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Within-subject time series angular velocity differences between in-game high and low velocity fastballs in college baseball pitchers

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ABSTRACT

Purpose: The purpose of the current study is to investigate the within-pitcher differences in time series angular velocities of the pelvis, trunk, shoulder, and elbow for high and low velocity fastballs in college baseball pitchers.
Methods: In-game data were retrospectively analyzed from 82 NCAA Division 1 pitchers ([1.89 ± 0.06] m, [92.8 ± 9.5] kg). Kinematic data were collected using an in-game markerless motion capture system. Time series data of pelvis, trunk, shoulder, and elbow angular velocities for each pitcher's fastest and slowest fastball were extracted for the pitch cycle (foot contact to ball release) and used for analysis. Within-subject time series comparisons were conducted using statistical parametric mapping (SPM) paired samples *t*-tests ($\alpha = 0.012\,5$).
Results: Each of the tested segments were significantly faster in the fastest fastball trial compared to the slowest fastball trial. The duration of significance in reference to the pitch cycle, test statistic, and *p*-value, for each segment are as follows: Pelvis: 0%–4%, $t = 3.54$, $p = 0.012$; Trunk: 30%–67%, $t = 5.62$, $p < 0.001$; Shoulder External Rotation: 3%–50%, $t = -6.03$, $p < 0.001$; Shoulder Internal Rotation: 96%–100%, $t = 4.11$, $p = 0.008$; Elbow: 75%–86%, $t = 4.13$, $p < 0.001$.
Discussion: Within-subjects differences exist in time series angular velocities when comparing the fastest and slowest fastball. These time series differences provide additional information to distinguish fastball velocity beyond what discrete metrics can provide. Pitchers should look to rotate each segment faster, and optimize the sequencing of these movements, to increase pitch velocity.

1. Introduction

In baseball pitching, higher fastball velocity is often associated with higher performance both duringgames and throughout a season.[1] To optimize ball velocity, a pitcher must execute rotational and linear movements in a way that allows for the fastest movement of the hand, which is the most distal aspect of the kinetic chain. This concept of the summation of velocities, known as the kinematic sequence, involves the peaking of segmental angular velocities from the most proximal to the most distal.[2,3] While optimizing the kinematic sequence, or the order of the peak angular velocities, has been shown to reduce the risk of injury,[4,5] limited research is available on the impact optimal kinematic sequencing has on fastball velocity.

Although limited research is available on the relationship between the kinematic sequence and baseball performance, previous studies have shown that, when investigated individually, the peak values of trunk, pelvis, shoulder, and elbow angular velocities impact fastball velocity. For example, Stodden and colleagues found that increased trunk rotational velocity resulted in increased pitch velocity within the same pitcher.[6] Further, when studying high school baseball pitchers, both Bullock and Orishimo found that peak trunk angular velocity was related to pitch velocity.[7,8] The relationship between peak trunk angular velocity and pitch velocity remained consistent in professional pitchers as well, where Luera and colleagues found that pitchers in a high velocity group had significantly higher peak trunk angular velocities when compared to pitchers in a low velocity group.[9] Similarly, Mine and colleagues' systematic review indicated that faster pelvis rotation resulted in faster ball velocity.[10] Increased shoulder and elbow angular velocities among pitchers have also been linked to higher pitch velocity.[11] Additionally, the timing of peak angular velocity achieved by the trunk and pelvis may impact pitch velocity, as longer durations between these peaks have resulted in increased fastball velocity.[12–14]

