[Sports Physical Therapy]

Elbow Joint Active Replication in College Pitchers Following Simulated Game Throwing: An Exploratory Study

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Background: Elbow injuries are common in college baseball players. Pitching creates stress and fatigue in and around the elbow. Lack of joint proprioception can contribute to nonphysiological joint loading and injury.

Hypothesis: There will be no difference in elbow joint active reproduction sense following a simulated 3-inning pitching sequence.

Study Design: Cross-sectional study.

Methods: Seventeen collegiate pitchers participated. Each pitcher was bilaterally tested for active elbow range of motion using goniometric technique. Percentages of motion determined positions for further study of elbow joint active replication sense (20%, 35%, 50%, 80%). The elbow was passively taken to a position and held for 10 seconds, then returned to full extension. Pitchers were asked to actively reproduce the angle. The opposite elbow was tested in the same manner. One week later, prethrowing joint position reproduction was tested; then a simulated 3-inning game was thrown. Immediately afterward, elbow joint active replication testing was performed. A repeated-measures analysis of variance analyzed differences.

Results: No change in active joint reproduction occurred in the nondominant elbow at any angle tested. Dominant elbows demonstrated significant losses of active joint reproduction following throwing. Significant differences occurred at the 35% and 80% angles ($P < .05$).

Conclusion: Active elbow joint replication sense may be compromised following 3 innings of throwing. Because joint proprioception is thought to be an important component of joint stabilization, an alteration in joint position sense may increase the risk of elbow injury during throwing.

Clinical Relevance: Pitching may cause a loss of active elbow joint replication.

Keywords: elbow; proprioception; pitching

Elbow joint injuries are common among college baseball players because of the tremendous stress placed on the elbow during throwing or pitching. Joint proprioception is the ability to detect movement, or *kinesthesia*, and perceive joint position.[19] Correct joint position sense may be important for injury prevention. Signals for joint position sense are thought to arise from receptors in the skin, muscles, and joint capsule.[19] Some also believe that intra-articular capsular receptors provide major contributions to joint position sense,[7,13] whereas others suspect that extra-articular receptors play a more important role.[6,9,14]

Proprioception and kinesthesia can be clinically assessed through reproduction of active joint position. Reproduction is thought to involve the stimulation of joint and muscle receptors, and it provides a more functional assessment of the afferent pathways.[20]

Although knee and shoulder joint proprioception have been studied extensively, only 2 studies have examined proprioception in the elbow.[19,22] Khabie et al examined the application of an elastic bandage to the elbow and the injection of an intra-articular anesthetic.[19] Based on an isokinetic device

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for determining range of motion tested, mean elbow joint position sense reproduction without a bandage was within 3.3° ± 1.3°; when an elastic bandage was applied, sense reproduction was diminished to 2.2° ± 1.2°. According to Khabie et al, the application of an elastic bandage improved position sense, which suggests that tactile cues from cutaneous or other extra-articular receptors may play a role in elbow proprioception.[19] Intra-articular anesthesia, however, had little effect, suggesting that intracapsular receptors play a lesser role in elbow proprioception. Using standard goniometry, Macrina et al assessed elbow joint proprioceptive characteristics in professional baseball players[22]—specifically, their ability to actively reproduce a passive joint position from a common starting point. Significant proprioceptive deficits existed for the dominant (4.23°) and nondominant (4.03°) elbows at 50% range of motion. A proprioceptive deficit (4.06°) occurred in the nondominant elbow at 90% range of motion. If muscle coordination is impaired as a result of altered joint proprioception, the elbow may be at risk for injury.

Muscle fatigue adversely alters upper and lower extremity joint proprioception and neuromuscular control.[2,21,23,27,32,33,39] Throwing a baseball at high velocities is considered a fatiguing activity. Following eccentric and concentric exercises, Brockett and colleagues found that elbow fatigue altered joint position sense; a gradual recovery of position sense to normal occurred by 3 days postexercise.[4] No studies have assessed active elbow joint replication following pitching. It is possible that significant injury occurs to the ulnar collateral ligament if proprioceptive deficits exist or if proprioception is diminished in midranges, wherein this ligament provides the greatest resistance to a valgus stress at the elbow.

The objectives of this study were to examine the effect of 3 simulated innings of throwing on active elbow joint replication testing. The null hypothesis was that there would be no significant difference in elbow joint active reproduction between the dominant and nondominant extremities following a simulated 3-inning pitching bout.

