Comparison of Elbow Flexion in Youth Baseball Pitchers With and Without Throwing-Arm Pain

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Background: More than half of all youth baseball pitchers report throwing-related pain in their throwing arm throughout a season.

Purpose/Hypothesis: The purpose of this study was to investigate differences in elbow flexion throughout the pitching cycle between youth baseball pitchers with and without throwing-arm pain. It was hypothesized that pitchers with throwing-arm pain would have decreased elbow flexion throughout the pitching cycle compared with those who were pain-free.

Study Design: Controlled laboratory study.

Methods: A total of 38 youth baseball pitchers (mean age, 13.3 ± 1.7 years; height, 164.4 ± 12.9 cm; weight, 57.1 ± 14 kg) were retrospectively selected from a database. Based on responses to a health history questionnaire, the pitchers were placed into a pain group if they indicated they were experiencing throwing-arm pain. Pitchers who indicated they were not experiencing throwing-arm pain were matched according to age, height, and weight to the pain group. All pitchers threw 3 fastballs to a catcher at the regulation distance. The mean elbow flexion of the 3 trials was used during analysis to investigate peak elbow flexion and time-normalized (0%-100%) elbow flexion across the pitch cycle (stride-foot contact to ball release). Elbow flexion was compared between the pain and pain-free groups using 1-dimensional statistical nonparametric mapping, and the mean peak elbow flexion between groups was compared using the Mann-Whitney *U* test.

Results: No significant differences were observed between the groups in elbow flexion throughout the pitching cycle ($P > .05$) and no group differences in peak elbow flexion ($U = 122$; $P = .09$).

Conclusion: Study findings indicated no significant differences in elbow flexion between youth baseball pitchers with versus without throwing-arm pain, unlike previous research reporting that pitchers with a history of medial elbow pain had altered elbow flexion and higher pitch velocities compared with those without a history of pain.

Clinical Relevance: Clinicians should consider other potential factors related to throwing-arm pain beyond elbow flexion. Moreover, it is advisable to focus on evidence-based modifiable factors shown to increase the risk of pain and injury in youth pitchers, such as exceeding pitch counts, number of innings pitched, increased training time, range-of-motion, and strength deficits.

Keywords: biomechanics; injury prevention; statistical parametric mapping

Throwing-associated pain in youth baseball is well-documented.[14,22,23] In a sample of 203 players aged between 8 and 18 years, 74% reported experiencing arm pain while throwing, which limited their ability to throw hard and led to self-reported changes in their throwing mechanics.[15] Existing research recognizes the critical role played by pitch types and counts, player characteristics, satisfaction with performance, years of experience, and fatigue in experiencing arm pain when throwing.[13,14,16] While previous work has reported the effects of a history of throwing-arm pain on pitching mechanics,[10] those findings are difficult to extrapolate to baseball pitchers actively in pain. Additionally, few studies have investigated upper-extremity mechanics associated with current throwing-arm pain in youth baseball pitchers.[4,13,14] With the widespread occurrence of throwing-arm pain among youth baseball pitchers, where a notable 46% were advised to persist in playing despite experiencing discomfort,[15] it is

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imperative to investigate whether pitchers currently experiencing pain are altering their mechanics compared with those who are pain-free.

Research suggests that shoulder kinetics, along with elbow and trunk kinematics, may be related to throwing-arm pain in youth baseball pitchers.[7,10,12,18] Specifically, an increase in the longitudinal shoulder force exerted on the humerus (commonly referred to as shoulder proximal force or shoulder distraction force) has been associated with throwing-arm pain in youth baseball pitchers.[12,18] Moreover, there are observable differences in elbow flexion at maximum shoulder external rotation, peak trunk rotation velocity, and peak pelvis rotation velocity between pitchers who have experienced medial elbow pain and those who have not.[10] Previous findings—including trunk lateral tilt and throwing-arm pain in youth baseball pitchers—are inconclusive.[7,10] While trunk lateral tilt at ball release significantly differed between those with and without a history of medial elbow pain,[9] no differences were found between pitchers who were currently experiencing throwing-arm pain compared with those who were not.[7] The limited and conflicting findings regarding baseball pitching biomechanics and pain highlight the need for further study.

Considering the well-established relationship between shoulder kinetics and throwing-arm pain in youth baseball pitchers,[18] it would be prudent to examine the kinematics associated with increased shoulder kinetics to gain insight into potential movement strategies that may contribute to throwing-arm pain in youth baseball pitchers. Previous research has identified several kinematic factors that influence shoulder distraction force, with elbow flexion being identified as a significant contributor at multiple time points in the pitching cycle.[24,25] Specifically, an extended elbow at stride-foot contact, peak elbow valgus torque, and ball release resulted in increased shoulder distraction force,[24] while a more flexed elbow at maximum shoulder external rotation also increased shoulder distraction force.[24,25] Because of the aforementioned relationship between elbow flexion at numerable events during the pitching cycle and shoulder distraction force, as well as the established association between shoulder distraction force and pitchers experiencing throwing-arm pain, it is postulated that pitchers with pain may alter their elbow flexion as a means of compensation.