While research suggests pitchers who have greater peak segmental

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Abbreviations

SPM	Statistical Parametric Mapping
NCAA	National Collegiate Athletics Association
SFC	Stride Foot Contact
BR	Ball Release
m	Meters
s	seconds
$m \cdot s^{-1}$:	Meters per second
mph	Miles per hour
Kg	Kilograms
Hz	Hertz

rotational velocities also throw with greater ball velocity, to our knowledge, investigations into the time series of the angular velocities of the pelvis, trunk, shoulder, and elbow influence on pitch velocity have yet to be explored. Conducting a time series analysis of the angular velocities could prove to be beneficial, as there may be time points during the pitch that influence pitch velocity that are beyond the scope of the traditional discrete metric analysis. Therefore, the primary aim of this paper is to examine the within-pitcher differences in angular velocity of the pelvis, trunk, shoulder, and elbow between the time series data of a pitcher's fastest and slowest velocity in-game fastballs. We hypothesize faster angular velocities of the pelvis, trunk, shoulder, and elbow will predict greater fastball velocity, with significant differences occurring near and encompassing, the peak angular velocity for each tested segment or joint. A secondary, exploratory aim was to investigate the temporal overlap during which multiple segments or joints show significant angular velocity differences between the fastest and slowest fastballs. We anticipate finding moments where multiple tested segments or joints show significant differences in angular velocity between high and low velocity fastballs simultaneously throughout the pitch cycle. This could suggest an optimal sequence for increasing fastball velocity, similar to what has been reported in the kinematic sequence.

2. Methods

2.1. Ethical approval statement

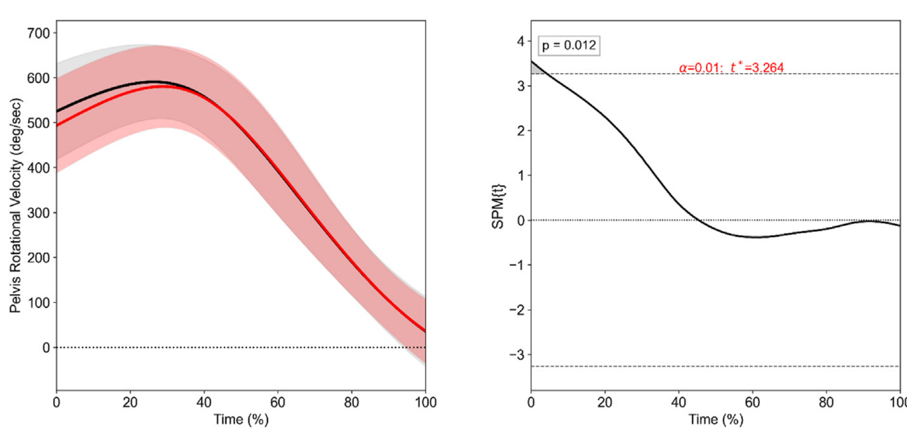
The retrospective analysis of previously collected baseball pitching data was approved by both the Auburn University Institutional Review Board (protocol 23–218 EX2304) and the University of Arkansas Institutional Review Board (protocol 2,102,318,176), both under exempt status. Obtaining informed consent was exempt by both Instituational Review Boards. This study was implemented in accordance with the Declaration of Helsinki.

2.2. Participants

In-game kinematic data from 82 National Collegiate Athletics Association (NCAA) Division 1 baseball pitchers ([1.89 ± 0.06] m, [92.8 ± 9.5] kg) were retrospectively analyzed. Pitchers were included if they had thrown at least 2 pitches considered fastballs during a competitive, sanctioned game. Pitchers who displayed a sidearm pitching style were excluded from the analysis, as they have demonstrated altered kinematics from the traditional overhand pitch.[15] Data from each pitcher's single fastest pitch velocity and single slowest pitch velocity fastball were used for a within-subject comparison. Single pitches were used to not distort the interpolated time series data by averaging inferred data from multiple pitches.[16]

2.3. Data collection

Pitching biomechanics data were collected using a permanently mounted, eight-camera markerless motion capture systems (KinaTrax Inc., Boca Raton, FL, USA) installed in separate baseball stadiums of two Southeastern Conference universities. Data collection and processing steps followed a format previously published[17] and are described herein. Cameras were digitally calibrated prior to each collection through still images and adjusting the video positioning to be consistent with the framing from the installation date. To account for any camera drift that occurred during a game, this same procedure was also performed multiple times throughout each game. All cameras were capturing raw video in full resolution at 300 Hz. Position data were then derived from the raw



Note: deg/sec = degrees per second; SPM(t) = Statistical Parametric Mapping test statistic value; % = percentage of pitch cycle; t* = critical t value; α = alpha level required for significance.

