The Effect of Muscle Fatigue on Muscle Force-Couple Activation of the Shoulder

Timothy J. Henry, Scott M. Lephart, Jorge Giraldo, David Stone, and Freddie H. Fu

Context: Muscle fatigue is an important concept in regard to the muscle function of the shoulder joint. Its effect on the muscle force couples of the glenohumeral joint has not been fully identified. ***Objective:*** To examine the effects of muscle fatigue on muscle force-couple activation in the normal shoulder. ***Design:*** Pretest, posttest. ***Patients:*** Ten male subjects, age 18–30 years, with no previous history of shoulder problems. ***Main Outcome Measures:*** EMG (area) values were assessed for the anterior and middle deltoid, subscapularis, and infraspinatus muscles during 4 dynamic stabilizing exercises before and after muscle fatigue. The exercises examined were a push-up, horizontal abduction, segmental stabilization, and rotational movement on a slide board. ***Results:*** No significant differences were observed for any of the muscles tested. ***Conclusions:*** The results of our study indicate that force-couple coactivation of the glenohumeral joint is not significantly altered after muscle fatigue. ***Key Words:*** shoulder rehabilitation, dynamic stabilization, shoulder EMG assessment

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Functional stability in the shoulder depends on a number of factors including dynamic stabilization.[1-3] Dynamic stability is the ability of the muscle force couples surrounding the glenohumeral joint to stabilize or center the head of the humerus on the glenoid surface. These muscle force couples are vital to proper kinematics and function in the shoulder complex because of the lack of inherent static stability provided in the glenohumeral joint.[3-8] Without proper activation of these muscle force couples, episodes of functional instability can occur. Many studies have elucidated the effects of injury on muscle-firing patterns in the upper extremity.[5,9] These studies have demonstrated aberrations in muscle-firing patterns in shoulders with glenohumeral instability, as well as painful shoulders.

Recently, muscle fatigue has been mentioned as a contributor to ligamentous injury in the knee. Fatigue has been defined many ways; however,

Henry is with the Athletic Training Program at SUNY College at Brockport, NY 14429. Lephart, Giraldo, Stone, and Fu are with the Neuromuscular Research Laboratory at the University of Pittsburgh.

the most widely accepted definitions are offered by Winter[10] and Enoka.[11] Winter[10] described muscle fatigue as occurring when the muscle tissue cannot support metabolism at the contractile element because of ischemia or local depletion of any of the metabolic substrates. Enoka[11] describes fatigue as a class of acute effects that impair performance, which includes both an increase in the perceived effort necessary to exert a desired force and an eventual inability to produce that force. A combination of these 2 definitions might be the most appropriate way of defining fatigue.[12]

It has been documented that quadriceps and hamstring muscle fatigue resulted in an average increase in anterior tibial translation of 32.5%.[13] In response to these findings it has been concluded that muscle fatigue affects dynamic stability, alters the neuromuscular response, and might play a role in the pathomechanics of injury during functional activity. Rozzi and Lephart[14] investigated the effects of muscle fatigue on knee-joint proprioception and neuromuscular control and concluded that muscle fatigue appears to affect muscle-firing patterns and might predispose both men and women to increased risk of ligamentous injury.

It has been reported that muscle fatigue in the upper extremity results in diminished proprioception and kinesthesia.[15–17] Because of the diminished afferent input, it is hypothesized that fatigue will similarly result in aberrations in dynamic stabilization and ultimately lead to functional instability and predisposition to injury. Without normal activation patterns of the muscle force couples, glenohumeral instability might occur.[18] The effect of fatigue on the dynamic stability of the shoulder has not yet been elucidated. The objective of this study was to examine the effects of muscle fatigue on muscle force-couple activation in the normal shoulder.

Methods

Ten male subjects volunteered for this study. All were healthy young adults, age 18–30 years, with no previous history of shoulder problems. Their mean age was 20.2 ± 3.6 years, mean height 70.5 ± 2.4 in, and mean weight 173 ± 8.8 lb. All were recreational athletes who participated in some type of athletic activity a minimum of 3 times per week.

