[Athletic Training]

Elbow Biomechanics of Pitching: Does Age or Experience Make a Difference?

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Background: Elbow pain and elbow injuries are common in youth baseball players. It is not clear whether pitching experience and/or age creates biomechanical differences at the elbow and whether these differences place an athlete at greater risk.

Hypotheses: (1) Youth pitchers will have differing elbow kinematics with regard to flexion/extension, internal/external rotation, and pronation/supination when compared with nonbaseball athletes and (2) younger youth pitchers will have differing elbow kinematics when compared with older youth pitchers.

Study Design: Case-control study.

Level of Evidence: Level 4.

Methods: Twenty-seven healthy male youths age 10 to 18 years were recruited and divided into an experience group (n = 18 pitchers) and a no experience group (n = 9 nonbaseball athletes). The experience group was subdivided by age into the younger experience subgroup (n = 10 pitchers) and the older experience subgroup (n = 8 pitchers). Biomechanics were recorded using an electromagnetic motion tracking system. Subjects from each group were averaged together, and a Mann-Whitney *U* test was utilized for statistical analysis.

Results: The experience group had greater external rotation during late cocking (–47.8° vs 5.8°) and greater flexion during early cocking (112.8° vs 100.1°). The younger experience subgroup had greater range of motion with supination-pronation during early cocking (21.9° vs 11.2°) and late cocking (5.9° vs 2.0°).

Conclusion: Youth athletes with pitching experience had an increase in maximal external rotation in late cocking and maximal flexion in early cocking, which suggests experience may be a factor to these parameters. The age of experienced baseball pitchers may be a factor due to differences observed with supination and pronation.

Clinical Relevance: Learning to throw is a skill that leads to changes in elbow motion; however, these changes may be stable once athletes reach grade school age. Minimal differences were noted between the younger and older experience subgroups, which may underscore the importance of teaching proper mechanics at a young age.

Keywords: elbow injuries; biomechanics; youth baseball; kinematics; pitching

Youth participation in organized sports in the United States has grown to 60 million per year,[14] and it is likely that approximately 8.6 million or more youth play baseball.[16] The incidence of elbow pain has increased as well, with 17% of youth players reporting pain during the 1976 season and 52% of youth players reporting pain in 2004.[9,10] Baseball athletes are participating at an increased frequency and intensity, which could make them more prone to injury. Athletes specializing in baseball and in positions with repetitive throwing often develop elbow injuries.[6,10,17,22] The combination of this increased throwing and the development of the physes make youth pitchers susceptible to a unique set of injuries along with the classic injuries seen in the mature thrower.[8] Perhaps the most devastating force to the elbow that should be minimized is excessive valgus load.[2,3] Distraction forces are responsible for medial elbow conditions such as Little League elbow (medial

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epicondylar apophysitis), stress fracture of the humerus, ulnar collateral ligament (UCL) injuries, flexor-pronator mass strains, ulnar neuritis, and tendinitis.[3]

As youth baseball athletes continue throughout their young careers, their pitching mechanics likely evolve as well. The degree to which an athlete's age and experience has an effect on pitching biomechanics is unclear. Previous studies have compared different levels of play (Little League, high school, and professional), which showed no significant biomechanical differences between groups.[7,18] However, this study investigated the differences in pitching motions among pediatric-aged athletes as they relate to both experience and age. The goal of our study was to characterize the motion and spatiotemporal parameters of the elbow in similarly aged youth athletes with and without pitching experience, as well as pitchers with similar experience and variable age.

METHODS

Institutional review board approval was obtained from Children's Hospital of Wisconsin before the recruitment of participants, and written assent and consent to participate were obtained from the subject and subject's parent before data were collected. Twenty-seven healthy male youths aged 10 to 18 years participated in the study and were divided into 2 groups based on experience. The experience group (EG) consisted of 18 pitchers and the no experience group (NG) consisted of 9 subjects who had not previously participated in baseball. Subjects in the EG group had at least 2 years of pitching experience (self-reported) and no previous injuries to their pitching arm. Again, subjects in the NG group had no organized baseball experience and no previous injuries to their dominant arm. The EG group was further divided into 2 subgroups based on age. The younger experience subgroup (YG) consisted of 10 athletes whereas the older experience subgroup (OG) consisted of 8 athletes.

