ORIGINAL RESEARCH

THE EFFECTS OF REPETITIVE OVERHEAD THROWING ON SHOULDER ROTATOR ISOKINETIC WORK-FATIGUE.

Dale RB[a]
Kovaleski JE[a]
Ogletree T[b]
Heitman RJ[a]
Norrell PM[a]

ABSTRACT

Background. Muscle strength and endurance of the shoulder rotators is important for overheard throwing performance and dynamic glenohumeral stability. Baseball pitching is distinguished as an intermittent activity with explosive, high intensity muscle contractions separated by periods of rest. Rotator cuff muscle performance could acutely decrease due to fatigue associated with bouts of throwing.

Objective. This study examined the effects of repeated overhead throwing upon isokinetic muscle performance of the shoulder rotators. Methods. Repeated-measures analyses of variance were used to compare peak torque, total work, and work-fatigue by muscle group, time, and contraction type. Ten collegiate baseball pitchers underwent isokinetic testing of the internal (IR) and external shoulder (ER) rotators one week before and immediately after a throwing protocol of 60 maximal-effort pitches arranged into four innings of 15 pitches per inning. Isokinetic testing consisted of 12 concentric and eccentric repetitions at 300 deg/sec for internal and external rotation of the throwing extremity.

Results. The main effect of time and the interaction of muscle group and contraction type were significant for work-fatigue. Post-hoc analysis revealed that subjects had significantly greater eccentric IR work-fatigue (13.3 + 1%) compared to the pre-test (7.3 + 2%).

Discussion and Conclusion. Throwing-related fatigue affected both muscle groups, especially the IR, which has implications for dynamic glenohumeral stability. Rehabilitation and conditioning programs for competitive baseball pitchers should emphasize eccentric muscle endurance training of the shoulder rotators.

Key Terms: shoulder, baseball pitching, rotator cuff

CORRESPONDENCE:
R. Barry Dale, PT, PhD, SCS, ATC
Assistant Professor
Department of Physical Therapy
University of South Alabama
1504 Springhill Avenue, Room 1214
Mobile, AL 36604
bdale@usouthal.edu

[a] University of South Alabama, Mobile, AL
[b] Thomas Hospital, Fairhope, AL

INTRODUCTION

Overhead throwing performance requires an intricate balance between the static and dynamic structures of the shoulder in order to maintain functional stability. Such integration requires muscular strength and endurance, flexibility, and neuromuscular control.[1-7] If any one of these factors is compromised, functional instability results, performance diminishes, and shoulder injuries are more likely to occur[7-9]

Previous studies have investigated the influence of extended pitching primarily on kinetic and kinematic parameters of the pitching motion.[3-5] Limited information exists on the effects of throwing on shoulder muscle strength and fatigue. Mullaney et al[10] examined the isometric muscle strength of various shoulder muscle groups after pitching multiple innings and indicated that upper extremity isometric muscle fatigue occurs in some shoulder and scapular muscles but not in the supraspinatus and external rotators. Since the supraspinatus and external rotators predominantly function dynamically during throwing, isometric assessment may not have been the appropriate testing-mode for evaluating supraspinatus and external rotation muscle function following a pitching performance.

Results from a study by Nocera et al[11] assessing shoulder strength of the external and internal rotators following throwing showed no significant decline when measured as a one repetition maximum (1RM) or as isokinetic peak torque. In addition, Mullaney and McHugh[12] assessed isokinetic strength and reported that the shoulder rotators fatigue similarly during concentric and eccentric muscle actions. Despite these recent findings, no published information exists on the occurrence of shoulder rotator fatigue that is based on isokinetic work and described as a work-fatigue index. No documentation exists of muscle-specific fatigue within the shoulder internal and external rotators before or after repetitive overhead throwing. The hypothesis to be tested is that shoulder internal and external rotation musculature could experience work-fatigue as a result of throwing which might have implications for controlling dynamic glenohumeral stability; especially if muscle-specific fatigue exists. Therefore, the purpose of this study was to determine the effects of repeated overhead throwing on shoulder internal and external rotator isokinetic muscle fatigue following a pitching performance.