METHODS

Participants

Participants were 17 men: age, 20.71 ± 1.2 years; height, 188.3 ± 4.8 cm; mass, 429.9 ± 28.43 kg. All volunteered and all were pitchers at a local university: 11 were right-hand dominant and 6 were left-hand dominant. Because only 17 pitchers were on the baseball team, a power analysis was not performed. All testing took place during early spring, before the season began. At the time of study, all pitchers were healthy, and all reported with no history of upper extremity injury, surgery, or central nervous system disorder. After explanation of the testing protocol, each pitcher signed an informed consent approved by the university's institutional review board. Each pitcher's pitching style was determined on the basis of videotape or coaching staff observation (Table 1).

Table 1. Pitching styles of participants.

Pitcher	Style
1	Upper three-quarters
2	Sidearm
3	Upper three-quarters
4	Upper three-quarters
5	Three-quarters
6	Short three-quarters
7	Three-quarters
8	Three-quarters
9	Three-quarters
10	Three-quarters
11	Sidearm
12	Low three-quarters
13	Upper three-quarters
14	Three-quarters
15	Three-quarters
16	Three-quarters
17	Low three-quarters

Table 2. Intraclass correlation coefficients for elbow flexion and extension.

	Flexion	Extension
Right	.956	.994
Left	.971	.982

Procedures and Reliability

A pilot study established intratester reliability on a group of 19 asymptomatic participants (38 elbows). Data collection was done on a single day. The second measurement occurred 30 to 60 minutes after the first. Reliability coefficients were calculated for elbow flexion and extension performed on each side ($ICC_{3,2}$) (Table 2).

All testing occurred at the athletic training facility adjacent to an indoor bullpen. A single throwing session was used to

Table 3. Descriptive statistics: mean ± SD.

	Age	Height	Weight
Pitchers (n, 17)	20.7 years ± 1.2	188.2 cm ± 4.8	88.5 kg ± 5.9

collect data. To decrease the risk of increased proprioceptive ability based on the learning effect, each participant was taken through the entire testing procedure approximately 1 week before taking measurements. The primary author took all measurements. Bilateral elbow active range of motion was assessed via standard goniometric measurement technique with the pitcher seated and with his elbow by his side.[26] Measurements of elbow flexion and extension have been found to have excellent reliability.[1,3,15,16,28,30] These measurements were used for all subsequent testing and for determining positions at data collection. Because pitchers have unique elbow ranges of motion, total range of motion and then a percentage of that range were used to calculate the positions to be tested/replicated. The percentages of motion used to determine joint reproduction were 20%, 35%, 50%, and 80% of complete active elbow range of motion. These ranges were chosen to test a variety of positions used during pitching.

To measure proprioception, the participant was seated on an athletic training table, eyes closed, with shoulders in 0° of abduction and elbows fully extended off the table's edge. The elbow was taken to full extension and then passively taken to the measurement position previously calculated, where it was held for 10 seconds. The pitcher's elbow was passively returned to full extension. The pitcher was asked to actively reproduce the angle for the 4 percentages of range of motion described above. In an attempt to decrease tactile cues, measurements were taken without contact between the goniometer and the lateral elbow. Immediately following these measurements, the pitcher threw 3 simulated innings, including 2 innings of 15 pitches, followed by 1 inning of 14 pitches. Each pitcher rested up to 5 minutes between innings. To make the throwing as realistic as possible, pitchers were allowed to throw whatever pitches they normally threw in a game. Immediately following the third inning, the pitcher returned to the athletic training room where the entire measurement procedure was repeated, starting with the dominant arm. Each measurement was taken as an absolute number in degrees of error from that pitcher's given percentage of motion tested. Reference to a positive or negative error was not calculated (ie, error in greater flexion or extension, respectively)—for example, if the 20% position for a pitcher was at 15° of elbow flexion, a 10° error could mean that the elbow moved to either 5° or 25° of flexion.

Analysis

A repeated-measures analysis of variance was used to analyze the differences between the prethrowing and postthrowing data with regard to elbow joint replication in both elbows. For post hoc analysis, paired-samples *t* tests with Bonferroni adjustment were used. The percentage of change for each elbow was computed by subtracting postpitching values from prepitching values and dividing this result by the prepitching value. Alpha level was set at .05. SPSS 15.0 was used to analyze the data. Because the range of motion data were not normally distributed, Friedman analysis of variance was used. For post hoc analysis, Wilcoxon signed rank tests with Bonferroni adjustment was used.

