DETERMINING RELATIONSHIPS BETWEEN KINEMATIC SEQUENCING AND BASEBALL PITCH VELOCITY USING MARKERLESS MOTION CAPTURE

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The purpose of this study was to determine how the timings and magnitudes of peak pelvis rotational velocity, peak trunk rotational velocity, peak elbow extension velocity, and peak shoulder internal rotation velocity affect pitch velocity. Eighty pitchers (187.2 ± 8.2cm, 89.3 ± 13.0kg, 20.1 ± 3.3yrs) had a minimum of 3 fastballs recorded and video was processed using pitchAI™. Average pitch velocity was 38.1 ± 2.5 m/s. A multilinear regression generated a significant prediction for pitch velocity ($R^2 = 0.368$ and $p < 0.01$). Pitcher weight ($\beta = 0.535$, $p < 0.001$), peak pelvis rotational velocity timing ($\beta = -0.157$, $p = 0.001$), peak elbow extension timing ($\beta = 0.122$, $p = 0.006$), and peak shoulder internal rotation timing ($\beta = -0.113$, $p = 0.018$), were significant contributors to the multilinear model. In conclusion, player weight and their kinematic sequence metrics from pitchAI™ can be significant predictors of pitch velocity.

KEYWORDS: markerless motion capture, kinematics, pitching

INTRODUCTION: Fastball velocity in professional baseball has been increasing since 2008 (Sullivan, 2019) and the incidence of elbow injuries has also increased (Conte et al., 2016). The kinematic sequence in pitching mechanics has been investigated to explore the influence on elbow and shoulder torques (Scarborough et al., 2021). Pitchers with a kinematic sequence characterized by proximal to distal angular velocities (pelvis, trunk, upper arm, forearm, hand) had the lowest arm torques, while pitchers who had the distal arm segments peak prior to the proximal arm segments had the highest torques (Scarborough et al., 2021). Kinematic sequencing characteristics have also been used in regression models and artificial intelligence models to identify significant predictors of pitch velocity and arm torques (Nicholson et al., 2022ab, Manzi et al., 2021). Using a gradient boosting machine model, the kinematic sequence metrics that were significant predictors of arm torques were shoulder internal rotation velocity, time from maximum pelvis rotation velocity to maximum trunk rotational velocity, maximum elbow extension velocity, maximum pelvis rotational velocity, and maximum trunk rotational velocity (Nicholson et al., 2022a). In the models for pitch velocity, the main predictor variables were maximum shoulder internal rotation velocity, maximum elbow extension velocity, and time between maximum pelvis and trunk rotational velocities (Nicholson et al., 2022b). Similarly, Manzi et al. (2021) found significant influence of the time between foot strike to peak pelvis velocity, peak pelvis to peak torso, peak torso to peak elbow, and peak elbow to ball release, on ball velocity and arm torque in professional pitchers. These studies suggest the timing, order and magnitude of the kinematic sequence can affect both pitch velocity and arm torque. Investigating factors in pitching mechanics associated with increasing pitch velocity, as well as correlations with increased arm torques have relied on marker-based motion capture. With the recent validation of pitchAI™ (Dobos et al., 2022), a single camera markerless motion capture solution, there is increased accessibility to pitching kinematics. The purpose of this study was to investigate how the timings and magnitudes of maximum pelvis rotational velocity, maximum trunk rotational velocity, maximum elbow extension velocity, and maximum shoulder internal rotation velocity from pitchAI™ influence pitch velocity using a multilinear regression. It was hypothesized that angular velocities of the trunk and shoulder would be significant predictors of pitch velocity.

METHODS: Eighty pitchers (187.2 ± 8.2cm, 89.3 ± 13.0kg, 20.1 ± 3.3yrs) ranging in skill level from high school (19), college (47), and professional (14) participated in this study, throwing maximum effort bullpens to a catcher at regulation distance. All participants provided informed consent and the project was approved by the university's research ethics board. Video was recorded at Driveline Baseball (Scottsdale, AZ) and KineticPro Baseball (Tampa, FL). Fastballs were recorded using an iPhone 8, or newer, at 240hz and 1080p. The instructions for video were to be eye level, as steady as possible, facing the open side of the pitcher, and framed so the pitcher fills as much of the frame as possible. Pitch velocity was concurrently collected using a Stalker Pro2 radar gun (Richardson, TX). All video data was processed through offline pitchAI™ source code providing joint center coordinate data as well as time series kinematics and summary metrics. Height, weight, and pitch velocity were paired with the corresponding pitch kinematics for analysis. All pitches were time normalized from 0% (foot-plant) to 100% (ball release). Both foot-plant and ball release are automatically tagged within pitchAI™ using custom algorithms (Dobos et al., 2022). The relative percentages where peak pelvis rotational velocity, peak trunk rotational velocity, peak elbow extension velocity, and peak shoulder internal rotation velocity occurred were extracted with the corresponding peak velocities to be used as predictor variables in the model. Height and weight were also extracted to provide context to the kinematic velocities. Pitch velocity was used as the dependent variable. The multilinear regression was performed in SPSS version 28 (IBM Corp., Armonk, N.Y.).