METHODS

Subjects

Ten male collegiate baseball pitchers (20.3 + 0.5 yr; 1.85 + 0.2 m; 88.1 + 2.8 kg) without injury to either shoulder volunteered to participate. Nine pitchers were right-hand dominant and one was left-hand dominant. Subjects averaged 10.1 + 0.9 years of pitching experience, dating back to youth league baseball. The Institutional Review Board of the University of South Alabama approved the study and all subjects gave informed consent to participate.

Instrumentation

Isokinetic testing of the shoulder rotator muscles was conducted using a Biodex System 3 (Biodex Corporation, Shirley, NY). Subjects were seated during the test with appropriate stabilization provided by a lap belt, criss-crossed chest straps, and footrest in accordance with the Biodex Isokinetic Dynamometer manual.13,14 The chair of the Biodex and the dynamometer attachment were individually adjusted to each subject to ensure proper fit and alignment and these settings were recorded from the numerical scale on the machine and attachment. A Velcro® strap was used to secure the forearm in the dynamometer attachment cradle. The upper extremity was positioned in shoulder abduction at 90° of elbow flexion and shoulder rotation was performed from 90° external rotation to 60° internal rotation, for a total range of motion of 150°. Gravity compensation was performed prior to each test.

Procedures

Subjects participated in two isokinetic tests (pre and post-throwing) and one pitching session. All testing was preceded by an orientation session in which the isokinetic testing and throwing protocols were explained and each subject performed isokinetic exercise to become familiar with the testing protocol.

Seven days before performing the throwing protocol, subjects participated in isokinetic testing of the shoulder internal rotators (IR) and external rotators (ER) by performing 12 concentric and eccentric contractions at 300 deg/sec. Subjects were given detailed verbal instruction of procedures and performed five warm-up repetitions prior to each test. For the IR and ER muscle groups, concentric contractions were tested initially, a 3-minute rest provided, and then the eccentric testing was performed.[15] Each muscle group worked for approximately six seconds during the 12 repetition set. With 180 seconds to recover, this provided a work-rest ratio of 1:30. Since each muscle group only worked for approximately six seconds, intramuscular ATP should have been adequately regenerated. Stone and Connelly[16] showed that complete ATP-phosphocreatine resynthesis occurs with a work:rest ratio of at least 1:12. Subjects were verbally encouraged to maximally move the extremity "as hard and as fast as possible" during concentric testing and to "resist or fight" the movement of the dynamometer attachment with eccentric testing. Subjects were not allowed visual feedback during testing.

Subjects returned one week after performing the pre-throwing isokinetic test and participated in the throwing session. All subjects stretched and warmed-up prior to pitching. Subjects threw from a standard pitching mound located in an outdoor bullpen, which was elevated 0.254 meters above the level of home plate. Throws were made to a catcher located behind home plate at a distance of 18.4 meters from the pitching mound and threw a baseball that weighed 0.14 kilograms. Maximum throwing speed was measured using a Jugs Radar Model 620-c Gun (Decatur Electronics; Decatur, IL) and calibrated with a tuning fork prior to all throwing sessions.

Each subject threw 60 maximal-effort pitches (all fastballs) arranged into four innings of 15 pitches per inning. Five pitches were thrown as a warm-up at the beginning of each inning at a self-selected intensity (straight fastballs only). The pitch rate was standardized by throwing every 15 seconds, which yielded a total of five minutes of throwing per half inning. Following the completion of 20 pitches (5 warm-up and 15 maximal throws), the subject rested in a seated position for five minutes before throwing another inning. Thus, the throwing protocol consisted of 20 minutes of pitching and 20 minutes of seated rest. One author monitored the pitches thrown, rest between innings, and recorded pitch velocities.

Subjects performed the second isokinetic test immediately following the completion of the throwing session. The procedures used were identical to those of the pre-throwing test.