Instrumentation

Intramuscular fine-wire electrodes were prepared for electromyographic (EMG) analysis. Consent forms approved by the university's Institutional Review Board were obtained for each subject, and precautions were taken to prevent complications from the invasive procedure. The skin was prepared according to sterile procedure by cleansing thoroughly with betadine and alcohol. After proper skin preparation over the targeted muscles, 0.05-mm stainless-steel-insulated wires with two 2- to 3-mm exposed tips were inserted into the infraspinatus, anterior deltoid, and middle deltoid muscles via a 1-1/2-in 25-gauge hypodermic needle. The electrode for the subscapularis was inserted via a 3-1/2-in 22-gauge spinal needle. Correct electrode placement was confirmed by a manual muscle test as described by Kendall.[19] The wires from each muscle were attached to insulated leads and taped to the subject's body. A surface-ground electrode was placed on the clavicle on the involved side. The signals from the leads were transmitted using a battery-operated FM transmitter capable of transmitting up to 4 signals simultaneously (Noraxon Telemyo System, Noraxon USA, Tucson, Ariz). The battery pack was held by a research assistant in order to prevent the pack from restricting bodily movements.

A maximum manual muscle test (MVC) was performed for each muscle and used for normalization and quantification of the electrical activity during the exercises. The MVC was taken according to joint-position standards developed by Kendall.[19] The MVC position for each muscle was confirmed during pilot studies before the commencement of the current investigation. The EMG signal was filtered by the receiver with a bandwidth of 16–500 Hz, amplified, and reconverted from analogue to digital data. The signal was then sent to a personal computer, where the raw EMG data were sampled at a frequency of 2500 Hz and further analyzed with the Noraxon software. All data analysis was performed on integrated EMG data.

The EMG data obtained were normalized by a maximum voluntary isometric contraction during specific manual muscle testing for each muscle. The MVC was measured for a period of 5 seconds. During normalization, a sample of the MVC corresponding to the exact time of the cycle for each individual exercise repetition (milliseconds) was used as 100% MVC for each exercise. Therefore, the area of the EMG obtained during the MVC for the exact time for each exercise was set at 100%.

Exercises

Four dynamic stabilizing exercises were performed before and immediately after a shoulder-fatigue protocol. Each of these exercises has been documented by Henry and Lephart[20] as being valid dynamic stabilizing exercises for the shoulder complex. The exercises were as follows: (1) closed kinetic chain shoulder horizontal abduction/adduction movements on the slide board: Subject begins in a push-up position, proceeds to horizontally abduct both arms to touch a mark on the slide board, and returns to the starting position (Figure 1); (2) closed kinetic chain shoulder-rotation movements on the slide board: Subject begins in a push-up position, traces a circle on the slide board with one arm and then the other (Figure 2); (3) closed kinetic chain shoulder segmental supporting movements on the slide board: Subject begins in a push-up position and maintains a supporting position with 1 arm while tracing a circle on the slide board with the other arm (Figure 2); and (4) a traditional push-up. Each of these exercises was performed 3 times as a warm-up and 3 trials for test. From the 3 trials, a

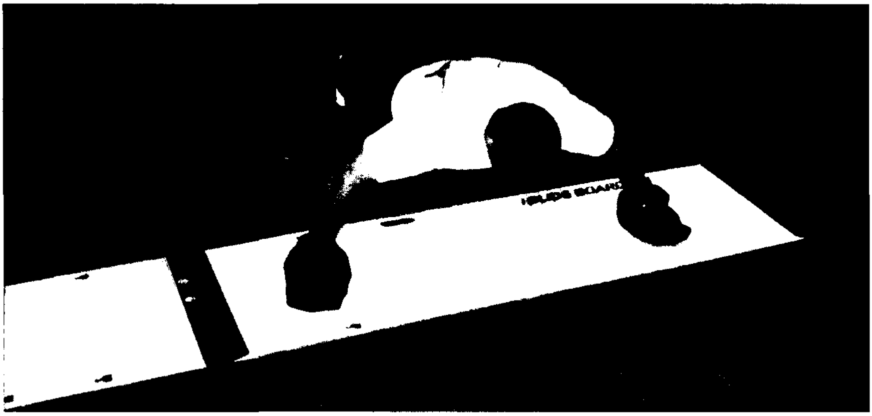

Figure 1 Patient performing shoulder horizontal abduction/adduction movement on the slide board.

