Comparison of Peak Shoulder Distraction Forces Between Pain and Pain-Free Youth Baseball Pitchers

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Background: Increased shoulder distraction force during a baseball pitch may make a pitcher susceptible to rotator cuff or glenohumeral labral injuries. A precursor to a pitching injury may be pain experienced in the throwing arm.

Purpose: To (1) compare peak shoulder distraction (PSD) forces in youth baseball pitchers with and without upper extremity pain when throwing a fastball and (2) assess if PSD forces across trials differ between pain and pain-free groups.

Study Design: Controlled laboratory study.

Methods: A total of 38 male baseball pitchers aged 11 to 18 years were separated into a pain-free group (n = 19; mean age, 13.2 ± 1.7 years; mean height, 163.9 ± 13.5 cm; mean weight, 57.4 ± 13.5 kg) and a pain group (n = 19; mean age, 13.3 ± 1.8 years; mean height, 164.9 ± 12.5 cm; mean weight, 56.7 ± 14.0 kg). Pitchers in the pain group indicated that they experienced pain in their upper extremity while throwing a baseball. Pitching mechanical data from 3 fastballs per pitcher were recorded with an electromagnetic tracking system and motion capture software. The mean PSD (mPSD) was calculated as the mean PSD of 3 pitches per pitcher, the trial with the highest recorded PSD was determined as the maximum-effort PSD (PSDmax), and the PSD range (rPSD) was defined as the difference of the PSD force of the trial with the highest PSD and the lowest PSD for each pitcher. The PSD force was normalized to the pitcher's body weight (%BW). Pitch velocity was also recorded.

Results: The mPSD force was 114%BW ± 36%BW for the pain group and 89%BW ± 21%BW for the pain-free group. Pitchers in the pain group exhibited a significantly higher PSDmax force ($t_{30.548} = 2.894$; $P = .007$) and mPSD force ($t_{29.231} = 2.709$; $P = .009$) compared with those in the pain-free group. There were no significant between-group differences in the rPSD force or pitch velocity.

Conclusion: The normalized PSDmax force was higher in pitchers who experienced pain while throwing fastballs compared with pitchers who were pain-free while throwing.

Clinical Relevance: Baseball pitchers who experience pain in their throwing arm are likely to have higher shoulder distraction forces. Improvement in pitching biomechanics and corrective exercises may assist in the mitigation of pain while pitching.

Keywords: baseball pitching; injury prevention; pain

Youth baseball is an increasingly popular sport, with >15 million athletes playing worldwide.[2,15,19,23] In parallel to its increase in participation, there is a growing number of reported upper extremity injuries. Despite attempts to prevent injuries through the adoption of safety guidelines, overuse injuries remain a concern for younger players.[20] Documented youth injury rates range between 1.26 and 4.0 injuries per 1000 athlete-exposures, with most injuries occurring in the shoulder and elbow in pitchers.[5,24,25] Recent reports in the sports literature have noted that youth athletes are less likely to seek medical treatment when soreness or fatigue in the throwing arm is present.[1,4,16] This characteristic is a concern, as research suggest that up to 50% of youth athletes experienced pain throughout their season,[16] thus heightening the need to identify unbiased biomechanical risk factors for an injury. There is also limited access to sports-related health care for youth athletes, so it is likely that injury rates are higher than presented.[4,7] The presence of symptoms, such as joint pain while throwing, should be used to inform early treatment plans, decrease the susceptibility to injuries, and mitigate the risk of joint degeneration.[4]

Youth baseball injuries associated with throwing commonly occur in the upper extremity. The most common

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throwing injuries sustained include strains to muscles and tendons as well as sprains to the ligaments involved in throwing.[9,10,23] Typical throwing-related shoulder injuries include labral abnormalities and rotator cuff strain, which have been theorized to stem from large external distraction forces at the glenohumeral joint during a pitch.[10] Although the theorized injury mechanism exists, research on shoulder distraction forces has mostly been restricted to performance (pitch velocity) and kinematic sequencing.[17,21] When discussing fastball velocity, greater shoulder distraction force typically results in a faster pitch velocity.[18] Experience level may also play a role in shoulder distraction forces related to velocity. Nicholson et al[21] found a significant positive correlation between shoulder distraction force and velocity in a group of high school pitchers, although the same correlation was not statistically significant in college players. Manzi et al[17] reported greater peak shoulder distraction (PSD) forces in pitchers whose pelvis reached maximum rotation velocity after maximum rotation velocity of the trunk compared with pitchers with a chronological peak sequencing order.