Fig. 1. Pelvis rotation velocity SPM results.
Note: deg/sec = degrees per second; SPM(t) = Statistical Parametric Mapping test statistic value; % = percentage of pitch cycle; t^* = critical t value; α = alpha level required for significance.

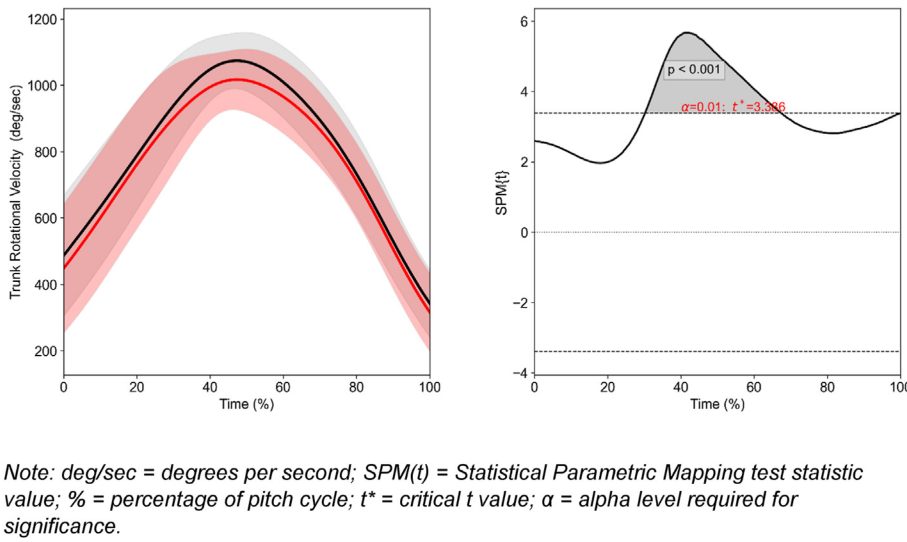


Fig. 2. Trunk rotation velocity SPM results.
Note: deg/sec = degrees per second; SPM(t) = Statistical Parametric Mapping test statistic value; % = percentage of pitch cycle; t^* = critical t value; α = alpha level required for significance.

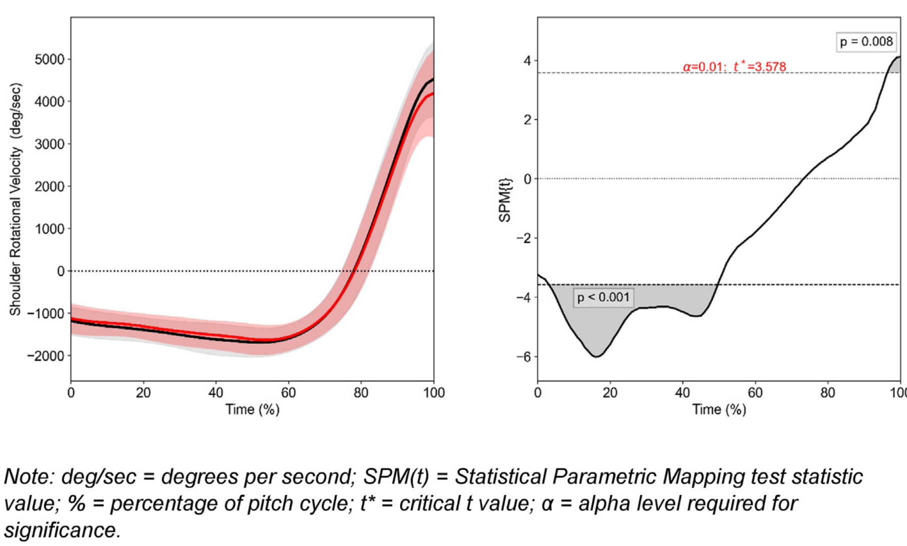


Fig. 3. Shoulder rotational velocity SPM results.
Note: deg/sec = degrees per second; SPM(t) = Statistical Parametric Mapping test statistic value; % = percentage of pitch cycle; t^* = critical t value; α = alpha level required for significance.