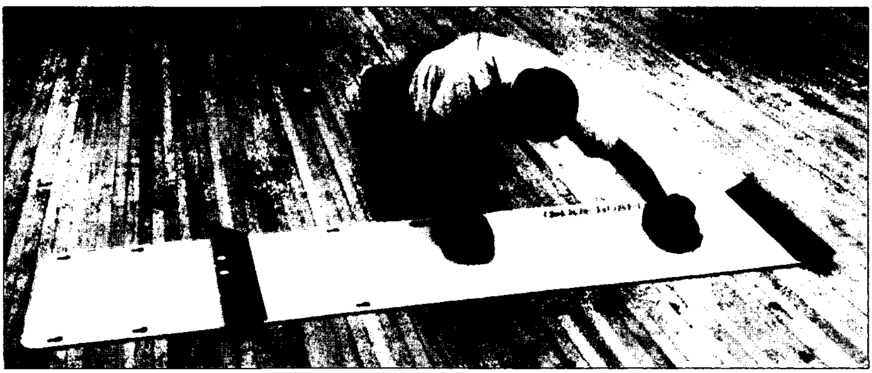

Figure 2 Patient performing closed kinetic chain rotational movements on the slide board with left-arm rotational movement and right-arm segmental supporting movement.

mean score was calculated and used for data analysis. The order of testing for the exercises was counterbalanced among all subjects. The entire postfatigue test was completed within 3 min of completion of the fatigue protocol. For each of the tests, the same investigator was used and the predetermined markings on the slide board remained constant.

Fatigue Protocol

Fatigue induction took place on the Biodex Isokinetic Dynamometer. Before muscle fatigue was induced, the peak concentric torque of the shoulder during the extension, adduction, and internal-rotation patterns (D2 extension) was determined. Each subject was positioned with the glenohumeral joint of the test limb aligned with the axis of rotation of the dynamometer and his feet placed on predetermined markings on the floor. The fatigue protocol was performed in a functional diagonal pattern with the dominant arm on the Biodex. Each subject began by completing 20 maximal repetitions eccentrically at 90° / s. Immediately afterward, subjects performed concentric repetitions at 120° / s until the torque value of 3 consecutive repetitions fell below 25% of the initial peak-torque value for the D2-extension portion of the diagonal pattern. The number of concentric repetitions performed in order to induce fatigue did not exceed 50 repetitions for any of the subjects.

Data Reduction

The area of the MVC for the exact duration of each of the 6 exercises was compared with the area of the EMG for each of the 4 muscles. This was compared with 25% of the MVC for each muscle. This percentage served as the minimum amount of muscle activity required in order for that particular muscle to provide stabilization for the humerus.

Paired *t* tests were conducted in order to determine whether the fatigue protocol had a significant effect on the muscle activity of the force couples. A paired *t* test was performed for each of the 4 muscles during each of the 4 exercises. A preset alpha level of $P < .05$ was selected to determine statistical significance.

Results

No significant differences were noted for any of the variables assessed between the pretreatment and posttreatment EMG values. The pretreatment and posttreatment mean scores and SDs are presented in Figures 3 through 6.

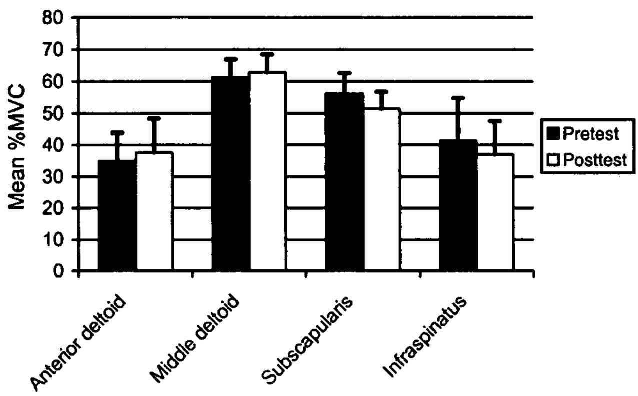

Figure 3 Mean EMG data for push-up exercise.

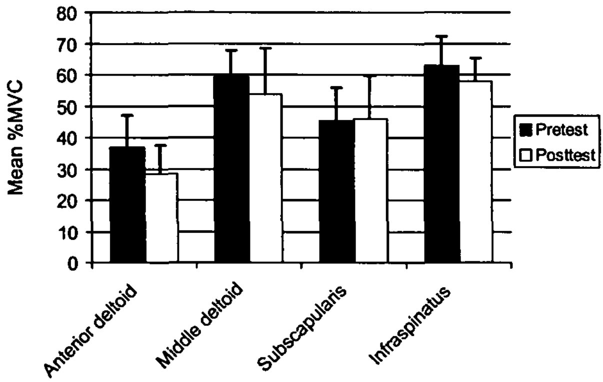

Figure 4 Mean EMG data for segmental supporting exercise on slide board.