All subjects were right-hand dominant, except for 1 participant in the NG group. All subjects in the EG group used an overhead pitching motion, whereas in the NG group, some participants threw side-armed. A portable pitching mound was used, and the subjects threw from the mound into a net located 10 feet away. A projector was used to project a picture of home plate and the backstop to simulate a game situation in the laboratory.

Pitching motion was captured using the 6D Research software (Skill Technologies) integrated with the Polhemus StarTrak electromagnetic motion tracking system (Polhemus) at a frequency of 120 Hz. Sensors (1.5 × 1.5 cm) were placed and secured to the subject using double-sided tape, athletic tape, and an elastic band at 4 separate locations: the dorsum of the hand, midpoint of the volar forearm, midpoint of the anterior humerus, and the dorsum of the lead foot (to track foot contact). These sensors attached to a signal processor. Virtual markers were used to track the motion of the shoulder and the sternum throughout the pitch cycle. The shoulder virtual markers consisted of 3 markers on the posterior, superior, and anterior aspects of the shoulder, whereas the sternal virtual marker consisted of 1 point placed on the sternum. The position and orientation of the 4 markers were measured with respect to one another.

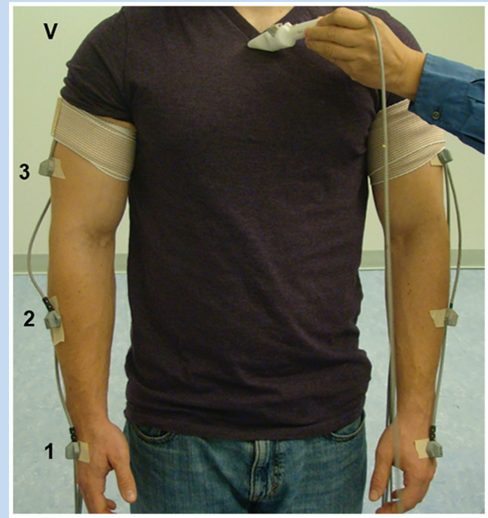

Figure 1. Neutral position before pitching: placement of the sensors on the humerus, forearm, and hand bilaterally; digitalization of the shoulder; sternal notch; and the third thoracic process. Marker 1, dorsal hand; marker 2, middle of the forearm; marker 3, middle of the humerus; V, virtual marker on the lateral aspect of the shoulder.

The coordinates for each marker were zeroed at the neutral wind up position with arms at the side (or at rest position) (Figure 1), indicating that movement data were taken with respect to the neutral position. The measurement error of the motion tracking system is less than 2°, which provides a reliable calculation.[15] Movement at the elbow in the sagittal plane was considered flexion and extension, with extension as negative motion (neutral position is when the arm is maximally extended) and flexion defined as positive motion (Figure 2a and b). Movement at the elbow in the transverse plane, which is understood to predominantly be a measure of shoulder rotation, was considered external rotation (lateral) and internal rotation (medial) motion of the forearm, with external rotation (valgus) defined as negative motion and internal rotation (varus) defined as positive motion (Figure 3a-c). Movement of the forearm relative to the humerus in the coronal plane was considered supination and pronation of the forearm, with supination defined as negative motion and pronation defined as positive motion (Figure 4a-c).

The phases of the pitch cycle were broken down into 5 stages: wind up, early cocking, late cocking, acceleration, and follow-through.[4,5,21] Wind up was the start of any movement to the separation of the hands. Early cocking followed with the separation of hands to stride foot contact (SFC). Late cocking was SFC to maximal external rotation (MER) at the shoulder. Acceleration was MER to ball release (BR). Followthrough was BR to completion of all motion.

