Upper and Lower Extremity Muscle Fatigue After a Baseball Pitching Performance

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Background: Previous studies have estimated joint torques and electromyogram activity associated with the pitching motion. Although previous studies have investigated the influence of extended pitching (fatigue) on kinematic and kinetic parameters, no attempts have been made to quantify the fatigue associated with a pitching performance.

Purpose: Considering previous investigations on muscle activity during pitching, this study investigated muscle fatigue in upper and lower extremity muscle groups after a pitching performance.

Study Design: Descriptive laboratory study.

Methods: Thirteen baseball pitchers from 4 universities and 1 independent minor league team were tested before and after 19 games. Pitchers threw an average of 99 pitches during an average of 7 innings. Shoulder, scapular, and lower extremity muscle strengths were assessed using a handheld dynamometer before and after the pitching performances.

Results: Baseline strength tests revealed that the pitching arm was 12% weaker (P = .02) in the empty can test (supraspinatus) compared to the contralateral side. Postgame shoulder strength tests revealed selective fatigue of 15% in shoulder flexion (P = .02), 18% fatigue in internal rotation (P = .03), and 11% fatigue in shoulder adduction (P = .01). Minimal fatigue was noted in the empty can test, scapular stabilizers, and hip musculature.

Conclusions: A trend toward significant baseline strength in internal rotation together with significant selective postgame fatigue on internal rotation of the dominant upper extremity indicate that the internal rotators experience a high performance demand during pitching. Weakness in the empty can test on the dominant arm combined with minimal postgame fatigue was surprising given that studies and injury patterns have indicated a high performance demand on the supraspinatus during pitching.

Keywords: pitching fatigue; performance demands; empty can test; rotator cuff

The pitching motion in baseball involves the coordinated action of lower and upper extremity muscle groups to propel a 149-g ball at linear velocities in excess of 90 mph. Glenohumeral angular velocities can be as high as 7000°/s at the point of ball release.[11,26] This repeated motion, over the course of multiple innings, could result in muscle fatigue that impairs performance and may increase vulnerability to injury.[2,3] Fatigue may be a key component of injury risk because it may lead to a loss of proper mechanics.[24]

The larger muscle groups such as the pectoralis and latissimus dorsi are essential for forward propulsion of the upper extremity.[12,16] The scapular muscles are essential for maintaining the scapula against the chest wall,[16] and the lower extremity muscles are thought to play an integral role in decelerating the upper body.[20] Fatigue in any of these muscles over the course of a game may predispose the shoulder to microtrauma.

Previous studies have investigated the influence of extended play on the pitching motion.[24] Barrentine et al[4] studied the kinematics associated with the pitching motion during simulated game situations. Kinematic changes over the course of the simulated game, including dropped elbow and decreased knee flexion at ball release, were considered to be an indication of fatigue. Murray et al[24] analyzed the changes in kinematic and kinetic parameters of the baseball pitch during game competition. Several parameters changed after 5 innings of pitching. These included decreases in maximum external rotation angle, knee angle at ball release, maximum distraction force at shoulder and elbow, and maximum horizontal adduction torque. These effects were associated with a 5-mph decrease in ball velocity. To our knowledge, there have been no attempts to evaluate and quantify the level of

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muscular fatigue associated with a pitching performance. This study was designed to quantify upper and lower extremity fatigue after an actual pitching performance in a real game situation.

MATERIALS AND METHODS

Subjects

Thirteen college and minor league–level male baseball pitchers volunteered to participate in both pregame and postgame testing. Subjects' mean age was 21 ± 2 years, mean weight was 87 ± 10 kg, and mean height was 187 ± 8 cm. All subjects signed informed consent forms, and the protocol was approved by the institutional review board. Subject inclusion criteria included (1) being a starting pitcher, (2) pitching at least 5 innings, and (3) taking a postgame test before "icing" the arm. Ten subjects were right-hand dominant, and 3 were left-hand dominant. Pitchers agreed to participate if pregame measurements were made 1 or 2 days before the pitching performance, as they were concerned about the potential performance impairment resulting from immediate pregame testing. Ten subjects were tested once, and 3 subjects were tested on more then 1 occasion (1 tested 2 times, 1 tested 3 times, and 1 tested 4 times) for a total of 19 game situations.