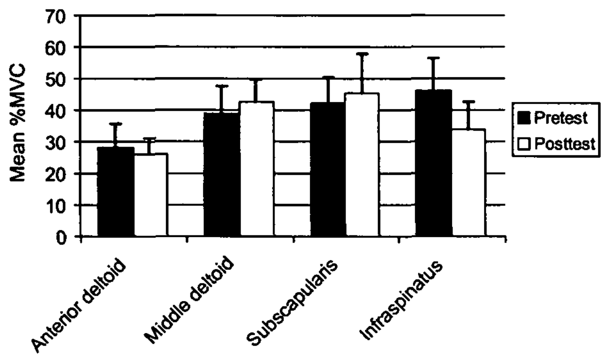

Figure 5 Mean EMG data for rotational movement on slide board.

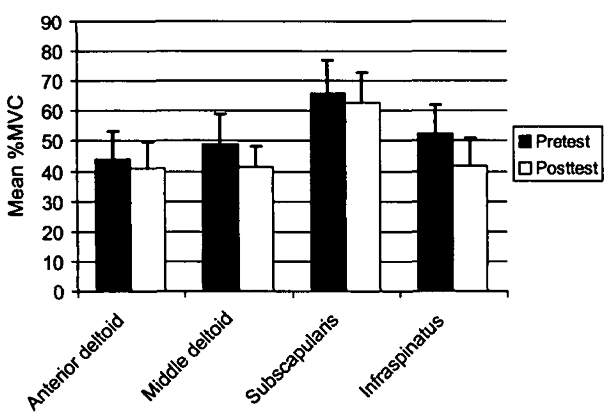

Figure 6 Mean EMG data for horizontal abduction/adduction movement on slide board.

Discussion

The present findings raise many issues with regard to the function of the dynamic stabilizers in the shoulder following fatigue. The results appear to indicate that the dynamic stabilizers function postfatigue similarly to the way they do in their normal, prefatigue state. The magnitude of the coactivation during the functional activities was not altered significantly after the fatigue protocol. This is an important finding with regard to dynamic stabilization of the glenohumeral joint. The subjects in this investigation had normal shoulders, and the prefatigue muscle activity during the 4 functional activities was used as baseline muscle activity for dynamic stabilization. The fact that no significant differences were noted confirms the ability of the muscle force couples of the glenohumeral joint to perform normally in the fatigued state.

None of the 4 muscles investigated in our study exhibited any significant difference in activation levels (area of EMG) from the prefatigue to the postfatigue state. It has been previously established that, compared with resting muscle, fatigue changes the EMG signal.[10,12,21,22] Those authors report that muscular fatigue appears to result in a reduction in membrane conduction velocity, while amplitude remains constant. This decrease in conduction increases the width of the muscle signal and, therefore, increases the area under the muscle signal curve. This is interpreted as an increase in the mean area of the muscle contraction.[10,12]

This finding is not supported by the results of our investigation, which revealed no increases in EMG area. Similarly, Hultman and Sjoholm[23] found that after a muscle-fatigue protocol, EMG activity quickly returned to normal levels, whereas force remained at a reduced level. This finding could certainly be considered consistent with the lack of significant changes noted in the EMG activity in our study.

The effect of fatigue on upper extremity dynamic stabilization has not been thoroughly investigated previously. One recent study, however, that was performed on the shoulder indicated no significant decrease in dynamic stabilization of the glenohumeral joint following muscle fatigue.[7] This study was performed with a 1-arm push-up in order to assess dynamic stabilization. The study performed by Myers[7] assessed both proprioception and neuromuscular control. The findings indicated a significant decrease in proprioceptive awareness but no significant alteration in neuromuscular control. Our results concur with the findings of Myers et al,[7] who state that it is difficult to explain the lack of a significant decrease in neuromuscular control. In essence, both the previous study and our current study describe a significant alteration in the afferent pathway but no alterations in the efferent pathway. According to previous literature describing neuromuscular control, this diminished joint afference would result in diminished neuromuscular control, or muscle stabilization.[7,24] The deficits in neuromuscular control would be manifested as aberrations in the muscle-firing patterns and EMG activity of the stabilizing musculature.[5,9] From the previous research we can conclude that joint afference, or proprioception, is significantly altered after muscle fatigue.

Other studies have established a relationship between fatigue and diminished joint-position sensibility and kinesthesia in both the lower and the upper extremity.[18] Recent research suggests that muscle fatigue worsens or impairs joint-position sensibility, in both the upper and the lower extremity.[16,25,26] Although joint-position sense was altered, the research revealed that joint kinesthesia was not significantly altered after muscle fatigue. These results were obtained in the quadriceps, hamstring, elbow, and shoulder. The deficits noted in joint-position sense might have a direct link to alterations that have been noted in muscle activity after fatigue.

