-game situation. It could be hypothesized that differences may be observed beyond the fifth inning and the 75-pitch mark, but additional research must be conducted to address this. However, three (3) of the pitchers were able to reach the 75-pitch mark, which is generally considered a significant workload within a single game. Thus, it could be argued that some of these pitchers approached a meaningful duration in the game. Further work should aim to expand upon the small sample size of pitchers in the current study.

CONCLUSION: CoM A/P Vel FC was found to significantly increase as time, Innings and Pitches, increased within a game. Pitch velocity showed no significant change across time. However, it should be noted that three of five pitchers exhibited a uniquely similar velocity pattern across differing pitches time scales. The findings suggest that pitch velocity may be a trailing indicator for fatigue, while underlying biomechanical compensation techniques are being leveraged by the pitcher as innings and pitches increase during an appearance.

REFERENCES:

Dowling, B., Manzi, J. E., Raab, G., Coladonato, C., Dines, J. S., & Fleisig, G. S. (2022). The relationship among lead knee extension, fastball velocity and elbow torque in professional baseball pitchers. *Sports Biomechanics*, DOI: 10.1080/14763141.2022.2050801. https://doi.org/10.1080/14763141.2022.2050801

Escamilla, R. F., Barrentine, S. W., Fleisig, G. S., Zheng, N., Takada, Y., Kingsley, D., & Andrews, J. R. (2007). Pitching Biomechanics as a Pitcher Approaches Muscular Fatigue during a Simulated Baseball Game. *AMERICAN JOURNAL OF SPORTS MEDICINE*, *35*(1), 23–33.

Fleisig, G. S., Slowik, J. S., Wassom, D., Yanagita, Y., Bishop, J., & Diffendaffer, A. (2022). Comparison of marker-less and marker-based motion capture for baseball pitching kinematics. *Sports Biomechanics*, 1–10. DOI: 10.1080/14763141.2022.2076608

Lin, H.-T., Su, F.-C., Nakamura, M., Chao, E. Y. S., Lin, H. T., & Su, F. C. (2003). COMPLEX CHAIN OF MOMENTUM TRANSFER OF BODY SEGMENTS IN THE BASEBALL PITCHING MOTION. In *Journal of the Chinese Institute of Engineers* (Vol. 26, Issue 6).

Lyman, S., Fleisig, G. S., Waterbor, J. W., Funkhouser, E. M., Pulley, L., Andrews, J. R., Osinki, E. D., & Roseman, J. M. (2001). Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Medicine and Science in Sports and Exercise*, *33*(11), 1803–1810.

Manzi, J. E., Dowling, B., Dines, J. S., Wang, Z., Kunze, K. N., Thacher, R., McElheny, K. L., & Carr, J. B. (2021). The association of stride length to ball velocity and elbow varus torque in professional pitchers. *Journal of Sports Sciences*, *39*(23), 2658–2664.

McNally, M. P., Borstad, J. D., Onate, J. A., & Chaudhari, A. M. W. (2015). Stride Leg Ground Reaction Forces Predict Throwing Velocity in Adult Recreational Baseball Pitchers. *Journal of Strength and Conditioning Research*, *29*(10), 2708–2715.

Whiteside, D. (2016). Changes in a Starting Pitcher's Performance Characteristics Across the Duration of a Major League Baseball Game. *International Journal of Sports Physiology and Performance*, *11*(2).

Whiteside, D., Martini, D. N., Zernicke, R. F., & Goulet, G. C. (2015). Ball Speed and Release Consistency Predict Pitching Success in Major League Baseball. *Journal of Strength and Conditioning Research*, *30*(7), 1787–1795.