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Electromyographic activity of selected scapular stabilizers during glenohumeral internal and external rotation contractions

Aaron K. Schachter, MD*, Malachy P. McHugh, PhD, Timothy F. Tyler, PT/ATC, Ian J. Kreminic, ME, Karl F. Orishimo, MS, Christopher Johnson, MPT, Simon Ben-Avi, PhD, Stephen J. Nicholas, MD

Orthopedic Health, LLC, Milford Hospital, Milford CT Simon, Cooper Union School for Advancement of Art and Science, School of Engineering, New York, NY

Hypothesis: An important synergistic relationship exists between the scapular stabilizers and the glenohumeral rotators. Information on the relative contribution of the scapular stabilizers to glenohumeral rotation would be useful for exercise prescription for overhead athletes and for patients with shoulder pathology. We hypothesized that the scapular stabilizers would be highly active during both maximal and submaximal internal and external rotation.

Materials and methods: Eight healthy male volunteers (16 shoulders) performed internal and external glenohumeral rotation testing at maximal and submaximal intensities. They also performed a scapular retraction rowing exercise at maximal and submaximal levels. Electromyographic (EMG) signals were recorded from the infraspinatus, pectoralis major, serratus anterior, and middle trapezius. Values were compared among muscle groups, among individual muscles at different intensity levels, and among individual muscles at different points in the arc of motion.

Results: For submaximal glenohumeral internal rotation, activity in the scapular stabilizers was not different ($P = .1\text{-}.83$) from activity in the internal rotator throughout the range of motion. For the initial two-thirds of maximal internal rotation, middle trapezius activity and pectoralis major activity were higher ($P < .05$) than serratus anterior activity. For submaximal external rotation, activity in the scapular stabilizers during the middle phase of the motion was higher ($P < .05$) than activity in the external rotators. For maximal external rotation these differences were present throughout the motion with middle trapezius activity exceeding 100% maximal voluntary contraction.

Conclusions: The scapular stabilizers functioned at a similar or higher intensity than the glenohumeral rotators during internal and external rotation. This highlights the importance of training the scapular stabilizers in upper extremity athletes and in patients with shoulder pathology.

Level of evidence: Basic Science Study.

Keywords: Scapular stabilizers; glenohumeral rotation; kinetic chain

This work was conducted at Nicholas Institute for Sports Medicine and Athletic Trauma (NISMAT), Lenox Hill Hospital, New York, NY.

*Reprint requests: Aaron K. Schachter, MD, Orthopedic Health LLC, 30 Commerce Park, Milford, CT 06824.

E-mail address: aaronschachtermd@gmail.com (A.K. Schachter).

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The term "scapular stabilizers" collectively refers to muscles whose net effect is to dynamically stabilize the scapula (eg, trapezius complex, serratus anterior). The 4 main functions of the scapular stabilizers, as described by Kibler and McMullen,[12] are:

1. to maintain a constant center of glenohumeral rotation while the arm, scapula, trunk, and body are in motion, which has been likened to a seal keeping a ball on its nose;
2. to provide scapular motion along the thoracic wall—scapular retraction facilitates the cocking phase of throwing, whereas protraction allows for the dissipation of decelerational forces in the follow-through phase of throwing;
3. to elevate the acromion and allow for clearance of the rotator cuff during glenohumeral rotation, thereby avoiding impingement; and
4. to link the upper extremity to the trunk, providing a vital link in the kinetic chain. This facilitates the pattern of serial muscle activation that transmits forces from the feet on the ground to the delivery point at the hand.

Prior electromyographic (EMG) studies have described the activity of the scapular stabilizers during various rehabilitation exerices.[3,4,6,14,16,17] These and other studies have helped to guide rehabilitation programs with a focus on the scapular stabilizers.[2,13] The role of the scapular stabilizers in activities that involve the concept of the kinetic chain has also been examined. Previous EMG studies analyzed the activity of the scapular stabilizers in activities such as the baseball throw and the tennis serve.[7-9,11,15,18] The scapular stabilizers demonstrate high activity in the late cocking and follow-through phases of the pitch/serve. Further, this activity was shown to be significantly higher in professional pitchers than in amateur pitchers.[7]

The intimate relationship of scapulohumeral and scapulothoracic function has further been demonstrated in studies focusing on fatigue and dysfunction. Fatigue of the rotator cuff external rotators has been shown to alter both glenohumeral and scapulothoracic kinematics.[2,5,19] Isolated fatigue of the scapular stabilizers has been shown to alter glenohumeral kinematics.[16] In addition, fatigue of the scapular retractors has been shown to reduce glenohumeral internal and external rotation strength.[21] Lastly, pathologic conditions have demonstrated alterations in the EMG activity of the scapular stabilizers.[10,15]

These previous studies show that an important synergistic relationship exists between the scapular stabilizers and the glenohumeral rotators. However, the relative contribution of the scapular stabilizers to glenohumeral rotation has not been quantified. This information would be useful for exercise prescription for overhead athletes and for patients with rotator cuff pathology. Therefore, the purpose of this study was to quantify the EMG activity of the scapular stabilizers during glenohumeral internal and external rotation. We hypothesized that the scapular stabilizers would be highly active during both maximal and submaximal internal and external rotation.