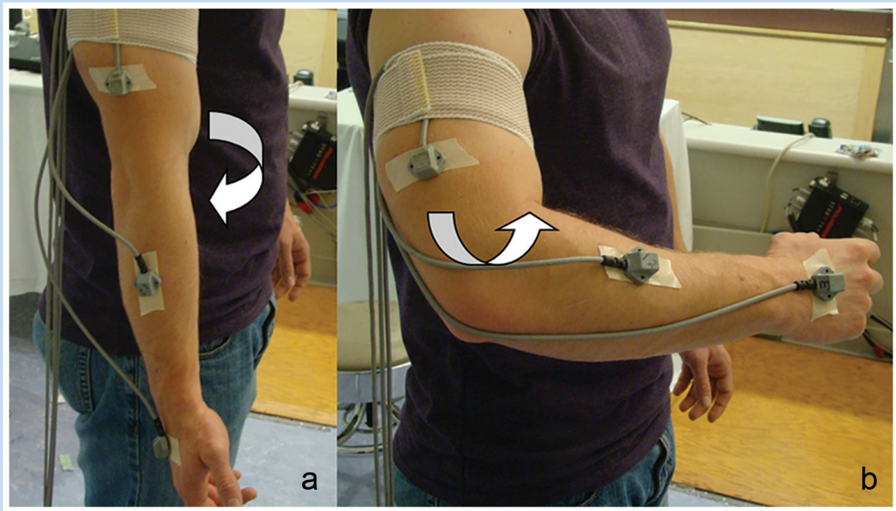

Figure 2. Measurement of extension (a, negative) and flexion (b, positive) of the forearm with respect to the humerus (between marker 2 and 3 in the *x*-axis).

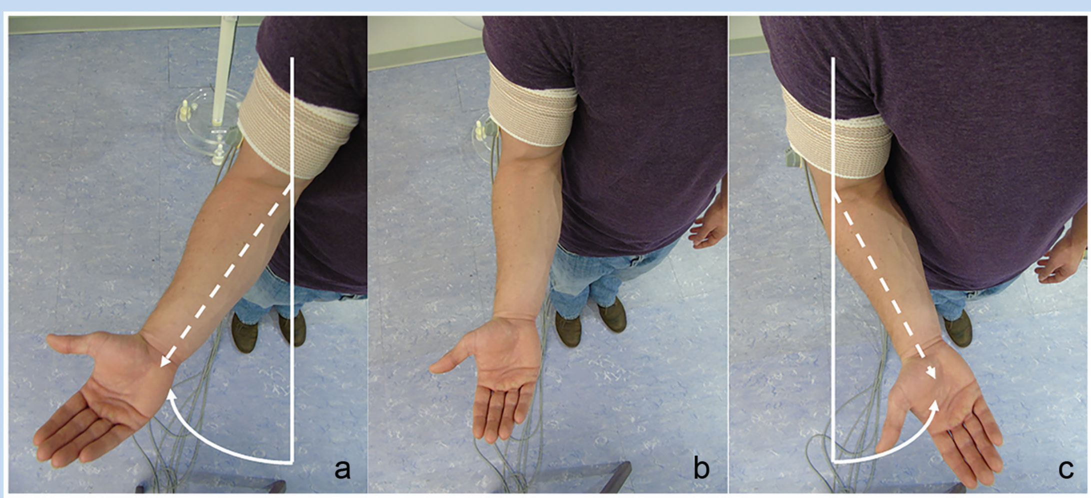

Figure 3. Measurement of external (a, negative), neutral (b), and internal (c, positive) rotation of the forearm with respect to the humerus (between markers 2 and 3 in the *z*-axis).