This study aimed to examine elbow flexion throughout the pitching cycle (stride-foot contact to ball release) between youth baseball pitchers who were actively experiencing throwing-arm pain and those who were pain free. It was hypothesized that pitchers experiencing throwing-arm pain would have decreased elbow flexion equating to a more extended elbow throughout the pitching cycle compared with those who were pain-free.

METHODS

After receiving institutional review board approval for the study protocol, 38 youth baseball pitchers (mean age, 13.3 ± 1.7 years; height, 164.4 ± 12.9 cm; weight, 57.1 ± 14 kg) were retrospectively selected from a database. All participants were considered youth baseball players (age range, 12-17 years), injury/surgery-free for the past 6 months, and active as pitchers on the team roster at the time of data collection. Participants completed a health history questionnaire upon arrival at the testing site, where they responded to the question, "Do you currently experience pain/discomfort?" If the participant answered "yes," they were then asked the following follow-up questions: "What is the location of your pain?" and "When do you currently experience pain?" Participants who selected "yes" to experiencing pain/discomfort, responded with a location of pain pertaining to the throwing-arm and indicated an onset of pain related to throwing were included in the pain group (n = 19; mean age, 13.3 ± 1.7 years; height, 164.9 ± 12.5 cm; weight, 56.7 ± 14 kg). After the pain group was established, participants in the database who indicated they were pain-free were matched to participants in the pain group based on age, height, and mass (n = 19; mean age, 13.2 ± 1.7 years; height, 163.9 ± 13.5 cm; weight, 57.4 ± 13.5 kg).

Kinematic data were collected using an electromagnetic tracking system (trakSTAR; Ascension Technologies) synchronized with biomechanical analysis software (TheMotionMonitor *xGen*; Innovative Sports Training). Fourteen electromagnetic sensors were applied using double-sided tape and secured with cohesive bandaging at anatomic locations consistent with previous research.[3,6,20] Position and orientation data for each of the 14 electromagnetic sensors were sampled at 100 Hz and independently filtered using a fourth-order, low-pass Butterworth filter with a cutoff frequency of 13.4 Hz.[3] Previous research has found that the sampling rate used for the given system is reliable for elbow kinematics in the baseball pitch.[11]

Before sensor attachment, participants were afforded the opportunity to complete a self-selected, nonthrowing warmup routine. After sensor attachment, participants were given an unlimited amount of time to do a preferred throwing warmup routine. Upon completion of the warmup, participants were instructed to throw fastballs to a catcher from a regulation distance, based on age and current competition level (11-12 years: 15.24 m; 13-14 years: 16.46 m; 14-18 years: 18.44 m; pitchers who were 14 years old pitched from the distance that corresponds with the distance they pitched in a game, which differs depending on the league). Participants pitched off a constructed mound outfitted with an embedded force plate (Bertec) and landed with their stride foot atop a second force plate embedded with the floor

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Ethical approval for this study was obtained from Auburn University (reference No. 18-121 EP 1803).