With regard to neuromuscular control and dynamic stabilization of the shoulder, it is very well documented that there is a direct relationship between muscle fatigue and diminished proprioception in the shoulder.[7,17] In addition, Wickiewicz[8] has demonstrated that once rotator-cuff muscles are fatigued, the humeral head migrates superiorly during activities that include arm elevation.

The lack of diminished neuromuscular control in our study might be related to the nature of the exercises. The exercises used in this study have been previously established as valid dynamic stabilizing exercises by Henry.[20] Each of these activities provided muscle coactivation of the dynamic force couples around the glenohumeral joint. The mechanism by which these exercises induce coactivation is based on the characteristics of closed kinetic chain exercise. These characteristics include compression of the humeral head into the glenoid fossa and stimulation of the articular mechanoreceptors. The stimulation of the articular mechanoreceptors elicits a coactivation response of the dynamic force couples. With regard to our findings, it is plausible to conclude that the joint compression provided by these dynamic stabilizing exercises is sufficient to stimulate muscle coactivation, even in the fatigued state. Thus, there were no significant decreases in neuromuscular control postfatigue. This explanation might fit the findings of Myers et al,[7] as well. Their study also employed an activity involving axial loading and joint compression of the shoulder.

The findings of our study are very important with regard to the shoulder joint. The importance of dynamic stabilization in the shoulder is well documented,[1,3,20,26,27] and the fact that neuromuscular control appears to be relatively unaffected by fatigue is a step in the right direction for understanding shoulder function. The results of our study, performed on normal shoulders, indicate that the sensorimotor system is efficient enough to provide muscle coactivation during functional activity after the induction of muscle fatigue.

One of the primary differences between previous studies and the present one is the method of assessing muscle activity. In many of the previous studies that documented alterations in the EMG, EMG activity in response to sustained or isometric-type contractions was measured. The EMG assessment in the present study was measured during a series of functional tasks, more specifically, dynamic stabilizing exercises. The use of indwelling electrodes should also be considered a possible limitation. With indwelling electrodes, the muscle activity recorded might only be representative of a small portion of a large muscle. This is not a concern in the present study, however, because of the consistency of our results.

In order to properly interpret our results, the fatigue protocol should be thoroughly examined. The protocol was induced on the shoulder musculature by having subjects perform concentric and eccentric exercises on the Biodex Isokinetic Dynamometer. Isokinetic dynamometers are a popular method of inducing muscle fatigue because of their ability to quantify muscle-force production.[14] The fatigue protocol was performed in an open kinetic chain position, whereas the test exercises were performed in a closed kinetic chain position. Previous fatigue protocols for both the upper and lower extremities employed the open-chain fatigue protocol because of the ability of the isokinetic dynamometer to provide objective evidence of muscle fatigue.[7,14] The degree of muscle fatigue was quantified by the subjects' ability to generate torque and was easily measured on the Biodex system. This method has been previously reported by Rozzi[14] and appears to follow the traditional definition of fatigue as the inability to generate force. Our subjects completed concentric repetitions in a diagonal pattern until they were unable to generate 25% of their peak torque for 3 consecutive repetitions. Although the isokinetic strength values produced during the diagonal pattern represented a significant decrease in peak torque, we have no conclusive method of confirming that the 4 target muscles experienced substantial fatigue. This should be considered a limitation of the study. The fatigue protocol employed is, however, similar to other referenced protocols in other refereed studies,[7,14] and we believe that our protocol produced muscle fatigue in the shoulder musculature.

Conclusion

The results of our study indicate that EMG activity of the muscle force couples of the glenohumeral joint is not significantly altered after muscle fatigue. Force-couple EMG activity was assessed during functional dynamic stabilization exercises for the upper extremity. Although proprioception has been demonstrated to be altered after muscle fatigue in the upper and lower extremities, neuromuscular control of the efferent pathway has not been shown to be significantly altered by muscle fatigue in the shoulder. The characteristics of dynamic stabilizing exercises commonly performed in the upper extremity might be sufficient to stimulate the coactivation of the shoulder musculature, even after the induction of muscle fatigue. The resultant joint compression and stimulation of articular structures might initiate force-couple coactivation and neuromuscular control of the shoulder.

Although this study begins the process of understanding the effect of fatigue on neuromuscular control and dynamic stabilization, further research is warranted in this area. The present study assessed the area of EMG during functional exercises. Further study in this area should assess muscle-firing patterns during these stabilization activities. Information on the muscle-firing patterns, in concert with information gathered here, might provide a more thorough understanding of the efferent pathway after muscle fatigue.

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