Statistical Analysis

The NG and EG groups were compared for statistical analysis (Table 1), and within the EG group, the YG and OG groups were compared (Table 2). The final statistical analyses were confined to looking at the early cocking, late cocking, and acceleration phases. A Shapiro-Wilk test was performed to determine whether the data had normal distribution. After conducting the test, it was determined that the majority of the variables tested had $P > 0.05$, which indicated a nonnormal distribution. As a result, a Mann-Whitney *U* test was employed to determine whether there were significant differences between groups with all variables. Statistical Package for the Social Sciences 22 (IBM Corp) software was used for data analysis. Statistical significance was set at $P < 0.05$.

RESULTS

Several differences were seen between the NG and EG groups (Tables 3 and 4), particularly with external rotation and flexion/extension. For velocity and acceleration, there were differences in flexion/extension in early cocking, but no differences were observed for velocity or acceleration in any plane during late cocking and acceleration.

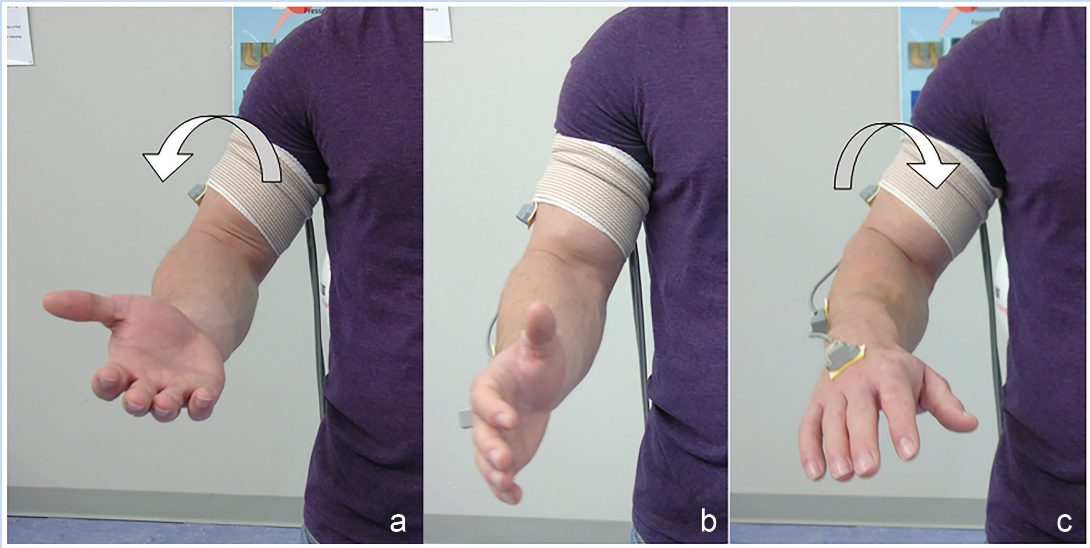

Figure 4. Measurement of supination (a, negative), neutral (b), and pronation (c, positive) of the forearm with respect to the humerus (between markers 2 and 3 in the y-axis).

Table 1. Study demographics: experience group (EG) vs no experience group (NG)[a]

	EG	NG
Participants, n	18	9
Age, y	12.5 (11.0, 15.0)	14.0 (11.0, 15.0)
Experience, y	7.00 (4.25, 8.25)	0 (0, 0)[b]

[a]Data presented as mean (95% CI).
[b]$P < 0.05$.

Table 2. Study demographics: younger experience subgroup (YG) vs older experience subgroup (OG)[a]

	YG	OG
Participants, n	10	8
Age, y	11.00 (10.25, 11.75)	16.00 (15.00, 16.25)[b]
Experience, y	6 (5, 7)	8.00 (3.00, 9.25)

[a]Data presented as mean (95% CI).
[b]$P < 0.05$.

Differences were also seen between the YG and OG groups (Tables 5 and 6). Between these 2 groups, YG had a larger range of motion with supination-pronation during early cocking and late cocking.