video using customized deep learning algorithms that are proprietary to KinaTrax. Kinematics and temporal events were calculated by KinaTrax using proprietary definitions through Visual3D (C-Motion Inc., Gaithersberg, MD, USA) software. The variables of interest (time series angular velocities of the pelvis, trunk, shoulder, and elbow) were extracted during the pitch cycle, from stride foot contact (SFC) to ball release (BR) from the processed data provided by KinaTrax. KinaTrax defines SFC as the first frame in which the lead foot contacts the ground, while BR is defined as 0.01 second (s) following the maximum anterior velocity of the most distal aspect of the pitching hand. Pitch velocity was recorded using a TrackMan V3 Stadium unit (TrackMan, Scottsdale, AZ) and calculated at the time of release. Pitch types were classified using the automatic pitch type classifier within the TrackMan software, and pitches used in this analysis were only considered if the pitch type was a four-seam or two-seam fastball. Customized Python (Python Software Foundation. Python Language Reference, version 3.12.3) scripts were used to synchronize the ball metric and kinematic data.

2.4. Statistical analysis

Time series angular velocity data of the pelvis, trunk, shoulder, and elbow from SFC to BR were normalized to 101 data points for analysis.[15] Four Statistical Parametric Mapping (SPM) paired samples t-tests were conducted to determine if and when there were differences between each pitcher's fastest and slowest fastballs for each variable of interest. Using a Sadik α adjustment to control for multiple comparisons, alpha levels for each test were set at 0.012 5.

3. Results

Mean fastball velocity for pitchers' fastest fastballs was (41.4 ± 1.4) m·s^{-1} ([92.6 ± 3.1] mph), while the mean fastball velocity of pitchers' slowest fastballs was (39.3 ± 1.2) m·s^{-1} ([87.9 ± 2.9] mph). The four tested angular velocity time series showed statistically significant differences between the fastest and slowest fastballs. Figs. 1–4 display time

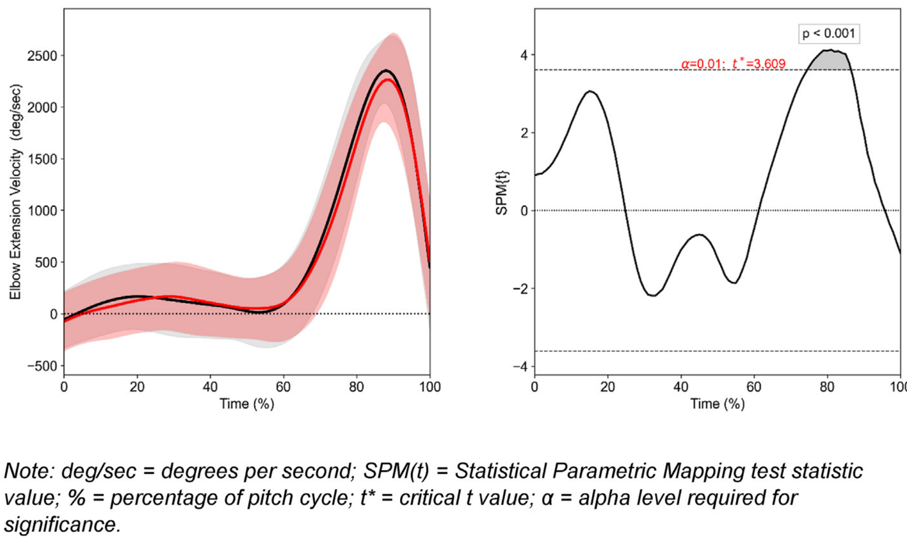


Fig. 4. Elbow extension velocity SPM results.
Note: deg/sec = degrees per second; SPM(t) = Statistical Parametric Mapping test statistic value; % = percentage of pitch cycle; t^* = critical t value; α = alpha level required for significance.