Data Analysis

The work-fatigue index (means + SEM) was recorded for concentric and eccentric IR and ER. Work-fatigue is the difference between the first one-third (first four repetitions of the 12) and last one-third (last four repetitions) of the work (Nm/kg) performed in a given set, which is then divided by the work in the first one-third of the set and multiplied by 100. This index measures the amount of fatigue from the beginning to the end of an endurance test bout, with a larger work-fatigue index value indicating greater fatigue.[17]

Reliability of the work-fatigue index was previously determined using ten additional healthy male subjects. Each subject performed 12 repetitions for concentric and eccentric ER and IR at 300 deg/sec, which was repeated one week later. Intra-class coefficients (ICC) ranged from 0.66 to 0.81. The ICC data were as follows: concentric ER = 0.69 (95% CI = 0.60-0.74); concentric IR = 0.81 (95% CI = 0.73-0.89); eccentric ER = 0.66 (95% CI = 0.59-0.72); and eccentric IR = 0.79 (95% CI = 0.73-0.84). These ICCs are considered to be "moderate" in strength, as ICC values of 0.75 or greater generally indicate high reliability.[18]

Concentric and eccentric peak torques and total work were normalized to body mass (Nm/kg). These data were analyzed for descriptive purposes and to document shoulder rotator strength across the pre- and post-test trials.

Data were analyzed with repeated measures analysis of variance (ANOVA) using within-subjects factors of muscle group (ER and IR), muscle action (concentric and eccentric), and time (pre-throwing and post-throwing). Post hoc analyses consisted of paired t-tests corrected for alpha inflation by the Bonferonni procedure. Additionally, to provide an indication of whether work-fatigue was indeed a meaningful measure of fatigue, a one-sample t-test was used to compare the work-fatigue index to a baseline value of zero that represented zero percent fatigue..

All statistical analyses set the alpha level at 0.05. Power was set to be 80% Apriori. Using ten subjects it was determined that a 12% difference in percent fatigue could be detected from pre-test to post-test assuming that the within subject variability was similar to values previously reported.[12,19]

RESULTS

The average pitched ball velocity was 36.7 + 1.2 m/s (82.1 ± 2.7 mph). The average ball velocity in the first inning was 36.87 + 0.6 m/s (82.5 + 1.3 mph), which was not statistically different ($p = 0.12$) from the ball velocity in the final inning (36.43 + 0.4 m/s or 81.5 + 0.9 mph). The mean time from the last ball thrown to commencement of the isokinetic post-test was 12.0 + 0.8 minutes.

Isokinetic Work-Fatigue Index

The main effect of time was significant ($p < 0.01$) for work-fatigue across muscle groups and muscle actions, with greater work-fatigue observed in the post-test (15.5 ± 1%) when compared to the pre-test (7.6 ± 2%). Post-hoc analysis ($p < 0.01$) showed greater eccentric IR work-fatigue following the throwing bout (13.3 + 1%) when compared to the pretest (7.3 + 2%). No significant main effects for work-fatigue were found for muscle group ($p = 0.07$) or muscle action ($p = 0.14$) *(Table 1)*.

The work-fatigue interaction for muscle group and muscle action was significant ($p < 0.02$). Post-hoc tests ($p < 0.01$) indicated greater eccentric work-fatigue (13.8 + 2%) of the ER compared to the IR (7.3 + 2%) for the pretest only.

For the pretest trial, only the eccentric ER work-fatigue index was significantly greater ($p < 0.001$) from the zero-fatigue baseline condition. Whereas, for the post-test trial, both the concentric and eccentric ER and IR work-fatigue values were found to be significantly different ($p < 0.05$) from the zero-fatigue baseline condition *(Table 1)*. This finding shows that work-fatigue values are indicative of fatigue occurring.

Table 1. *Normalized total work (Ng/kg) and work-fatigue (Means ± SEM)*

		Total Work		Work Fatigue	
		Concentric	Eccentric	Concentric	Eccentric
ER**	pre-test	6.74 ± 0.44	9.44 ± 0.89*	8.41 ± 3.41	13.78 ± 1.9 §¶
	post-test	6.81 ± 0.44	9.13 ± 1.11*	13.40 ± 4.2¶	16.42 ± 3.0¶
IR**	pre-test	10.23 ± 0.97†	19.35 ± 0.98*†	7.40 ± 4.00	7.3 ± 2.0
	post-test	10.59 ± 0.68†	17.92 ± 1.23*†	18.35 ± 3.9¶	13.30 ± 1.3‡¶