DISCUSSION

In this study, the EG group had larger external rotation (valgus positioning) across the elbow during early cocking, late cocking, and acceleration. This greater angle of rotation

Table 3. Angles of experience group (EG) vs no experience group (NG)[a]

Phase		EG, deg	NG, deg
Early cocking	Max FE	120.8 (106.1, 128.8)	100.1 (75.8, 110.4)[b]
	Diff FE	60.1 (31.2, 84.3)	31.1 (17.5, 46.2)[b]
	Diff SP	14.6 (11.6, 23.9)	13.1 (7, 18.5)[b]
	Max IE	–33.5 (–47.5, –17.8)	24.1 (–28.4, 34.7)[b]
	Min IE	–52.4 (–71.8, –45.1)	5.2 (–41.2, 21.8)[b]
Late cocking	Max FE	70.6 (56.9, 91.8)	61 (52.8, 79.3)
	Max IE	–38.4 (–60.7, –27.4)	11 (–33.3, 27.5)[b]
	Min IE	–47.8 (–62.9, –36.4)	5.8 (–35.2, 26.6)[b]
Acceleration	Max FE	65.5 (55.8, 86.1)	69.9 (63.2, 79.5)
	Max IE	–44.6 (–56.6, –29)	16.2 (–34.6, 26.3)[b]
	Min IE	–56.6 (–65.8, –37.2)	6.3 (–42.9, 21.2)[b]

Diff, difference; FE, flexion and extension; IE, internal and external rotation; Max, maximum; Min, minimum; SP, supination and pronation.
[a]Data presented as mean (95% CI).
[b]$P < 0.05$.

Table 4. Velocities of experience group (EG) vs no experience group (NG)[a]

Phase		EG, deg/s	NG, deg/s
Early cocking	Min FE	–183.8 (–236.3, –139.3)	–99.6 (–146.2, –38.3)[b]
	Diff FE	261.1 (189.7, 369.2)	137.7 (107.6, 200.1)[b]
	Min SP	–59.8 (–89.4, –41.5)	–29.6 (–59, –15.8)[b]

Diff, difference; FE, flexion and extension; Min, minimum; SP, supination and pronation.
[a]Data presented as mean (95% CI).
[b]$P < 0.05$.

suggests that this group may be generating a larger valgus torque across their elbow,[1,19,20] which is a risk factor for medial elbow pain and injury.[2,12] Increased strength, along with age and experience, are causes of greater external rotation, which would lead to greater valgus torque.[11,13] These results, which only looked at age and experience, suggest that the motion changes related to this increase may be due to pitching experience.[11,13]

An increase in flexion during the transition between late cocking and acceleration can reduce elbow valgus load.[1] In this study, the EG group only had a greater maximum angle in early cocking and not during late cocking or acceleration (see Table 3). Since early cocking is a lower risk phase of the pitching cycle, the clinical significance of this finding is unclear. However, previous studies found no statistically significant differences in elbow flexion between levels of play.[7] Our data build upon this previous research and suggest that experience does not play a factor in elbow flexion during late cocking and acceleration when pitchers are compared with youth who did not participate in organized baseball.

Comparing younger and older experienced players (YG vs OG), there were significant differences found in only 3 categories, but because the number of participants was so small, the significance of these findings remains in question. The YG group had greater range of motion in supination and pronation in both the early and late cocking phases (see Table 5). Although the cause of these differences is unclear, this may be due to decreased motor control, which would be an expected

Table 5. Angles of younger experience subgroup (YG) vs older experience subgroup (OG)[a]