While a relationship between increased glenohumeral distraction force and the injury risk has been theorized, its effect on upper extremity pain and the risk of injuries remains unclear. Greater peak proximal shoulder force (described as force directed proximally along the longitudinal axis of the humerus; ie, internal compression force) during the acceleration phase (maximum external rotation to ball release) has been reported in pitchers with upper extremity pain compared with their pain-free counterparts.[14] Moreover, in softball, a single pitching study determined that those with upper extremity pain had higher shoulder distraction forces at ball release compared with those without pain.[22] The limited evidence surrounding mechanics that may contribute to the presence of pain in baseball pitching justifies the need for additional research in this area.

The purpose of this study was to investigate self-reported throwing arm pain and shoulder distraction forces in youth baseball pitchers. Specifically, this study examined differences in the mean, peak, and range of shoulder distraction forces between a group of pain-free pitchers and a group of pitchers who reported pain in their throwing arm. It was hypothesized that the pain group would have higher means, peaks, and ranges in shoulder distraction force.

METHODS

The protocol for this study received institutional review board approval. We retrospectively analyzed 38 male baseball pitchers from a pooled data base (mean age, 13.3 ± 1.7 years [range, 11-18 years]; mean height, 164.4 ± 12.9 cm; mean weight, 57.1 ± 14.0 kg) playing at levels from Little League to high school baseball to participate. Inclusion criteria for the participants were as follows: (1) active on a roster of a baseball team, (2) a primary or secondary pitcher position, (3) injury-free for the past 6 months, and (4) no surgical history over the past 6 months.

TABLE 1
Characteristics of Upper Extremity Pain for Pain Group (n = 19)[a]

	n (%)
Location of pain	
Elbow	15 (79)
Shoulder	5 (26)
Forearm/hand	3 (16)
Upper arm	2 (11)
Onset of pain	
Associated with use	13 (68)
After use	4 (21)
Unspecified	5 (26)

[a]Some pitchers reported multiple answers for location of pain and onset of pain.

Before testing, all procedures were thoroughly explained, and parental consent and participant assent were obtained. The athlete was then asked to complete a health history questionnaire at the time of data collection (data collection took place year-round). The questionnaire contained the following question: "Do you currently experience any pain/discomfort in your upper extremity, specifically your throwing side?" Grouping was based on a "yes/no" response to this question. Participants who selected "no" to this question were placed in the pain-free group (n = 19; mean age, 13.2 ± 1.7 years; mean height, 163.9 ± 13.5 cm; mean weight, 57.4 ± 13.5 kg). Participants who reported "yes" and selected any pain location on their upper extremity were placed in the pain group (n = 19; mean age, 13.3 ± 1.8 years; mean height, 164.9 ± 12.5 cm; mean weight, 56.7 ± 14.0 kg). Table 1 includes the descriptors of pain as answered on the health history questionnaire by participants in the pain group.

The participants then underwent isometric strength testing of internal and external rotation of their dominant shoulder. The testing protocol had the participant lying supine with his dominant arm abducted 90° at the shoulder and the elbow flexed to 90°, with the wrist perpendicular to the ground. Using a handheld dynamometer placed against the front of the wrist, the athlete was instructed to press into the dynamometer and hold pressure against it for a 3-second count so that force production was captured for