RESULTS

Table 3 displays descriptive statistics. Table 4 shows mean pretest and posttest error measurements. Significant losses of active dominant elbow joint reproduction replication occurred following simulated 3 innings of throwing. Post hoc analysis with Wilcoxon showed that significant loss of elbow active joint reproduction occurred at 35% and 80% ($P < .05$) (Table 4). Data indicate no change in active joint reproduction of the nondominant elbow at any angle. When examining the mean percentage change in the elbows, larger replication errors can be seen in the throwing arm (Table 5).

DISCUSSION

The elbow joint is inherently stable owing to bony configuration and geometry, and this stability is enhanced through static and dynamic joint constraints. The elbow joint capsule provides static restraint. The anterior capsule becomes taut in full extension and lax during flexion.[38] The greatest capsular laxity occurs at approximately 80° of flexion.[18] Other tissues are thought to play a role in proprioception. Both capsule and ligaments, as well as articular, muscular, and cutaneous tissues, contain nociceptive pain-free nerve endings and proprioceptive mechanoreceptors consisting of Pacinian corpuscles, Ruffini endings, and Golgi tendon organ–like endings.[17]

During throwing from end of arm acceleration to arm deceleration, the elbow extends at approximately 2500 degrees per second.[11] Deceleration creates a large amount of muscle activity from strong eccentric biceps brachii contractions.[37] Muscle damage induced by eccentric exercise produces a disturbance in proprioception.[4,31,36] It is doubtful that pitching in the present study caused eccentric muscle damage, because the athletes studied were all in excellent physical condition and throwing with no symptoms. It is possible, though, that

Table 4. Measurements in degrees of error for pitchers' elbow joint active position replication.

Measurement	Test	Mean ± SD	Range[a]	95% CI[b]
Nondominant				
20%	PRE	5.58 ± 5.04	1-21	2.99-8.18
	POST	5.76 ± 5.79	0-22	2.78-8.74
35%	PRE	5.71 ± 4.41	0-17	3.43-7.97
	POST	6.35 ± 5.88	0-13	3.32-9.37
50%	PRE	4.76 ± 3.54	1-13	2.94-6.58
	POST	5.71 ± 4.83	0-18	3.22-8.19
80%	PRE	3.41 ± 2.06	0-8	2.35-4.47
	POST	3.35 ± 2.55	0-10	2.04-4.66
Dominant				
20%	PRE	4.35 ± 2.76	0-90	2.93-5.77
	POST	6.65 ± 6.33	0-18	3.39-9.90
35%	PRE	3.94 ± 3.36[c]	0-13	2.21-5.67
	POST	9.00 ± 6.26[c]	0-22	5.77-12.21
50%	PRE	5.35 ± 3.79	0-13	3.40-7.30
	POST	7.47 ± 5.23	0-17	4.78-10.16
80%	PRE	2.71 ± 1.89[c]	0-7	1.73-3.68
	POST	4.59 ± 3.16[c]	0-13	2.96-6.21

[a]Minimum-maximum.
[b]Confidence interval.
[c]Significant difference, $P < .05$.

Table 5. Mean percentage change in replication error between elbows.

Range of Motion	Dominant	Nondominant
20%	145.00	66.60
35%	203.30	78.29
50%	70.29	65.44
80%	98.27	21.98

the eccentric action of the elbow during throwing did cause an alteration in joint position sense. This change in position sense may not be enough to demonstrate changes in muscle following fatigue, such as strength decrements and/or pain to palpation, yet it may be enough to cause an alteration in joint position sense. The elbow joint musculature may also become fatigued after a 3-inning simulated game. Fatigue appears to cause sensorimotor system deficits,[5,12,24,25,29,34,35] potentially resulting in the inability to appreciate and maintain the ideal throwing mechanics in the shoulder model. If this also occurs at the elbow, breakdowns in throwing mechanics may follow. Following 3 innings of simulated throwing, the dominant elbow may have lost some elbow active joint position sense via the inability to replicate various positions. This loss likely occurred at 35% and 80% of the total elbow range of motion. The findings of the present study are more implicative of these possibilities than those of Macrina et al, who found significant losses of elbow active joint position sense in the throwing elbows of professional pitchers at only 50% range of motion.[22] Macrina et al did not assess elbow proprioception after simulated pitching, which may account for the differences between findings.[22]

No significant loss of position sense occurred at the 20% range of motion. Full elbow extension is the closed-packed position of the ulnohumeral joint. It is in this position that the capsule is most taut and joint surfaces most congruent. In a stable position such as this, proprioception may not be as important as it is as the elbow flexes. It is not uncommon for pitchers to lose elbow extension in their throwing arms. Ellenbecker and colleagues found 5° of elbow extension loss in the throwing elbows of professional baseball pitchers.[8] Flexion contractures in the throwing elbows occurred in up to 50% of professional baseball pitchers.[40]

In the present study, replication of angles representing 35% and 80% of range of motion in the human elbow may represent a significant change in joint position sense following simulated pitching. These ranges of motion are where elbow capsular tension begins to increase during elbow movement. These ranges are a transition between dynamic stability from forearm muscles and that of capsular-enhanced stability from ulnohumeral, radiohumeral, and radioulnar joints. Capsular tissues that determine joint position sense may be altered in this range, especially after a physically demanding activity such as throwing.