Phase		YG, deg	OG, deg
Early cocking	Max FE	110.5 (102.7, 122)	125.1 (115.9, 130.8)
	Min FE	44.3 (42, 74.2)	62.5 (26.2, 90.5)
	Diff FE	68.5 (41.5, 85.7)	57.6 (28, 76.2)
	Max SP	21.6 (18.4, 25.2)	12.7 (4.3, 18.4)
	Min SP	0.2 (–6.6, 5.1)	–1 (–6.9, 5)
	Diff SP	21.9 (15.4, 25)	11.2 (7.1, 13.7)[b]
	Max IE	–20.5 (–37.6, –4.8)	–44.9 (–59.6, –30.2)
	Min IE	–46.4 (–66.2, –31)	–53.5 (–73.7, –47)
	Diff IE	26.8 (11.2, 45)	14.7 (14.1, 16.7)
Late cocking	Max FE	76.3 (55.9, 82.6)	64.8 (60.1, 102.6)
	Min FE	31.4 (43.6, 60.7)	63.6 (54.2, 97.1)
	Diff FE	44.8 (10.4, 24.9)	6 (4.9, 6.3)[b]
	Max SP	29.3 (–6.1, 8.5)	–2 (–4, 18.8)
	Min SP	23.4 (–11, –0.5)	–5.2 (–7.2, 18.4)
	Diff SP	5.9 (4.9, 7.8)	2 (0.9, 3.2)[b]
	Max IE	–27.8 (–43.8,2.9)	–45.1 (–74.1, –37.5)
	Min IE	–52.5 (–52.5, –9.6)	–50.8 (–74.9, –44.1)
	Diff IE	24.6 (2.8, 10.5)	3.8 (1.6, 5.8)
Acceleration	Max FE	59.9 (55.5, 75.9)	69 (59.2, 96.3)
	Min FE	48.5 (37.4, 58.5)	61.1 (44.8, 79.5)
	Diff FE	14.3 (8.5, 17.8)	14.7 (8.6, 15.6)
	Max SP	–1.3 (–8.2, 11.2)	–1.3 (–6.3, 17.9)
	Min SP	–8.6 (–16.2, 3)	–2.8 (–9.2, 0.9)
	Diff SP	8.2 (3.9, 11.6)	6 (3.3, 7.6)
	Max IE	–33 (–55.8, –1.7)	–51.6 (–65.2, –38)
	Min IE	–36.7 (–64.1, –3.8])	–57 (–75, –56.4)
	Diff IE	8.2 (5, 11.7)	10 (9, 13.7)

Diff, difference; IE, internal and external rotation; Max, maximum; Min, minimum; SP, supination and pronation.
[a]Data presented as mean (95% CI).
[b]$P < 0.05$.

finding in younger age groups. As an athlete progresses in age, the variability in motion from pitch to pitch should become less, and range of motion may decrease.

Of interest, no significant differences with the low sample size were observed for velocity and acceleration. We expected that increased experience and age-related physical maturity would demonstrate increases in these variables, similar to increases seen in ball velocity.

Several limitations of this study should be discussed. First, the study was limited by small groups and should be replicated following power analysis to determine appropriate sample size. Second, our participants were asked to throw at maximal effort, and this may have altered mechanics. Third, surface markers may not have exactly replicated the kinematics as they are not directly attached to bone, and reproducibility of placing markers was not performed. In addition, cords were attached to the markers, which may have affected the mechanics of our participants. Finally, it would have been ideal to recruit participants who were matched separately for age and experience in the 2 arms of the study, although we did see that the groups were quite similar naturally.

Table 6. Velocities of younger experience subgroup (YG) vs older experience subgroup (OG)[a]

Phase		YG, deg/s	OG, deg/s
Late cocking	Diff FE	152.4 (132.1, 283.9)	62.5 (27.9, 108.3)[b]
	Min SP	–99.2 (–146.8, –94.8)	–24.8 (–62.2, –6.1)[b]
	Diff SP	158.3 (91.7, 250.9)	15.9 (9.9, 51.2)[b]
	Max IE	73.2 (31.1, 132.5)	–4.1 (–21.9, 28.3)[b]
	Diff IE	174.1 (80, 196.2)	56.8 (50.6, 63.2)[b]

Diff, difference; FE, flexion and extension; IE, internal and external rotation; Max, maximum; Min, minimum; SP, supination and pronation.
[a]Data presented as mean (95% CI).
[b]$P < 0.05$.

CONCLUSION

Throwing experience may be a factor for maximum external rotation and maximal flexion. Age does not appear to contribute significantly to pitching kinematics in experienced pitchers. If proper mechanics are taught at a young age, these mechanics appear to continue throughout a career.

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