Testing Protocol

The tester met with each pitcher before his scheduled pitching start for testing (10 pretests 1 day prior, 9 pretests 2 days prior). At this time, the nature of the testing procedure was explained to the subjects. Passive glenohumeral internal rotation and external rotation range of motion was measured goniometrically with the subjects supine at 90° of shoulder abduction with 90° of elbow flexion; external rotation was measured with the patient in the supine position. Standard goniometric landmarks were used while the subject's arm was passively externally rotated. The subjects' scapulae were stabilized by their body weight in the supine position. Subjects were considered at the end range when the examiner detected scapulothoracic motion. Internal rotation was measured in a similar fashion. Subjects were passively internally rotated and considered at the end range when scapular motion or shoulder protraction was detected. To prevent muscular guarding or apprehension, measurements were repeated 3 times until a repeatable measurement was recorded.

Strength tests were performed using a handheld dynamometer (Lafayette Instruments, Lafayette, Ind). This dynamometer had a sensitivity of 0.1 kg and was calibrated before testing according to the manufacturer's recommendation. The validity and reliability of testing upper extremity strength with handheld dynamometers have been well documented.[9,19,25,29] Donatelli et al[9] reported high intrarater reliability with intraclass correlation coefficients for the middle trapezius (0.933), lower trapezius (0.891), supraspinatus (empty can test) (0.995), internal rotation at 90° of abduction (0.932), and external rotation at 90° of abduction (0.960). Six shoulder and 3 scapular strength tests were performed on both the dominant and nondominant arms. All upper extremity strength tests were performed as break tests with the handheld dynamometer force being applied just proximal to the wrist joint. The starting arm (dominant vs nondominant) was randomly selected (coin toss). The order of tests was as follows: shoulder flexion, abduction, scaption, internal rotation, external rotation; hip flexion, abduction, adduction; shoulder adduction, middle trapezius, lower trapezius, rhomboids; and grip strength. The average of 2 repetitions in each strength test was recorded.

Shoulder flexion and abduction strength measurements were performed in the sitting position. Subjects stabilized themselves by grasping onto the plinth with their contralateral arm. The subject's arm was placed at 90° of flexion in the sagittal plane for flexion testing and 90° of abduction in the frontal plane for abduction testing. The empty can test (supraspinatus) was performed with the arm at 90° of abduction and 30° anterior to the frontal plane with full glenohumeral internal rotation. The empty can test positioning is thought to evaluate supraspinatus muscle strength.[9,19,30,32] Shoulder internal and external rotation strength measurements were made with the patient in the supine position. Subjects were placed with the shoulder in 90° of abduction with the elbow flexed at 90°. Glenohumeral rotation was placed at neutral for both internal and external rotation tests. For external rotation, the dynamometer was placed on the dorsal side of the wrist. For internal rotation, the dynamometer was placed on the volar side of the wrist. Shoulder adduction testing was performed in the prone position with the arm by the side, in slight extension, and with the palmer surface facing medially. Pressure was applied on the palmar side of the wrist into abduction and flexion.[18]

Scapular stabilizers were tested in the prone position. Lower and middle trapezius tests were set up according to Donatelli et al.[9] The lower trapezius muscle group was tested with the shoulder abducted to 145° with full glenohumeral joint external rotation. The middle trapezius muscle group was tested with the shoulder abducted to 90° with full glenohumeral external rotation. Rhomboid testing was performed with the upper extremity horizontally abducted to 90° with full glenohumeral internal rotation (thumb down) and scapula adducted.[18] A standardized grip strength measurement was performed using the handheld grip dynamometer (Jamar, Bolingbrook, Ill) with a neutral glenohumeral position and the elbow at 90° of flexion.

Lower extremity strength tests were performed for seated hip flexion, side-lying hip abduction, side-lying hip adduction, and prone hip extension.[18,34] All lower extremity break tests were replicated for both pivot and nonpivot lower extremities. The pivot leg of a right-handed pitcher is considered the right or push-off leg, whereas the nonpivot leg is considered the left or landing leg. On completion of the game (range of 15-25 minutes after pitching performance), the range of motion and strength measurements were repeated in the same order as pregame testing.