RESULTS: A total of 391 pitches were included in this study, averaging 4-5 pitches per pitcher, with an average velocity of 38.1 ± 2.5 m/s. The most common order of the kinematic sequence was peak pelvis rotational velocity, peak trunk rotational velocity, peak elbow extension velocity, then peak shoulder internal rotation velocity. The only other observed order had peak trunk rotational velocity first, then peak pelvis rotational velocity, with the elbow and shoulder remaining the same. The extracted metrics can be found in table 1. The multiple linear regression model produced a significant prediction of pitch velocity with an $R^2 = 0.368$, SEE = 4.56, and $p < 0.001$. The significant predictors of pitch velocity were weight (β = 0.535, SE = 0.012, $p < 0.001$), peak pelvis rotational velocity timing (β = -0.157, SE = 0.012, $p = 0.001$), peak elbow extension velocity timing (β = 0.122, SE = 0.019, $p = 0.006$), and peak shoulder internal rotation velocity timing (β = -0.113, SE = 0.03, $p = 0.018$) (table 2).

Table 1: Averages of Extracted Metrics (%PitchCycle: 0% FP, 100% BR)

Metric	Mean
Peak Pelvis Timing (% PC)	26.2 ± 22.7
Peak Trunk Timing (% PC)	42.2 ± 16.9
Peak Elbow Timing (% PC)	83.4 ± 12.9
Peak Shoulder Timing (% PC)	100.5 ± 9.1
Peak Pelvis Velocity (°/s)	686 ± 110
Peak Trunk Velocity (°/s)	1128 ± 207
Peak Elbow Velocity (°/s)	1702 ± 348
Peak Shoulder Velocity (°/s)	3573 ± 735
Height (cm)	186.7 ± 8.2
Weight (kg)	89.3 ± 13.0
Pitch Velocity (m/s)	38.1 ± 2.5

Table 2: Multilinear Regression Predictor Variables

Metric	B	Std. Error	β	t	Significance
Constant	**54.668**	**7.209**		**7.583**	
Weight	0.105	0.012	0.535	8.626	<0.001

Peak Pelvis Timing	-0.039	0.012	-0.157	-3.200	0.001
Peak Elbow Timing	0.054	0.019	0.122	2.752	0.006
Peak Shoulder Timing	-0.071	0.030	-0.113	-2.377	0.018
Peak Trunk Timing	0.032	0.016	0.095	1.942	0.053
Peak Pelvis Velocity	0.005	0.003	0.095	1.805	0.072
Peak Trunk Velocity	0.002	0.002	0.066	1.188	0.235
Height	0.044	0.043	0.064	1.033	0.302
Peak Shoulder Velocity	0.000	0.000	-0.044	-0.954	0.340
Peak Elbow Velocity	0.000	0.001	-0.010	-0.234	0.815

DISCUSSION: The kinematic sequencing characteristics from pitchAI™ produced a significant model for pitch velocity using a multilinear regression. The model indicated that pitchers with greater body mass, earlier peak pelvis rotational velocity timing, later peak elbow extension timing, and earlier peak shoulder internal rotation timing may have faster pitch velocities. Effective timing of the kinematic sequence is hypothesized to improve energy transfer between segments from the lower half to the arm, however more research is required to fully understand the effect of the kinematic sequence on energy flow in pitching. The extracted metrics from pitchAI™ compared well to literature with the relative timings for the pelvis and trunk within 10% of established ranges, and elbow and shoulder timings lining up well (Aguinaldo & Escamilla, 2019; Escamilla et al., 2002; Stodden et al., 2005; Matsuo et al., 2001). The observed order of the kinematic sequence from pitchAI™ was different from Scarborough (2021,2022), likely due to differences in processing. PitchAI™ calculates the rate of change of joint angles, while Scarborough calculated the magnitude of segment angular velocities. The kinematic velocities also compared well for the pelvis and trunk, but elbow velocities were generally slower in pitchAI™ by about 1000°/s, and the shoulder was slower by about 500°/s compared to the lower end of the established ranges (Escamilla at al., 2002; Matsuo et al., 2001; Nicholson et al., 2022ab). The differences in velocity may be due to differences in maximum and minimum joint angles from different models and filtering methods, resulting in slower velocities of the shoulder and elbow in pitchAI™, however within pitcher data was consistent for both the shoulder and elbow velocities. Different from the influential predictor variables in literature, the relative timings of the peak pelvis rotational velocity, peak elbow extension velocity, and peak shoulder internal rotation velocity were significant predictors. Nicholson et al., 2022 used a multilinear regression to predict pitch velocity using many kinematic factors, however some similar kinematic sequencing characteristics were significant predictors; maximum humeral rotation velocity, maximum trunk rotation velocity, and maximum elbow extension velocity. This is more common with other literature as the kinematic velocities are often significant predictors while timings are not. Based on Fleisig et al., 1999, there are minimal differences in kinematic velocities between youth, high school, college, and professional athletes; considering the athletes in this study were of the high school, college, and professional level, there may have been minimal differences in kinematic velocities, while the relative timings may have differed, as well as increased body size throughout the development levels. This project was not without limitations, as pitchAI™ is a single camera system with a simple model in comparison to multi-camera and marker-based systems. Thus, velocities of faster moving segments were different from literature; however, the timings were very similar. Consistency of video is also a limitation with pitchAI™ as the data was collected by different groups in different settings and was used for secondary analysis; however, consistent standards for multi-cite collaborations is a strength.

CONCLUSION: In conclusion, some pitchAI™ kinematic sequencing metrics may be related to pitch velocity. The results from the multilinear regression indicate that pitchers with greater body weight, earlier peak pelvis rotational velocities, later peak elbow extension velocities, and earlier peak shoulder internal rotation velocities may have increased pitch velocity. Identifying kinematic sequence using pitchAI™ can provide insight towards what may be limiting velocity. Gaining lean body mass through strength training and providing specific drills to target earlier pelvis rotational velocity, and/or limiting early elbow extension velocity, and/or improving the timing of peak shoulder internal rotation velocity could lead to increased fastball velocity.

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