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

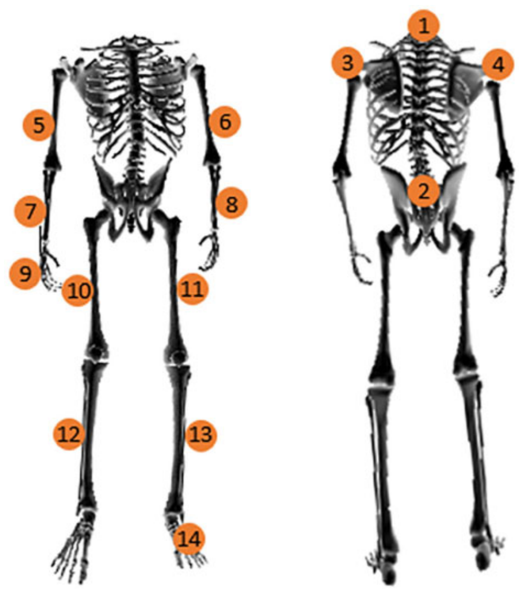

Figure 1. Sensor locations for right-handed pitchers. Left-handed pitchers had sensor 9 on their left hand and sensor 14 on their right foot.

internal rotation. The same protocol was used to capture force production for external rotation, except that the dynamometer was placed against the back of the wrist.

Kinematic data were collected using an electromagnetic tracking system (trakSTAR; Ascension Technologies), sampling at a minimum of 100 Hz, and synchronized with The MotionMonitor software (Innovative Sports Training). Data collection procedures and sensor placement were consistent with previous literature, which includes research evaluating shoulder kinematics and kinetics.[3,8,22] Sensor locations are shown in Figure 1. Sensor placement was as follows: bilateral sensors on the lateral aspect of the shank at the midpoint between the joint line of the knee and the lateral malleolus of the ankle, bilateral sensors on the lateral aspect of the thigh at the midpoint between the greater trochanter of the femur and the joint line of the knee, bilateral sensors on the lateral aspect of the distal third of the humerus, bilateral sensors on the lateral aspect of the distal third of the forearm, bilateral sensors on the superior-lateral aspect of the spine of the scapula, a single sensor on the spinous process of C7, a single sensor along the midline of the L5-S1 joint space, 1 sensor placed at the midpoint of the third metacarpal of the throwing hand, and 1 sensor placed at the midpoint of the second metatarsal of the stride foot (opposite of the throwing hand).[3,8,22]

After sensor attachment and digitization occurred, each participant was allotted unlimited time for a throwing warm-up and to become familiarized with the testing protocol. The testing protocol included capturing coordinate data on pitchers throwing 3 maximum-effort fastballs. All pitches were thrown from a pitching mound of synthetic turf, using a regulation-sized baseball, to a target set at a regulation distance based on age and current competitive throwing distance to home plate (15.24 m for 11-12 years, 16.46 m for 13-14 years, 18.44 m for 15-18 years). Only pitches that were in the strike zone were used for data analysis.

TABLE 2
Comparison of Variables of Interest Between Groups[a]

	Pain Group (n = 19)	Pain-Free Group (n = 19)	P
mPSD, %BW	114 ± 36	89 ± 21	**.009**
rPSD, %BW	24 ± 14	17 ± 13	.144
PSDmax, %BW	127 ± 38	98 ± 24	**.007**
Pitch velocity, m/s	25.8 ± 4.3	24.8 ± 4.0	.463

[a]Data are reported as mean ± SD. Boldface P values indicate a statistically significant difference between groups ($P < .05$). BW, body weight; mPSD, mean peak shoulder distraction; PSDmax, maximum-effort peak shoulder distraction; rPSD, peak shoulder distraction range.

The following PSD force variables were examined: the mean of a pitcher's PSD across the 3 recorded pitches (mPSD), the range of a pitcher's PSD (rPSD) across pitches (difference between the highest and lowest PSD), and the highest recorded PSD (PSDmax). Biomechanical data were collected and processed using The MotionMonitor software. All raw data were independently filtered with a fourth-order Butterworth filter at a cutoff frequency of 13.4 Hz.[8,22] PSD force was defined as the greatest longitudinal force directed down the axis of the humerus in the throwing arm after stride foot contact. Shoulder distraction forces were normalized to the pitcher's body weight (%BW), and PSD was identified using a time stamping method, which was then extracted for analysis.