TABLE 1
Baseline Strength Measurements (Pregame)

Strength Test	Baseline Pregame Strength		Dominant vs Nondominant, P
	Dominant, kg	Nondominant, kg	
Shoulder tests			
Flexion	14.1 ± 1.8	14.2 ± 2.7	.99
Abduction	12.9 ± 2.1	13.0 ± 2.6	.99
Empty can test (supraspinatus)	11.5 ± 1.9	13.0 ± 2.8	.02[a]
Internal rotation	23.7 ± 4.9	21.4 ± 4.8	.08
External rotation	18.3 ± 3.8	21.1 ± 4.2	.37
Adduction	16.7 ± 5.4	15.9 ± 4.9	.99
Scapular stabilizer tests			
Middle trapezius	9.4 ± 2.2	9.6 ± 2.3	.99
Lower trapezius	9.9 ± 2.9	9.8 ± 2.8	.99
Rhomboids	10.5 ± 2.6	10.3 ± 3.0	.99
	Nonpivot Leg	Pivot Leg	
Hip tests			
Flexion	34.5 ± 6.6	35.2 ± 6.6	.99
Abduction	19.7 ± 4.8	20.5 ± 6.0	.99
Adduction	20.4 ± 4.8	20.3 ± 4.9	.99
Extension	21.6 ± 5.3	22.3 ± 5.2	.97
Grip strength test	61.9 ± 2.1	60.5 ± 2.1	.13

[a]Dominance effect at baseline.

Data Analysis

Dominance effects (dominant vs nondominant for upper extremity and pivot vs nonpivot for lower extremity) at baseline (pregame testing) were tested using paired t tests. The percent change in strength values from pregame to postgame was calculated for each side in both upper and lower extremity tests. One-sample t tests were used to determine if the percent change in strength was significantly different from 0 for each test. In addition, percent change in strength in the dominant versus nondominant upper extremity and pivot versus nonpivot lower extremity was compared using paired t tests. Selective fatigue was defined as a strength decline that was significantly greater than 0 and that was also significantly greater than the change in strength on the contralateral side. A P value of <.05 was deemed significant. Bonferroni corrections were applied to t tests to maintain a type I error rate of <5% ($P < .05$). Because there were 6 shoulder strength tests, the threshold for significance was set at $P < .008$. The threshold for significance was $P < .017$ for scapular stabilizer strength tests (3 tests), $P < .0125$ for hip strength tests (4 tests), and $P < .025$ for shoulder range of motion tests (2 tests).

RESULTS

Subjects completed an average of 7 ± 2 innings and threw an average of 99 ± 29 pitches per game. In baseline testing, the dominant side was 12.6% weaker in the empty can test ($P = .02$) (see Table 1). The external rotation/internal rotation ratio on the dominant side was lower (0.78) than on the nondominant side (0.98) ($P = .01$). Internal rotation range of motion was 10.9° less on the dominant side ($P = .001$) and external range of motion was 16.5° greater on the dominant side ($P = .02$) when compared to the nondominant shoulder (Table 2). There were no effects of dominance for any other strength tests at baseline (Table 1).

There was significant fatigue on the dominant side in all shoulder strength tests with the exception of the empty can test and external rotation (Table 3). The greatest fatigue was seen in internal rotation (18%). Shoulder abduction fatigue on the dominant side (12%) was not significantly greater than the change in the nondominant side ($P = .50$). For internal rotation, adduction, and flexion, selective fatigue was apparent on the dominant side (Table 3).

There was no apparent fatigue in the scapular stabilizers, grip strength, or hip muscle groups (see Table 3). Internal rotation and external rotation range of motion did not change from pregame to postgame (see Table 4).

All analyses were repeated excluding the data from the additional games for the players tested on more then 1 occasion. All fatigue effects for these 13 single games were similar to those reported for all 19 games. Significant effects were apparent for shoulder flexion (18%), abduction (16%), internal rotation (20%), external rotation (15%), and adduction (8%) (n = 13; all $P < .05$).

Based on the standard deviation of the nonsignificant dominant-side fatigue effects shown in Table 3, we estimated that we had the power to detect a strength loss of 10% for the empty can test, 15% for external rotation, 13%

TABLE 2
Baseline (Pregame) Range of Motion Measurement

	Dominant	Nondominant	*P*
Internal rotation (90° abduction)	63.5° ± 8.7°	74.4° ± 9.8°	.001[a]
External rotation (90° abduction)	137.3° ± 18.3°	120.8° ± 11.9°	.02[a]

[a]Dominance effect at baseline for both internal rotation and external rotation.

