DIFFERENCES IN TEMPORAL VARIABLES AND THEIR EFFECT ON KINETICS IN HIGH SCHOOL PITCHERS WITH HIGH AND LOW PITCH VELOCITIES

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The purpose of this study was to compare temporal parameters between high and low velocity high school (HS) pitchers and investigate the influence these parameters have on both pitch speed and upper extremity kinetics. 30 healthy right-handed HS male pitchers with no recent injuries, and clearance to play were included. A 3D motion analysis system was used. Analysis included 15 kinetic and 35 temporal variables. Statistical tests conducted in SPSS. Correlation strength was interpreted as weak, moderate, or strong. High velocity and low velocity throwers showed differences in the timing to progress through the pitching cycle and these temporal variables showed separate relations to pitch speed and kinetics.

KEYWORDS: baseball, pitching, biomechanics, injury, timing

INTRODUCTION: In baseball, increasing pitch velocity is a well-known predictor of a player's success on the mound (Whiteside et al., 2016). Coaches and scouts seek out players that throw at higher velocities, which encourages players to focus on improving their throwing velocity to increase their competitive edge over their peers (Lehmen et al., 2013). However, higher pitching speeds have also been correlated with increased risk of injury (Coughlin et al., 2019; Slowik et al., 2019). To optimize long-term performance, researchers continue investigating the biomechanics of the pitching cycle with the goal of identifying variables that influence pitch speed without increasing a player's risk of injury.

Specifically, researchers have observed that temporal (timing) variations within the pitching cycle have an influence on both ball velocity as well as throwing arm kinetics (forces and torques) associated with common injuries (Aguinaldo & Escamilla, 2019; Manzi et al., 2021; Matsuo et al., 2001; Stodden et al., 2005; Urbin et al., 2013; Werner et al., 2008). However, there remains little research in temporal variations within high school (HS) pitchers despite evidence that timing in the pitching cycle influences both ball velocity and kinetic forces related to throwing arm injuries. This is especially important for the HS population as pitchers experience significantly more injuries than positional players with a previous report revealing 63.3% of the injuries involved the throwing arm (Shanley et al., 2011).

Therefore, the purpose of this study was to compare temporal parameters between high and low velocity HS pitchers and investigate the influence these parameters have on both pitch speed and upper extremity kinetics. We hypothesized that (1) high velocity pitchers (HVP) and low velocity pitchers (LVP) will have temporal differences within the pitching cycle; and (2) upper extremity kinetics and ball velocity would be influenced by these differing temporal parameters. Identifying temporal differences between the two velocity groups and the kinetic influences timing has within the pitching cycle will help the players and coaches make proper adjustments to prevent injury while maximizing ball velocity.

METHODS: Thirty healthy right-handed HS male pitchers were included in this study. Inclusion criteria at the time of testing required subjects to be actively participating on a HS baseball team; no history of current injury or severe injury that required more than two weeks of rest or rehabilitation within the past six months; and all participants had been cleared by their primary care provider to play. The subjects provided medical history and completed written informed assent and guardian consent, as approved by the Institutional Review Board before partaking in the testing.

Eight Raptor-E cameras (Motion Analysis Corp, Santa Rosa, CA) were positioned around an artificial pitching mound to capture the motion of pitchers wearing 47 retroreflective markers at 300 Hz as described by Albiero et al. (2022). Data processing followed an established protocol (Albiero et al.,2022). For each subject, the three fastest strikes were processed. The pitching

cycle was divided into six phases (wind-up, stride, arm cocking, arm acceleration, arm deceleration, follow-through) (Fleisig et al., 1995). Data used for analyzes included 15 kinetic variables and 35 temporal variables. Force variables were normalized by body mass and torque variables were normalized by body mass and height. Based on the median pitch velocity for the entire sample, subjects were grouped as HVP (> 33.8 m/s) or LVP (< 33.5 m/s).
Means and standard deviations were calculated for all variables. A Welch's T-test was used to compare the demographic and temporal variables between HVPs and LVPs with a p-value set at 0.05. The statistically significant temporal variables were then used in a two-tailed Pearson correlation test to determine the relationships between pitch speed and kinetic variables. The strength of a correlation was assessed as weak (.1 < | r | < .3), moderate (.3 < | r | < .5), or strong (| r | > .5) (Cohen, 1988). SPSS Statistics software (version 27, IBM Corporation, Armonk, NY) was used to analyze the data.