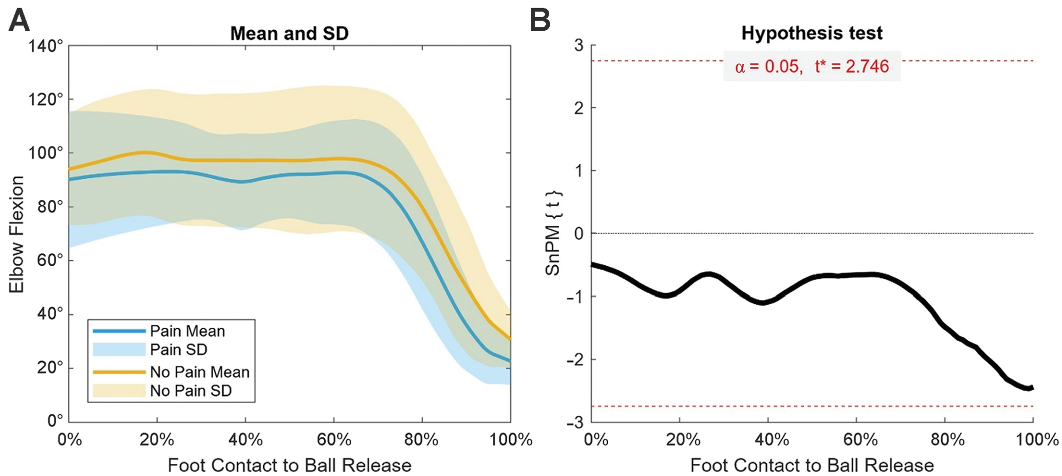

Figure 1. (A) Group means (±1 SD, indicated by shaded areas) for elbow flexion from stride-foot contact (0%) to ball release (100%); 180° represents a fully flexed elbow and 0° represents a fully extended elbow. (B) Bidirectional test statistic continuum comparing the pain and pain-free groups. The red dashed lines indicate the test statistic critical threshold. SnPM{t}, statistical nonparametric mapping *t* test .

platform (Bertec). Each force plate collected ground-reaction force data at 1200 Hz. Three fastballs deemed in the strike zone were recorded and used for analysis.

Euler angle decomposition sequences at the elbow were defined according to the International Society of Biomechanics recommendations to describe the position of the forearm relative to the upper arm in the *Z-X-Y* Euler rotation sequence. The movement about the *Z*-axis (mediolateral) represented elbow joint flexion-extension angle.[26] Full elbow extension was represented as 0° and full elbow flexion was 180°. Time series data of elbow flexion were extracted and normalized from 0% (stride-foot contact) to 100% (ball release). The stride-foot contact was defined as the first frame where the lead foot contacted the ground, resulting in a vertical ground-reaction force of >5 N. Ball release was defined as the frame of peak angular hand velocity. Data between stride-foot contact and ball release were interpolated to 101 data points (0%-100%) and were statistically analyzed using a customized MATLAB script (Version 2022a; The MathWorks).

Time-normalized, throwing-arm elbow flexion was compared between groups (pain/no-pain) using a 1-dimensional, independent-sample statistical nonparametric mapping (SnPM) *t* test. To use the mean elbow flexion from a participant's 3 trials used in the SnPM, maximum elbow flexion (maximum values represent greater elbow flexion) was extracted for each participant's trials and averaged for comparison between groups. This was an additional measure taken to corroborate findings from this study regardless of processing methodology.[5] A nonparametric Mann-Whitney *U* test was performed to compare mean peak elbow flexion values between groups. The SnPM testing was used to determine whether elbow flexion differed at any point throughout the pitching cycle between the pain and pain-free groups. The Mann-Whitney *U* test was used to determine whether peak elbow flexion differences existed between groups. Nonparametric

TABLE 1
Locations of Pain for the Pain Group (n = 19 Pitchers)[a]

Pain Location	N (%)
Elbow	15 (78)
Shoulder/upper arm	7 (37)
Forearm/hand	3 (16)

[a]Some pitchers reported multiple pain locations.

testing was performed because of the limited sample size (n < 20 per group) and limits in normality checking of time series data although single trial and averaged trial data were visually inspected across the pitching cycle to ensure appropriateness of the data. All statistical testing was conducted with an α level set a priori to .05.

RESULTS

Locations of reported pain for the pain group are described in Table 1. Pitch velocities for the pain and pain-free groups were 25.7 ± 4.2 m/s (57.7 ± 9.5 mph) and 24.8 ± 4 m/s (55.5 ± 8.9 mph), respectively (U = 158; P = .522). The median peak elbow flexion was 102° (95% CI, 96.9°-113°) for the pain group and 116° (95% CI, 101°-122°) for the pain-free group. The SnPM revealed no significant differences between groups in elbow flexion throughout the pitching cycle (Figure 1). The Mann-Whitney *U* test also revealed no significant differences in mean peak elbow flexion between groups (U = 122; P = .09).

DISCUSSION

Our hypothesis that elbow flexion would be decreased (more extended) in the pain group was not supported, as no significant group differences were found across the pitching cycle. Because of the potential consequences of pitching with pain, investigators also compared the mean peak elbow flexion between groups. This was a conscientious measure based on the work of Dames et al[5] who reported significantly smaller values in peaks from averaged waveform data than peaks from multiple trials that were averaged. The averaged peak values of elbow flexion also resulted in no significant differences between groups.

The results of the present study differ from those of Huang et al,[10] who found that youth baseball pitchers with a history of medial elbow pain had less elbow flexion (a more extended elbow) at maximum shoulder external rotation compared with their pain-free peers. The discrepancy in the findings of the present study may be attributed to examining elbow flexion across the entire pitching cycle rather than at specific events during the pitch. Further, the impact of pitch velocity, multiple versus singular throwing-arm pain locations, and timeline of pain status (history vs current pain) could help explain the differences between these 2 studies.