IR: Internal Rotators
ER: External Rotators
* Eccentric total work (TW) > concentric TW (p<0.05)
† IR TW > ER TW (p<0.05)
‡ Post-test IR work-fatigue > pretest IR work-fatigue (p<0.05)
§ Eccentric ER work-fatigue > eccentric IR work-fatigue at pre-test (p<0.01)
¶ Work-fatigue values were significantly different from 0.0 (p<0.05)

Total Work and Peak Torque

Total work and peak torque values normalized to body weight are presented in Tables 1 and 2. Significant peak torque main effects ($p < 0.05$) for muscle group and contraction mode existed, but not for time ($p > 0.05$). Comparisons showed that IR eccentric and concentric total work and peak torque were greater than ER eccentric and concentric values, respectively.

DISCUSSION

A paucity of research exists examining the impact of muscle fatigue on upper extremity muscle function in the throwing athlete. Increasing our understanding of these effects may be imperative in preventing injury.5,10,20 The practical significance of this study was that shoulder rotator work-fatigue was observed in both muscle groups and in both muscle actions after a bout of repetitive throwing. Specifically, a significant difference pre to post-test for work-fatigue was found. Post-hoc analysis revealed greater eccentric IR work-fatigue (13.3 + 1%) compared to the pre-test (7.3 + 2%).

The importance of these findings appears clinically relevant to the biomechanics of pitching. The rotator cuff muscles are active throughout the entire throwing motion, with activity levels peaking during the cocking phase, as the infraspinatus and teres minor provide external rotation and the subscapularis and supraspinatus assist in providing stability to the glenohumeral joint.[3,21] The findings support the hypothesis that repetitive eccentric IR activity during the cocking phase of throwing diminished the thrower's capacity to maintain work output over the 12 repetitions of the isokinetic post-test. Increased fatigue could lead to a lack of coordination and control by the rotator cuff during this phase of throwing and result in excessive movement of the humeral head with added stress on the anterior stabilizing structures of the shoulder.3 To date, no other study has analyzed shoulder isokinetic eccentric work-fatigue immediately following a pitching performance.

Although a number of studies examining baseball pitching performance in relation to shoulder strength and throwing velocity exist, there is a lack of information regarding the direct effects of throwing on shoulder muscle work-fatigue.[11,13-15,22-25] Decreased performance in baseball pitching depends upon many factors including pitching pace, pitching style, and the athlete's physical conditioning.[22] To control for these variables among the pitchers, throwing rate and rest between innings were standardized. The athletes were instructed to give their best effort and were allowed to throw only fastballs as an approach to standardize pitch type and relative exertion levels relating to ball velocity. It is important to note that the throwing bout likely contributed to the increased isokinetic work-fatigue values observed after throwing even though ball velocity did not significantly change over the 60 pitches. The absence of change in throwing velocity after the 60 pitches demonstrates that the athletes were physically capable of both performing and completing the throwing protocol. Since the isokinetic pre- and post-tests consisted of the same number of repetitions performed and since greater work-fatigue was observed in the post-throwing isokinetic test, it seems appropriate to conclude that repetitive throwing contributed to greater eccentric muscle fatigue.

When compared to the pre-test isokinetic total work and peak torque values, the post-test values were not significantly changed. These findings are supported in part by Nocera et al11 who reported peak torque was unchanged after a throwing bout. It may be important to emphasize that a peak torque value represents only one repetition within a given set and may not be a sensitive indicator of the ability of a muscle to sustain work over time. Furthermore, comparing peak torque values across time is difficult when metabolic recovery is likely to occur. In this study, the elapsed time of approximately 12 minutes from the completion of the throwing bout to the isokinetic post-test could have been sufficient to allow metabolic recovery and, thus, no differences in peak torque would be expected.