Table 1
Timepoints of significant differences between fastball groupings for tested segments.

Variable (°/s)	Significant Timepoint (% of Pitch Cycle)
Pelvis Rotational Velocity	0%–4%
Trunk Rotational Velocity	30%–67%
Shoulder External Rotational Velocity	3%–50%
Shoulder Internal Rotational Velocity	96%–100%
Elbow Extension Velocity	75%–86%

Note:; % of Pitch Cycle: percentage of time from Stride Foot Contact to Ball Release when the significant differences occurred.

series graphs of means (solid line) and standard deviations (shaded area) of fastest (black) and slowest (red) fastballs for the specified variable on the left and the time series test statistic continuum on the right. For the time series test statistic continuum, the dashed horizontal lines demonstrate the bi-directional critical test statistic, and shaded areas represent timepoints of significance on the right. For each test, the maximum or minimum value of the test statistic, dependent upon directionality of significance, is noted within the text, using the verbiage “maximum t” and “minimum t”. Full time-series test statistic results are depicted in Figs. 1–4.

The pelvis rotational velocity (Fig. 1) was significantly different from 0% of the pitch to 4% of the pitch (maximum $t = 3.54$, minimum $p = 0.012$). The trunk rotational velocity (Fig. 2) was significantly different between the groups, from 30% of the pitch to 67% of the pitch cycle (maximum $t = 5.62$, minimum $p < 0.001$). The shoulder rotational velocity (Fig. 3) was significantly different for external rotation from 3% of the pitch to 50% of the pitch (minimum $t = -6.03$, minimum $p < 0.001$), and for internal rotation from 96% of the pitch to 100% of the pitch cycle (maximum $t = 4.11$, minimum $p = 0.008$). The elbow extension velocity (Fig. 4) was significantly different from 75% of the pitch to 86% of the pitch cycle (maximum $t = 4.13$, minimum $p < 0.001$).

4. Discussion

This study aimed to identify angular velocity differences between a pitcher's fastest and slowest in-game fastball. It was hypothesized that the fastest fastballs would result in higher angular velocities across all measured variables. The results of the SPM analysis supported this hypothesis, showing that the pelvis, trunk, shoulder, and elbow all demonstrated increased angular velocities at some point during the pitch cycle (SFC to BR). These findings align with existing literature that supports a positive relationship between peak angular velocity of each tested segment or joint and fastball velocity.[6,10,11] This study represents the first known use of SPM in this type of investigation. The analysis revealed differences in angular velocity between high and low velocity fastballs throughout the pitching motion, not just at the peak velocity.

A secondary, exploratory aim of the manuscript was to investigate the temporal overlap between the significant timepoints of the segments. This was in an attempt to identify when multiple segments might contribute to pitch velocity, further exemplifying an idealized movement pattern for performance. Table 1 summarizes the timepoints of significant differences between the fastball groupings for each variable.

Our findings show notable variations in fastball speed and timing of peak values for various pitching variables. This aligns with existing research suggesting an effective kinematic sequence optimizes the baseball pitching delivery. However, our study also highlights a key distinction: the optimal sequencing of shoulder and elbow angular velocities may vary, as evidenced by the differing timing of significant events in our results. The traditional kinematic sequence suggests that a proximal to distal approach of the summation of velocities would optimize performance, in which the order of peaks would be pelvis rotation velocity, trunk rotation velocity, shoulder internal rotation velocity, and finishing with elbow extension velocity, to achieve the greatest resultant velocity of the hand at ball release.[3,18] Contrary to the sequencing identified in the traditional kinematic sequence, we found the elbow extension velocity peaked prior to the peak of shoulder internal rotation velocity, along with the timepoint of significance being earlier for the elbow extension velocity compared to shoulder internal rotation velocity. We theorize that the earlier elbow extension velocity's purpose is to lengthen the throwing arm and decrease the moment of inertia for the glenohumeral joint to internally rotate around [19] prior to BR, thereby increasing the linear translation velocity of the throwing hand. This suggests that pitchers may use developed movement strategies that slightly deviate from the traditional proximal to distal theory of the kinematic sequence to produce higher velocity in their fastball pitches. For athletes who are trying to increase their fastball velocity by means of increasing elbow extension velocity and creating a better sequencing pattern, research by Fleisig and colleagues suggests throwing underweighted balls (4 ounces) increases the angular velocity of the elbow, along with increasing ball velocity.[20]