TABLE 3
Postgame Fatigue Measurements[a]

	Postgame Fatigue, % Strength Loss		
Strength Test	Dominant	Nondominant	Dominant vs Nondominant, *P*
Shoulder tests			
Flexion	15 ± 14[b]	5 ± 12	.02
Abduction	12 ± 16[c]	5 ± 9	.50
Empty can test (supraspinatus test)	6 ± 13	5 ± 10	.99
Internal rotation	18 ± 19[b]	4 ± 16	.03
External rotation	11 ± 19	4 ± 11	.69
Adduction	11 ± 14[c]	–1 ± 14	.02
Scapular stabilizer tests			
Middle trapezius	6 ± 17	–9 ± 24	.02
Lower trapezius	4 ± 15	1 ± 16	.99
Rhomboids	9 ± 19	–2 ± 24	.15
Hip tests			
Flexion	6 ± 16	5 ± 18	.99
Abduction	6 ± 18	6 ± 15	.99
Adduction	4 ± 15	4 ± 17	.99
Extension	2 ± 20	4 ± 15	.99
Grip strength test	4 ± 9	–4 ± 8	.04

[a]Mean ± SD for percent fatigue. Fatigue = [(pregame strength – postgame strength)/pregame strength] × 100.
[b]$P < .01$.
[c]$P < .05$. Percent fatigue significantly greater than 0.

TABLE 4
Range of Motion Measurement Changes[a]

	Dominant Pregame vs Postgame	Nondominant Pregame vs Postgame	*P*
Internal rotation (90° abduction)	–2.7° ± 9.5°	3.6° ± 7.2°	.26
External rotation (90° abduction)	5.7° ± 11.5°	3.5° ± 7.6°	.99

[a]No significant selective fatigue effect on internal or external range of motion.

for the middle trapezius, 12% for the lower trapezius, 15% for the rhomboids, 12.5% for hip flexion, 14.5% for hip abduction, 12% for hip adduction, and 16% for hip extension using an α level of .05 (adjusted for multiple comparisons) and a β level of 0.2 (80% power).

DISCUSSION

Previous studies investigating EMG activity during the pitching motion have demonstrated marked activity in the internal rotators,[12,16] external rotators,[12,17] supraspinatus,[12,15] and scapular stabilizers.[12,16] EMG activity was high in the internal rotators (77%-185% maximum volitional contraction [MVC]), moderate in the deltoids (43% MVC), and somewhat variable in the adductors (latissimus dorsi) (14%-185% MVC).[12,16] The supraspinatus muscle activity was reported to be minimal to moderate (14%-72% MVC).[12] In a preliminary EMG investigation by Jobe et al, supraspinatus muscle activity was elevated, most notably in the early cocking and follow-through stage.[17] Differences in EMG techniques between studies and relatively high measurement variability for dynamic EMG measurements probably contributed to the wide range in reported EMG values. Despite this variability, the highest EMG activity across studies was seen generally in the internal rotators. This is in agreement with the current findings with respect to the fatigue in internal rotation (18%).

Strength measurements for professional baseball players have been reported in previous studies using isokinetic[5,6,10,35] and handheld dynamometry.[9,19] Studies using the handheld dynamometer revealed weakness on the dominant side in external rotation[9] and the empty can test.[19] Increased strength was noted with internal rotation and middle and lower trapezius muscles.[9] In the current study, the empty can test revealed a 12.6% strength deficit in the dominant shoulder, whereas the dominant shoulder internal rotation showed a trend toward a significant baseline strength (9.9% stronger). Weakness in the empty can test was previously attributed to "subclinical pathology."[19] In the current study, weakness on the dominant side and the lack of fatigue after the pitching performance are not consistent with a high demand on the supraspinatus during pitching. Alternatively, the lack of muscle fatigue in the empty can test may be explained by the fact that this muscle works primarily eccentrically during the deceleration phase of pitching.[1,9,11] It has been previously shown in knee extensors[31] and plantar flexors[13] that maximum eccentric muscle contractions are extremely fatigue resistant despite high force production. Eccentric fatigue resistance may explain the lack of fatigue in the supraspinatus during the pitching motion. This may also be true of the external rotators during the pitching motion. Selective fatigue was not apparent in the external rotators after a pitching performance. This finding may be explained by the primarily eccentric contractions of the external rotators during deceleration. Future work should examine eccentric and concentric fatigue patterns of the shoulder musculature.