We found no difference in pitch velocity between groups, while Huang et al[10] indicated pain history may be influenced by pitch velocity because of the significantly faster pitch velocity observed in the history of the pain group. Although pitch velocity is consistently associated with injury risk across all skill levels, restricting pitch velocity is not a practical solution, as it is counterintuitive to pitching performance. In addition, elbow flexion at maximum shoulder external rotation is suggested to influence pitch velocity for nonelite pitchers.[19] Considering the known influence of elbow flexion at maximum shoulder external rotation on pitch velocity, it remains unclear whether the combined effect of these 2 measures influenced the significant findings observed by Huang et al.[10] Therefore, the results of previous literature should be interpreted with caution, as it may be difficult to distinguish whether pain history is influenced by elbow flexion at maximum shoulder external rotation when accounting for pitch velocity or if pain may be more commonly associated with an increased pitch velocity.

The pain locations identified in the present study were joints and/or segments of the throwing arm. A similar study examined youth baseball pitchers with various pain locations in their throwing arm and found no differences in the more proximal segments (trunk and pelvis) kinematics.[7] Thus, an investigation into throwing-arm kinematics using a similar cohort was a necessary step in identifying potential kinematics related to throwing-arm pain in youth baseball pitchers. As previous work has shown that a more extended elbow is associated with greater shoulder distraction force and elbow valgus moment,[1,17,21,25] the observably more extended elbow seen in the present study could be a factor in the pitcher's throwing-arm kinetics, which may be, in turn, related to their throwing-arm pain. The results of the present study may be helpful to direct future investigations of throwing-arm pain in youth baseball pitching to include throwing-arm kinetics and the other kinematics that are associated with increased kinetics.

Studies examining baseball pitching biomechanics and pain should consider the implications of the timing of pain onset. The retrospective nature of the present study, as well as the Huang et al[10] study, limits the ability to establish a clear connection between kinematics and the occurrence of upper extremity pain and injury.[21] To gain a better understanding of the kinematics associated with upper extremity pain while pitching, it would benefit future investigations to employ longitudinal tracking of biomechanics, which would enable evaluation of potential cause and effect relationships between biomechanical changes and a pitcher's health status. For example, Anz et al[2] prospectively examined a cohort of major league pitchers over 3 seasons and found that pitchers who experienced injuries had significantly greater shoulder external rotation torque and elbow valgus torque than those who remained injury free. Conducting prospective and longitudinal studies to identify the causal effect associated with the onset of pain along with the cessation of pain will assist in understanding why discrepancies between studies exist.

Future studies should also include additional throwing-arm kinematics and kinetics to assess their potential contributions to pain. Thus far, it is well-established that the kinetics of the shoulder and elbow play a significant role in influencing pain and injury[8]; therefore, it could prove useful to examine other joints and their impact on the kinetics at the shoulder and elbow. Although research involving the biomechanics of pain and injury in youth baseball is ever evolving, there are established recommendations for injury mitigation. It is recommended that pitchers closely monitor pitching loads, ensure adequate rest between pitching outings, and promptly seek medical treatment at the onset of pain to ensure their injury risk is limited.

Limitations

The limitations of the present study include its small sample size, the age of participants (youth), its cross-sectional nature with limited pitch volumes, the inability to control for outside pitching loads, and the individuality of pain. Statistical precautions (using nonparametric tests) were used as an attempt to negate the limited sample size in addition to comparison methodologies. With the commonality of pain in youth baseball pitching, the limitation of a cross-sectional study and limited numbers of pitches per pitcher is introduced. Moreover, the cross-sectional nature did not allow for control over additional pitch loads—that is, the number of pitches thrown during the season, consecutive days of throwing, etc. This should be mitigated in future research by longitudinally investigating pitching biomechanics throughout an entire season. Utilizing biomechanical pitching evaluations throughout a season, as done in previous studies with more advanced pitchers, may assist in identifying the associations between pitching mechanics and pain/injury that could potentially determine a causal effect that kinematic or kinetic changes have on pain and injury status.[2,21,24,25] This would also naturally allow for an increased number of pitches per athlete, leading to investigations of variability between pitches and pitch types. Because of the stated limitations, readers should use reasonable caution when drawing conclusions. These limitations would be best addressed in future research by including multiple age groups, increasing the overall sample size, and stratifying reported pain locations when possible.

CONCLUSION

The present study investigated whether elbow flexion during the baseball pitching cycle (stride-foot contact to ball release) differed based on current pain status. The findings revealed no differences in elbow flexion between pitchers experiencing throwing-arm pain and those who were pain free. These results, paired with results from previous research, suggest that the differentiation in elbow flexion observed in previous research could potentially be attributed to alterations in elbow flexion associated with the cessation of pain or altered mechanics associated with increased pitch velocity.

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