A notable discovery from our time series data in the SPM analysis is

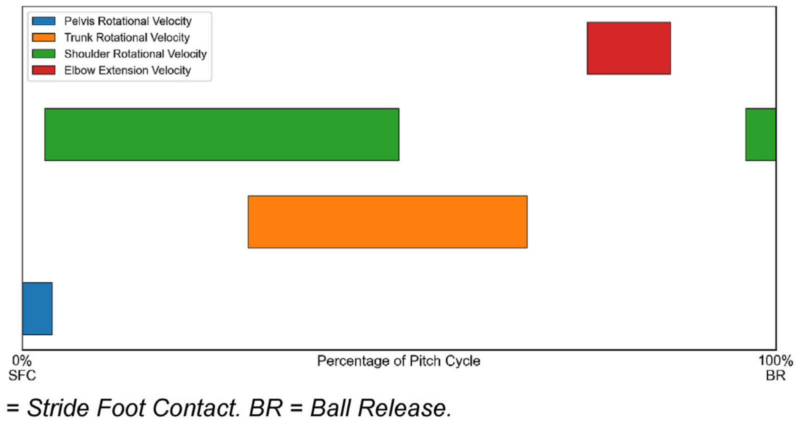


Fig. 5. Significant time periods of each angular velocity throughout the pitch cycle.
Note: SFC = Stride Foot Contact. BR = Ball Release.

the identification of the initial significant timepoint of the shoulder rotation velocity. This occurs from 0% of the pitch cycle to 51% of the pitch cycle while the shoulder is externally rotating. Notably, the fastest fastball group demonstrates a higher rate of external rotation during this time period. Notably, there is a corresponding overlap in significant timepoints between the trunk and shoulder. This overlap occurs during 23% of the pitch cycle (from 28% to 51%) where both shoulder external rotation velocity and trunk rotation velocity significantly differ between the fastest and slowest fastball groupings, as seen in Fig. 5. The authors theorize that the significance seen in external rotation is passive in nature, presumably due to the inertia of the baseball in the hand and the trunk rotating away from the throwing arm at a faster pace during the faster pitches. The alignment of significant timepoints between an active movement by the trunk and a passive action of the shoulder suggests that maximizing trunk rotation velocity is crucial in enhancing fastball velocity for collegiate baseball pitchers.

Due to pelvis rotation velocity having significant differences at 0% of the pitch cycle (at SFC), a follow up analysis was performed to investigate prior to our defined pitch cycle. This follow up investigation included the same SPM paired samples *t*-test but was performed with the time series being the 101 data point from 50 frames prior to SFC to 50 frames after SFC. This resulted in a significant difference between groups from 31% to 52% of that timeframe, suggesting the pelvis contributes to the difference in pitch velocity prior to SFC.

Similarly, shoulder rotational velocity had significance at 100% of the pitch cycle (at BR). Thus, a follow up analysis with the time series adjusted to 50 frames before and after BR was performed. The results of the follow up analysis indicated that there are significant differences in shoulder rotational velocity from 48% to 52% of the timeframe centered around BR, suggesting that part of the deceleration phase also sees the shoulder moving faster.