Statistical analysis was performed using SPSS Statistics software (Version 28; IBM) with an alpha level set a priori to $P < .05$. Also, 2-tailed independent-samples t tests were performed to examine if mPSD, PSDmax, and rPSD forces were greater in the pain group than in the pain-free group. Simple-comparison parametric testing was used based on equal sample sizes and normal distributions (Shapiro-Wilk test: $P > .05$) for most variables, except for rPSD force for the pain group and in the combined cohort, which showed positive skewness based on visual inspection.

RESULTS

The comparison of the mPSD force, the rPSD force, the PSDmax force, and pitch velocity between the pain and pain-free groups is presented in Table 2.

mPSD Force

The homogeneity of variance was rejected based on the Levene test ($F = 9.868$; $P = .003$). An independent-samples t test revealed that the group that experienced pain had significantly higher mPSD forces than the group that was pain-free ($t_{29.231} = 2.709$; $P = .009$).

TABLE 3
Results by Pain Location for Pain Group (n = 19)[a]

	mPSD, %BW	rPSD, %BW	PSDmax, %BW
Shoulder (n = 5)	107 ± 26	29 ± 14	123 ± 31
Elbow (n = 15)	113 ± 36	24 ± 15	125 ± 38
Forearm/hand (n = 3)	118 ± 51	23 ± 10	130 ± 56
Upper arm (n = 2)	91 ± 27	26 ± 17	107 ± 39

[a]Data are reported as mean ± SD. mPSD, mean peak shoulder distraction; PSDmax, maximum-effort peak shoulder distraction; rPSD, peak shoulder distraction range.

rPSD Force

The homogeneity of variance was not rejected based on the Levene test ($F = 0.607$; $P = .441$). An independent-samples t test for rPSD force revealed no significant difference between the 2 groups ($t_{36} = 1.496$; $P = .144$).

PSDmax Force

The homogeneity of variance was rejected based on the Levene test ($F = 5.489$; $P = .025$). An independent-samples t test revealed that the group that experienced pain had significantly higher PSDmax forces than the group that was pain-free ($t_{30.548} = 2.894$; $P = .007$).

Pitch Velocity

Mean values of pitch velocity for the pain and pain-free groups were as follows: 25.8 ± 4.3 and 24.8 ± 4.0 m/s, respectively. The homogeneity of variance was maintained based on the Levene test ($F = 0.182$; $P = .672$). An independent-samples t test revealed that there was no difference in pitch velocity between the group that experienced pain and the group that was pain-free ($t_{36} = 2.894$; $P = .463$).

Pain Location

Participants in the pain group were subgrouped based on pain location. Descriptive statistics for each subgroup can be found in Table 3. Independent-samples t tests revealed no differences between the pain location subgroups in mPSD, rPSD, and PSDmax forces. However, the subgroup that experienced pain in the elbow displayed significantly greater mPSD forces ($t_{32} = 2.433$; $P = .020$) and PSDmax forces ($t_{32} = 2.529$; $P = .017$) compared with the pain-free group. Additionally, the shoulder pain subgroup displayed a trend towards significance of greater mPSD forces than their pain-free peers ($t_{22} = 1.895$, $P = .071$). Beyond the shoulder and elbow subgroups, no other subgroups reported significant differences or results that approached significance in any of the variables of interest to the pain-free group; however, the limited sample size in each subgroup exhibits the need for further investigation.

TABLE 4
Comparison of Isometric Strength Between Groups[a]

	Pain Group (n = 17)	Pain-Free Group (n = 15)	P
Raw ER, N	151.3 ± 53.4	135.4 ± 51.0	.398
Raw IR, N	160.4 ± 44.9	150.0 ± 52.9	.553
Normalized ER, %BW	26.8 ± 9.7	23.8 ± 8.7	.366
Normalized IR, %BW	28.8 ± 9.2	27.0 ± 12.4	.631

[a]Data are reported as mean ± SD. BW, body weight; ER, external rotation; IR, internal rotation.