RESULTS: There were 15 players in both the high velocity and low velocity groups. Demographic and pitch speed comparisons between the groups are shown in Table 1.

Table 1. Welch's T-Test between high and low velocity groups demographic data and ball velocity. * indicates statistical significance (p < 0.05).

	High Velocity			Low Velocity			
	Mean	±	SD	Mean	±	SD	p-value
Pitch Speed (m/s)	35.7	±	0.9	31.6	±	1.3	<0.001*
Age (years)	16.5	±	0.8	16.3	±	1.4	0.707
Height (cm)	184.0	±	6.8	183.7	±	6.2	0.918
Mass (kg)	80.5	±	9.4	76.0	±	9.0	0.198
Pitching Experience (years)	3.7	±	0.6	3.5	±	0.7	0.287

Of the thirty-five temporal variables, six onset variables occurred significantly earlier within the pitching cycle (from foot contact to shoulder maximum internal rotation angle) in the high velocity group (Table 2). Table 3 shows the two-tailed Pearson correlation results between the six temporal variables listed in Table 2 with pitch speed and the kinetic variables. Out of the 96 calculated relationships, 23 showed significant results. Of those results, no strong correlations were found, 13 had moderate strength correlations and 10 weak correlations.

Table 2. Welch's T-Test between high and low velocity groups temporal data. %PC: percent of Pitch Cycle. * indicates statistical significance (p < 0.05).

	High Velocity			Low Velocity			
	Mean	±	SD	Mean	±	SD	p-value
Max Lead Hip Adduction Velocity (% PC)	36.0	±	8.1	44.1	±	12.5	0.045*
Max Elbow Extension Velocity (% PC)	71.7	±	4.1	75.0	±	3.2	0.020*
Max Wrist Flexion Velocity (% PC)	75.8	±	3.7	78.5	±	3.4	0.045*
Max Shoulder Internal Rotation Velocity (% PC)	80.5	±	4.0	83.8	±	2.8	0.015*
Max External Rotation (% PC)	62.6	±	3.9	66.2	±	3.9	0.016*
Ball Release (% PC)	77.6	±	3.5	80.3	±	2.3	0.022*

DISCUSSION: In our study, we found significant temporal differences between high velocity pitchers (HVPs) and low velocity pitchers (LVPs). Specifically, HVPs were quicker to achieve their maximum velocities for lead hip adduction, elbow extension, wrist flexion, and shoulder internal rotation relative to percent pitch cycle. The HVPs were also quicker to reach maximum external rotation (MER) and ball release (BR). Only the onset time to lead hip adduction velocity and shoulder internal rotation velocity showed moderate and weak relationships with pitch speed, respectively. This agrees with prior studies that showed slower throwing velocities to be associated with longer time to reach shoulder internal rotation velocity, however, our study also showed increased time to lead hip adduction velocity to correlate with decreased ball velocity, although this variable was not reported in other studies (Stodden et al., 2005; Matsuo et al., 2001).
The six temporal variables that differed between HVPs and LVPs were negatively correlated with shoulder compressive force. This finding may be significant in injury prevention because

it supports the proposal made by McLeod and Andrews (1986) that high shoulder compressive forces can lead to increased grinding between the humerus and labrum, ultimately increasing the risk of a labrum tear.

Our data showed that all temporal variables, except time to lead hip adduction velocity, had a significant negative relationship with elbow flexion torque, which has been linked to superior labrum anterior posterior (SLAP) tear injuries. Moreover, onset time to shoulder internal rotation velocity and lead hip adduction velocity has significant relationships to elbow medial shear force and elbow varus torque, respectively, which have been associated with an increased risk of avascular necrosis, osteochondritis dissecans, or osteochondral chip fracture and ulnar collateral ligament injury, respectively (Fleisig et al., 1995).

Regarding throwing arm kinetics, previous research has found that an earlier onset of trunk rotation (Aguinaldo & Escamilla, 2019) and less time spent in early portions of the pitching cycle (Urbin et al., 2013; Manzi et al., 2020) are related to increased joint stress. However, our study did not find a significant relationship between the onset of trunk rotation and throwing arm kinetics. Instead, we identified six temporal variables that differed significantly between HVPs and LVPs and found that all of them correlated moderately with one or more kinetic variables, except for onset time to wrist flexion velocity.