Little work has been done examining the muscular activity and contributions of the lower extremities during the baseball pitch. However, it is recognized that the whole body, including the trunk and lower extremities, is essential to effective pitching.[33] The trunk and lower extremities are key components to conserving energy, decelerating the shoulder, and maintaining trunk sway.[20] In a study by Yamanouchi,[36] peak abductor and adductor muscle activity during the pitching motion was 73% to 84% of MVC. In comparing experienced high school baseball pitchers to nonbaseball players, Yamanouchi[36] found increased lower extremity activity during the pitching motion in the experienced players. However, in the present study minimal fatigue was seen in the hip musculature of the pivot or nonpivot leg.

The most common musculotendinous injuries sustained by baseball pitchers are injuries to the rotator cuff.[7,8,22,23,27] These are primarily overuse injuries attributable to the repetitive action of the pitching motion. Rotator cuff injuries predominantly involve the supraspinatus tendon.[14,15,27] The empty can test is thought to be a test of supraspinatus function[15,30,32]; hence, Magnusson et al[19] attributed weakness in the empty can test, in professional pitchers, to "subclinical pathology." The fact that minimal fatigue was seen in the empty can test in the present study was surprising given the susceptibility of the supraspinatus to injury. There are several possible explanations for this: (1) the empty can test may not be a good test of supraspinatus function; (2) supraspinatus injury may reflect impingement injury due to inadequate humeral head depression rather than overuse of the supraspinatus; (3) as previously stated, the supraspinatus is thought to work primarily eccentrically during the pitching motion, and eccentric contractions are relatively fatigue resistant; and (4) weakness and minimal fatigue in the empty can test may reflect function in a muscle (or muscles) that has developed fatigue resistance due to repetitive low intensity use. Weakness has previously been associated with fatigue resistance.[21,28]

Although it may be inevitable, rotator cuff muscle fatigue during a pitching performance may have implications for shoulder abnormalities. The balance between the humeral head depressors and the arm elevators is a crucial component to maintaining a healthy throwing shoulder. This study revealed inconsistent fatigue patterns between rotator cuff muscles; selective fatigue was apparent in the internal rotators but not in the external rotators. In addition, fatigue patterns were inconsistent between shoulder elevators; selective fatigue was apparent in shoulder flexion but not abduction. The resultant changes in the force coupled with different fatigue patterns may have implications for injury. The loss of muscular control associated with fatigue may cause the glenohumeral head to migrate within the glenoid fossa, allowing internal impingement of the posterior cuff.

Although all of our subjects were cleared of any upper extremity abnormalities, the possibility of "subclinical pathology" of the supraspinatus, described by Magnusson et al,[19] may be a result of internal impingement. Considering the significant supraspinatus baseline strength deficit and the lack of fatigue associated with this muscle after the pitching performance, the supraspinatus may be a victim of the rotator cuff entrapment associated with internal impingement. This repetitive entrapment and continual torsional ringing of the rotator cuff over the articular surface may be responsible for the supraspinatus baseline weakness. Future studies are required to establish if baseline strength and/or specific fatigue patterns are associated with an increased risk of rotator cuff injury.

CONCLUSION

In previous studies, the musculoskeletal demand of the pitching motion has been examined using estimates of joint torques derived from kinematic analysis of the pitching motion[11] or from EMG activity recorded during the pitching motion in a laboratory setting.[16,17] This study was designed to quantify muscle fatigue of specific muscle groups associated with an actual pitching performance. Muscle fatigue was seen primarily in the shoulder muscles, with minimal fatigue in the scapular and hip musculature. Of the muscle groups tested, selective fatigue was apparent with shoulder internal rotation, adduction, and flexion. Surprisingly, the supraspinatus (empty can test) was found to have minimal fatigue after a pitching performance. The finding that internal rotation strength showed a trend toward significant higher baseline measurements in the dominant arm and marked fatigue after a game indicates that the internal rotators experience a high performance demand during pitching.

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