Isometric Strength

Isometric strength values were recorded for 32 of the 38 participants (pain group: n = 17; pain-free group: n = 15). Table 4 presents the results of the between-group comparison of internal rotation and external rotation, both raw (force production in N) and normalized to body weight. There were no significant differences in isometric strength between the groups.

DISCUSSION

The purpose of this study was to examine shoulder distraction forces in competitively active youth baseball pitchers with and without pain. The hypothesis was partially supported, as pitchers who experienced upper extremity pain on the throwing side had significantly higher mPSD and PSDmax forces than pain-free pitchers. These findings corroborate previous research that found that self-reported pain in the throwing arm is associated with different pitching biomechanics compared with pain-free pitchers.[12,14] Keeley et al[14] identified that for every 1-N increase in peak proximally directed force (internal compressive force) in the shoulder during the acceleration phase, there was a 4.6% increase in the likelihood that a person would exhibit shoulder pain. While the results of Keeley et al are important in observing that forces applied to the upper extremity are altered when a pitcher is in pain, these findings were specifically looking at the acceleration phase. However, research suggests that shoulder distraction forces may peak after the acceleration phase.[10] The study specifically investigated PSD forces, which may occur during the deceleration phase. During the deceleration phase, the body is attempting to take all the force that was generated to accelerate the baseball and slow down the movement of the upper extremity.[10,11] This is, in part, achieved by the musculature attempting to stabilize the humeral head in the glenoid fossa to protect against injuries, specifically placing the rotator cuff musculature under an eccentric load to reduce translation that may be caused by distraction forces.[10] Electromyography studies have identified that those with anterior glenohumeral instability have an increase in the activation of the biceps brachii and the infraspinatus during the deceleration phase.[11] Previous research indicated that the increase in activity was to assist in stabilization because of the high levels of distraction forces during the deceleration phase of the pitch.[10,11] Because of the nature of cross-sectional studies, it cannot be concluded that greater shoulder distraction forces are a result of pain or the cause of pain. However, the current study provides sufficient evidence for further investigation into the cause and effect of shoulder distraction forces and pain in youth baseball pitchers.

The hypothesis that the rPSD force would be different in the pain-free group compared with the pain group was not supported. The thought behind the hypothesis was that the pain group would increase the variability of pitching biomechanics to attempt to compensate for pain. Previous research has shown that healthy pitchers have minimal variation in mechanics. Although further investigation is warranted, the current study shows that youth baseball pitchers experiencing pain also exhibited limited variation in kinetics. While the variation in movement needs to be further examined, the findings of this study suggest that pitchers with throwing arm pain experience greater stress on their shoulder with every fastball pitch rather than the occasional fastball pitch.

It was found that those who experienced pain did not differ in mPSD, rPSD, or PSDmax forces depending on the location of their upper extremity pain. However, the subgroup that experienced pain in the elbow did have significantly higher mPSD and PSDmax forces than the pain-free group. Previous research has identified that in youth baseball pitchers, as joint loads on the upper extremity increase, so does transfer across the shoulder and elbow. Therefore, pain experienced in the elbow may be associated with increased compensatory forces at the shoulder to maintain performance. Additionally, while not statistically significant, the subgroup that experienced pain in the shoulder did experience greater PSDmax forces, approaching statistical significance ($t_{22} = 1.895$; $P = .071$). The limited sample size in the shoulder subgroup ($n = 5$) may have contributed to the result approaching, but not reaching, significance. Further, the limited sample sizes in the forearm/hand and upper arm subgroups may have influenced the statistical analysis. Additional research is needed for these subgroups to determine if significance may be obtained with an increased sample size.

Numerable other factors, alongside the presence of pain, may influence the magnitude of PSD forces. Several kinematic and kinetic variables, along with pitch performance, have been associated with shoulder distraction forces.[18,21,26,27] Based on the influence that these variables have on shoulder distraction, and the relationship between pain and shoulder distraction forces found in the current study, it is suggested that improving mechanics may reduce PSD forces and the risk of pain or injuries to the shoulder.