Table 2. *Normalized peak torque (Nm/kg) Means ± SEM*

		Concentric	Eccentric
ER	pre-test	0.38 ± 0.02	0.51 ± 0.03*
	post-test	0.39 ± 0.02	0.53 ± 0.03*
IR	pre-test	0.60 ± 0.04†	0.93 ± 0.05*†
	post-test	0.63 ± 0.03†	0.94 ± 0.05*†

IR: Internal Rotators
ER: External Rotators
* Eccentric > concentric ($p<0.05$)
† IR > ER ($p<0.05$)

Work-Fatigue

High-intensity muscle contractions often lead to a significant decline in contractile function, which is the basic definition of skeletal muscle fatigue.[12] Isokinetic muscle endurance is the capacity of a muscle to perform work, and fatigue is measured as a decline in work production over a series of consecutive contractions.[26] Total work performed over several isokinetic contractions has been reported as a valid indicator of the endurance capacity of a single muscle group. Kannus et al[27] showed that the total work performed during a 25 repetition isokinetic test and the total work performed for the final five of the 25 repetitions were both as significant and consistent as peak torque in measuring muscle endurance capacity.

Mullaney and McHugh[12] examined 32 maximal effort isokinetic contractions of the shoulder rotators at 120 deg/sec and calculated muscle fatigue using average torque decrements from the first and last five repetitions of each set. They reported isokinetic testing at 120 deg/sec based on preliminary data that showed subjects had difficulty consistently maintaining peak torque at higher testing speeds. In contrast, the isokinetic protocol used in this study incorporated a faster isokinetic speed (300 deg/sec), but included only one set of 12-maximal effort ER/IR repetitions. From pilot work, one set of 12 repetitions was chosen based on a high degree of delayed-onset-muscle-soreness that occurred following performance of multiple sets which included a greater number of eccentric muscle actions. More importantly, the pilot work showed that subjects were unable to maintain isokinetic speed at 300 deg/sec for 20 repetitions after a throwing bout.

Post-hoc analysis showed greater post-test work fatigue (13.3%) when compared to the pre-test (7.3%) for only the shoulder IR muscles. This finding is similar to those of Mullaney et al10 who reported that repetitive overhead throwing caused an 18% decrease in post-game IR isometric muscle strength. In addition, Mullaney et al[10] observed no significant decrease in the isometric muscle force of the ER following throwing. The findings in this study and those previously reported by Mullaney et al[10] demonstrate the high performance demands placed on the IR during repetitive overhead throwing. The absence of measurable isometric fatigue assessed by isometric testing could be explained by the dynamic nature by which the ER muscles function during throwing.[3] This finding further illustrates the importance of muscle testing specificity and the significance of assessing a performance-related activity such as throwing.

Clinical Implications

Shoulder rotator cuff muscle strength and endurance is important to act against potentially injurious forces produced during the throwing motion.[9,28] Distraction forces commonly reach or surpass equivalency to body mass and the failure to counteract these forces is often cited as a potential injury mechanism for repetitive microtrauma.[3,8,28] Repetitive microtrauma related to multiple bouts of overhead throwing is thought to contribute to injury of the rotator cuff musculature, which is one of the most common injuries in baseball pitchers.[8,29-31] Andrews and Wilk8 proposed that the repetitive microtrauma associated with throwing leads to tissue fatigue, inflammation, decreased muscle performance with resulting instability, and ultimately tissue damage.

Insidious rotator cuff injury could be associated with impaired dynamic stability related to muscle fatigue.[3] The finding that the eccentric fatigue occurred in both muscle groups after throwing is an important consideration about dynamic stability during prolonged bouts of overhead throwing.[8] For pitchers lacking ER eccentric fatigue resistance, dynamic stability may be compromised during arm deceleration in latter innings compared to early innings. This reduction in eccentric work coupled with a fatigue-induced decline of joint position sense[7,32] could allow superior migration of the humeral head on the face of the glenoid fossa that is associated with impingement and other glenohumeral injuries.[9,33] It is well documented that the IR muscles are stronger than ER,[10,15,23,34-38] but we found that throwing induced similar percentages of fatigue in both muscle groups in both concentric and eccentric muscle actions.

CONCLUSION

The results of this study demonstrated greater IR and ER work-fatigue after a pitching performance with the IR eccentric work-fatigue showing the greatest fatigue. These findings have implications for pre-season conditioning and post-injury rehabilitation of overhead throwing athletes and underscore the importance of eccentric endurance training exercise for the rotator cuff musculature. Future studies are necessary to validate these findings and to further determine the clinical usefulness of the work-fatigue index.

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