Table 3. Two-tailed Pearson correlation results between significant temporal variables with pitch speed and normalized kinetics within stages of the pitching cycle. E: elbow; S: shoulder; SIRV: shoulder internal rotation velocity; MER: shoulder maximum external rotation. * indicates statistical significance ($p < 0.05$)

	Lead Hip Adduction Velocity		Elbow Extension Velocity		Wrist Flexion Velocity		SIRV		MER		Ball Release	
	r	p	r	p	r	p	r	p	r	p	r	p
Pitch speed	-0.35	<0.01*	-0.15	0.17	-0.11	0.29	-0.22	0.04*	-0.15	0.15	-0.12	0.25
Arm Cocking												
(E) Medial Shear Force	-0.29	<0.01*	-0.20	0.06	-0.13	0.24	-0.32	<0.01*	-0.20	0.06	-0.20	0.06
(E) Varus Torque	-0.19	0.07	-0.15	0.14	-0.16	0.14	-0.22	0.04*	-0.14	0.19	-0.16	0.14
(S) Ant. Shear Force	-0.13	0.22	-0.06	0.58	-0.01	0.96	-0.08	0.48	-0.11	0.29	-0.11	0.31
(S) Sup. Shear Force	-0.22	0.04*	0.10	0.37	0.07	0.51	-0.03	0.79	0.05	0.65	0.13	0.22
(S) Adduction Torque	-0.30	<0.01*	-0.04	0.72	0.02	0.85	-0.12	0.27	-0.09	0.38	-0.02	0.88
(S) Horizontal Add. Torque	0.05	0.66	0.05	0.64	0.00	0.97	0.02	0.89	0.09	0.40	0.12	0.28
(S) Internal Rotation Torque	-0.16	0.13	-0.20	0.06	-0.18	0.08	-0.26	0.01*	-0.21	0.05*	-0.20	0.06
Arm Acceleration												
(E) Anterior Shear Force	0.02	0.84	0.26	0.01*	0.04	0.70	0.31	<0.01*	0.11	0.29	0.12	0.26
(E) Flexion Torque	-0.13	0.22	-0.37	<0.01*	-0.23	0.03*	-0.43	<0.01*	-0.34	<0.01*	-0.41	<0.01*
Arm Deceleration												
(E) Compressive Force	0.06	0.54	0.00	0.99	-0.03	0.76	-0.01	0.94	0.01	0.92	-0.01	0.90
(S) Compressive Force	-0.45	<0.01*	-0.34	<0.01*	-0.26	0.01*	-0.42	<0.01*	-0.30	<0.01*	-0.33	<0.01*
(S) Post. Shear Force	-0.15	0.15	0.02	0.82	0.04	0.69	-0.05	0.66	0.05	0.65	0.12	0.25
(S) Inf. Shear Force	-0.09	0.38	-0.04	0.69	0.00	1.00	-0.08	0.47	-0.04	0.71	-0.07	0.49
(S) Horizontal Abduction Torque	0.11	0.31	0.13	0.21	0.03	0.75	0.23	0.03*	0.05	0.62	0.00	0.99
(S) Adduction Torque	-0.06	0.57	-0.05	0.62	0.04	0.71	0.09	0.41	-0.14	0.19	-0.07	0.54

This study was not without limitations. Due to the smaller sample size, a median split analysis was used to divide the groups. Ideally, groups would be divided as one standard deviation above and below the average pitch velocity, with the median group eliminated. The p-value was not adjusted for the large number of tests run. Lastly, only the timing of percent cycle was compared across the groups. The lengths of the phases were not analyzed within the groups, as the HVP group showed it was in the arm acceleration phase (between MER and BR) longer than the LVP (15% to 14.5%, respectively). Future work plans to include absolute timing between phases and a multiple variable model.

CONCLUSION: The findings of this study have significant implications for pitchers, as timing within the pitch cycle of high-velocity pitches (HVPs) and low-velocity pitches (LVPs) can influence joint kinetics related to common pitching injuries. Pitchers and coaches should look at timing variables as an option for adjustments in pitching techniques. Future studies could explore how altering timing within the pitching cycle may help reduce joint kinetics in pitchers of different skill levels and populations.

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