The current study presents evidence that during college baseball pitchers' fastest fastball thrown in a game, they display increased angular velocities at the pelvis, trunk, shoulder, and elbow compared to their slowest in-game fastball. Clinically, the current study points to the need for training athletes to rotate faster and sequence in optimal patterns. Often times, these trainings use a combination of generalized drills, such as rotational medicine ball throws, and sport-specific training modalities, such as throwing overweight and underweight baseballs during practice. The authors suggest that, under guidance from trained professionals, baseball pitchers focus their training on increasing the angular velocities and optimizing the sequencing of the pelvis, trunk, shoulder and elbow.

4.1. Limitations

While the current study puts a revitalized spin on the study of the effect, the kinematic sequence and rotational velocities have on fastball velocity by using full time series data and SPM, the current study does not come without the inclusion of limitations. The first limitation is using a singular fastest and slowest pitch for each participant for comparison, as opposed to the traditional practice of averaging multiple trials for each participant. This was a deliberate choice since prior research suggests that the averaging of previously interpolated time series data creates distortion nearing the peaks,[16] which was where we expected and observed significant differences. This also introduces a limitation of the pitch counts of pitchers and how fatigue may influence pitch velocity. Research suggests a negative relationship between fatigue and pitch velocity[21]; however, the relationship between fatigue and angular velocities of the pelvis, trunk, shoulder, and elbow have not been investigated in college pitchers. Due to these limitations, future works may use alternative methodology, such as a mixed model study, to negate using a single pitch per pitcher per group, along with identifying the influence of pitch count on angular velocities in college baseball pitchers.

Additionally, while all pitchers were on a roster in the highest division of intercollegiate baseball (NCAA Division 1), a wide discrepancy in pitch velocities was observed. This is exemplified by the between-subjects' range of fastball pitch velocity being 22.4 mph (maximum pitch velocity of fastest group was 99.2; minimum pitch velocity of slowest group was 77.4). While prior work has described differences in biomechanics between competition levels, to the authors' knowledge, no study has looked at biomechanical differences between conferences within NCAA Division 1 baseball. Because of this, only a within-subjects' analysis was performed, allowing each pitcher to be compared to themselves. Future work should be conducted on differences within the same level of competition to identify a potential cause of the large discrepancy in pitch velocity between subjects.

5. Conclusion

The current study aimed to identify the differences in time series angular velocities of the pelvis, trunk, shoulder, and elbow between a college baseball pitcher's fastest and slowest in-game fastball with available data. Results indicated that the angular velocities of all four variables were significantly higher in the fastest pitches when compared to the slowest pitches throughout various stages of the pitch cycle (SFC to BR), suggesting a positive relationship between angular velocity and pitch velocity. Additionally, we identified a sequence in which each variable showed significant differences between pitch groupings, resembling the kinematic sequence, with a notable difference being elbow extension velocity significance occurring prior to shoulder internal rotation velocity significance. There was also evidence of overlap between different segments at various time points, suggesting the involvement of multiple simultaneous factors. For pitchers seeking guidance on increasing their pitch velocity, or improving their velocity consistency, it is recommended to focus on moving faster through each segment/joint in a pattern from proximal to distal. This approach aims to maximize hand speed, ultimately leading to improved pitching outcomes.

Ethical approval statement

The retrospective analysis of previously collected baseball pitching data was approved by both the Auburn University Institutional Review Board (protocol 23–218 EX2304) and the University of Arkansas Institutional Review Board (protocol 2,102,318,176), both under exempt status. Obtaining informed consent was exempted by both Institutional Review Boards. This study was implemented in accordance with the Declaration of Helsinki.

Conflict of interest

All authors delclare that they have no known personal or financial conflicts of interest that could have influenced the reported work of the current study.

CRediT authorship contribution statement

Adam Nebel: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Abigail Schmitt:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Kevin Giordano:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Gretchen Oliver:** Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors of the submission WITHIN-SUBJECT TIME SERIES ANGULAR VELOCITY DIFFERENCES BETWEEN HIGH AND LOW VELOCITY FASTBALLS IN COLLEGE BASEBALL PITCHERS report no conflicts of interest.

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