Even more puzzling was the unchanged position sense at 50% range of motion. This position would be close to that of the greatest capsular laxity, 70° of elbow flexion, where proprioception may be used to the greatest extent. Because the elbow moves through this position during throwing, proprioceptors may be selectively trained in this range. Alternatively, dynamic muscular stability may be used to a greater extent at 50% of the elbow's motion. This position may allow the greatest elbow capsular laxity, where throwers use dynamic stability at maximal effort levels to help promote joint stability. Unfortunately, no studies exist describing active elbow joint reproduction testing following functional activities such as throwing.

Numerous studies indicate that ligament and capsular proprioceptive receptors may be more active or important at extremes of motion. Although this may occur in shoulder, ankle, and hip joints, it may not happen in the elbow where inherent stability is increased from elbow flexion to elbow extension.

Although this study did not assess fatigue following throwing, the results appear to be consistent with those of researchers who examined the shoulder and knee.[5,33,35] Fatiguing exercise or activities can significantly reduce joint position sense.[5,33,35] In one study of the shoulder, fatiguing exercise caused a minimal change in the ability to detect threshold shoulder motion, from 0.92° before exercise to 1.59° after exercise, an increase of 73%.[5] Voight et al,[35] using active and passive joint repositioning following fatigue, found significant differences in the ability to determine a given shoulder's static position. Active repositioning following fatigue increased error score by 1.7° in the nondominant arm, whereas dominant arm error increased by 3.3°.

Further support for the effects of fatigue comes from studies of the knee. Skinner et al[33] evaluated effects of position sense following exercise. A significant decrease occurred in the participants' ability to reproduce knee joint angles, as compared with that of the preexercise condition. Skinner et al also demonstrated an average 1° loss of active joint reproduction sense.

The significant losses in active reproduction sense in these studies are consistent or well below the 6° and 2° differences in the present study. The present results are consistent with those of previous studies based on joint proprioceptive loss—namely, a significant loss occurs in the elbow following a functional activity.

LIMITATIONS

A small sample size was a significant limitation of this sample of convenience. A power analysis was not performed. However, significant differences in active joint position sense occurred following simulated throwing. The significant differences detected are not likely due to measurement error, because of the excellent intrarater reliability (Table 2).

Although it is clear that our measurement technique is reliable, what is unclear is the accuracy of the technique. Differences between means in Table 4 range from 0.05° to 5.05° as measured by standard goniometry. In most instances, the mean differences are barely larger than the reported standard deviations, which calls into question the accuracy of this measurement technique. We cannot differentiate 0.05° of motion with standard universal goniometry. Fish and Wingate[10] published standard goniometric error for elbow flexion and extension as plus or minus 2.4° to 3.4°. With that in mind, the inadequacies of using standard universal goniometric technique must be considered when interpreting these data.

In the past, some studies assessing proprioception relied on placing participants' tested extremities in a pneumatic sleeve to reduce contributions of cutaneous stimuli to position sense. A pneumatic device was not used for this study; therefore, differences may be due to contributions of cutaneous stimuli to the forearm.

Although participants were asked to turn their heads and close their eyes, a blindfold and headset were not used to diminish visual and auditory cues. An assistant ensured that the pitcher's head was turned and the eyes were closed during testing, so it is doubtful that any participant used visual cues. Nothing was done to negate auditory cues, although testing was done in a busy athletic training room where background noise was consistent.

Because we did not assess elbow muscle strength, muscle fatigue may have caused the reported differences. Throwing approximately 99 pitches can cause up to 18% fatigue in selected shoulder muscles.[25] It is possible that throwing approximately one half of this amount could induce fatigue of the musculature surrounding the elbow.

CONCLUSIONS

The determination of proprioceptive qualities for the elbow of the college-age pitcher following throwing aids in the understanding of elbow function. The results suggest that a proprioceptive loss may occur after a simulated 3-inning game.

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