The results of the current study showed no difference in velocity between the pain and pain-free groups but demonstrated a significant difference in mPSD and PSDmax forces. This is important, given that previous research has suggested that there is a positive relationship between shoulder distraction forces and pitch velocity.[18] These findings, which are contrary to those in the current literature, may suggest that pitchers who have pain in their throwing arm might be compensating for deficiencies elsewhere by increasing their shoulder distraction forces but not experiencing an increase in pitch velocity. These findings call for further investigation as to why kinetic values were greater in the pain group while the velocities were similar, as increased loads resulted in no measurable performance increase, and what other mechanical changes may be influencing this compensation pattern.

Additionally, the current study revealed no difference between the groups on isometric strength testing for shoulder internal and external rotation, both from raw strength (total force in N) and normalized strength (shown as %BW) perspectives. While isometric strength may be insignificant, the point at which PSD force of the pitching motion occurs is in line with when eccentric contraction of the infraspinatus occurs.[10,11] The insignificant results from isometric strength testing, paired with knowledge of eccentric load timing and PSD force timing, suggest that further research is needed on eccentric strength of the rotator cuff musculature.

Greater shoulder distraction forces may be associated with upper extremity pain in youth baseball pitchers; therefore, a youth baseball pitcher with pain should direct his efforts toward mitigating the large shoulder distraction forces that they may be experiencing. Increased shoulder distraction force is suggested to increase the eccentric load that is placed on the rotator cuff musculature.[6] These large eccentric forces are applied to the humerus by the rotator cuff and the biceps brachii to assist in stabilizing the joint.[6] Thus, pain mitigation efforts should focus on strengthening the rotator cuff and biceps brachii in an eccentric manner.[6] These can range from novice exercises (such as side-lying external rotation) to advanced exercises (plyometric ball caught over the shoulder).

Results from this study assist in identifying a kinetic variable that may influence upper extremity pain in youth baseball pitchers. It was found that both mPSD and PSDmax forces were significantly larger in the pain group than in the pain-free group. These findings were consistent regardless of the location of pain in the upper extremity. Additionally, the increased kinetics did not result in an increase in velocity, which is inconsistent with previous literature.[18] These factors establish that athletes with throwing arm pain may be using shoulder distraction forces as a compensatory mechanism for that pain, and the increased stresses do not positively affect performance. As the presence of pain may be easily assessed and linked to injuries, knowledge of the contributors to pain would help us to take proactive approaches such as corrective exercises and mechanical coaching to mitigate throwing arm disorders.

Limitations

This study has several limitations including the small availability of pitchers self-reporting pain in their throwing arm. To account for the limited number, group sizes were directly matched, and participants in the pain-free group were matched based on their height, age, and weight. Further, this study used 3 trials for analyzing shoulder distraction, although current research indicates that the minimum number of trials needed to examine shoulder distraction forces within a 90% CI is 2.[13] While it is unknown if 3 trials is sufficient for determining ranges or maximum values of shoulder distraction forces, the collection procedure used is consistent with previous research and intended to be conscientious of total pitch volume.[8] Additionally, this study only looked at the time point of stride foot contact until follow-through. While shoulder distraction forces occur at many time points throughout the pitch, current research identifies the time point just before ball release to just after ball release as having the greatest shoulder distraction forces.[10] This study was also a cross-sectional study, which does not demonstrate a cause and effect relationship between self-reported pain and increased shoulder distraction forces. Further longitudinal studies should be conducted to obtain measurements both before pain and after pain to determine a potential cause and effect relationship. Athletes also had various locations of reported pain, which could be seen as a limitation. This was addressed by subgroup analysis that found no differences in any variable based on the location of pain. However, further investigation is needed, as the subgroups were limited in sample size. Finally, the limitation of using youth players with differences in maturation is notable when discussing youth athletics. Thus, for this study, we chose to match the athletes demographically.

CONCLUSION

Youth baseball pitchers with upper extremity pain had increased mPSD forces compared with a pain-free group. PSDmax forces were also higher in the pain group. However, no differences were observed between the groups when comparing rPSD forces, isometric strength, or pitch velocities. Further research is needed to determine other contributors to upper extremity pain and shoulder distraction in youth baseball pitchers.

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