Materials and methods

This study received approval from Lenox Hill Hospital Institutional Review Board (#L08.04.27E).

The study enrolled 8 male volunteers who had no previous history of shoulder injury or pathology. Both shoulders were tested for each participant, equaling 16 shoulders in the study. EMG activity was recorded from 4 muscles on each shoulder: a glenohumeral external rotator (infraspinatus), a glenohumeral internal rotator (pectoralis major), and 2 scapular stabilizers (serratus anterior and the middle trapezius). Surface EMG was used to measure all muscles except for the infraspinatus, in which fine wire EMG was used.

Procedures

EMG activity was recorded during manual isometric maximal voluntary contractions (MVC) for each muscle for subsequent normalization procedures. The infraspinatus MVC test was resisted external rotation at 0° abduction and 0° external rotation. For middle trapezius MVC testing, participants resisted horizontal adduction with the arm at 90° of abduction in the plane of the torso and with the elbow flexed to 90°. All volunteers were required to maintain their trunk position in the same plane as the arm. For pectoralis major MVC testing, horizontal abduction was resisted with the arm at 90° of abduction in the plane of the scapula and with the elbow flexed to 90°. For serratus anterior MVC testing, the tester provided resistance against a serratus punch with the arm flexed to 90° and the elbow extended.

Next, seated glenohumeral internal and external rotation contractions were performed on an isokinetic dynamometer (Biodex System 2, Biodex Medical Systems, Shirley, NY) at a position of 90° abduction in the plane of the torso. No external stabilization of the trunk was provided to maximize the contribution of the participants' dynamic stabilizers. The shoulder that first underwent testing was randomly assigned. Five maximal repetitions were then performed at 60° after a warm-up period. Contractions were performed between 0° and 90° of external rotation. After a brief rest period, 20 repetitions were performed at 50% of the respective maximal internal and external efforts.

The individual then performed a scapular retraction exercise (supinated row) on a cable column. Three repetitions of an isometric maximal row were recorded, followed by 20 isotonic repetitions (rows) at 50% of the isometric maximum. The isometric row was performed with the arm in the plane of the trunk. Lastly, after a brief rest period, the isokinetic glenohumeral rotational exercise protocol was performed with the contralateral shoulder.

EMG techniques

For the infraspinatus, a paired fine wire electrode (Chalgren Enterprises Inc. Gilroy, CA) was inserted 2 cm inferior to the center of the scapular spine. For the middle trapezius, a pair of surface electrodes (Ag/AgCl; 1-cm diameter, 2-cm interelectrode distance) were placed midway between the midpoint of the spine of the scapula and the spinous process of the vertebra at the same level. For the pectoralis major, a pair of surface electrodes was placed just medial to the axillary fold. For the serratus anterior, a pair of surface electrodes was placed just lateral to the inferior angle of the scapula (Fig. 1). EMG signals were filtered (10-500 Hz) and amplified (60 dB; Noraxon TeleMyo) before sampling at 1 kHz (BioPac Systems AcqKnowledge) and then rectified and smoothed (100 ms RMS).

EMG signals were recorded by telemetry, filtered (range, 10-500 Hz), and amplified (60 dB) (Noraxon) before sampling at 1 kHz (Run Technologies, Phoenix, AZ). All data were analyzed with a custom software package written in MATLAB (The Mathworks, Natick, MA). EMG signals were rectified and smoothed (100 ms RMS). All EMG data for each individual were normalized to the MVC testing for the respective muscle:

- infraspinatus—manual external rotation MVC test or maximal isokinetic external rotation contractions, whichever was higher;
- middle trapezius—horizontal abduction MVC test or maximal isometric scapular retraction, whichever was higher;
- pectoralis major—horizontal adduction MVC test or maximal isokinetic internal rotation, whichever was higher;
- serratus anterior—resisted serratus punch MVC test.

To evaluate function during specific aspects of rotation, glenohumeral data were analyzed for 3 phases of both internal and external rotation, dividing each 90° arc into 30° segments.

Statistical analyses

Normalized EMG data were not normally distributed, and nonparametric statistics were used to analyze the data. Differences in EMG activity (% of MVC) between the different muscles and between the different phases of motion were assessed using Friedman tests for main effects and Wilcoxon signed rank tests for pairwise comparisons, with appropriate Bonferroni adjustments. Median values are reported in the text and displayed in the figures. From previous data comparing surface and fine wire EMG signals between rotator cuff and muscles (infraspinatus and supraspinatus) and scapular stabilizers (upper trapezius), we estimated that a difference in % MVC of greater than 20% between muscles or between phases of motion could be detected as significant ($P < .05$) with 80% power with the sample size used in this study.[1]

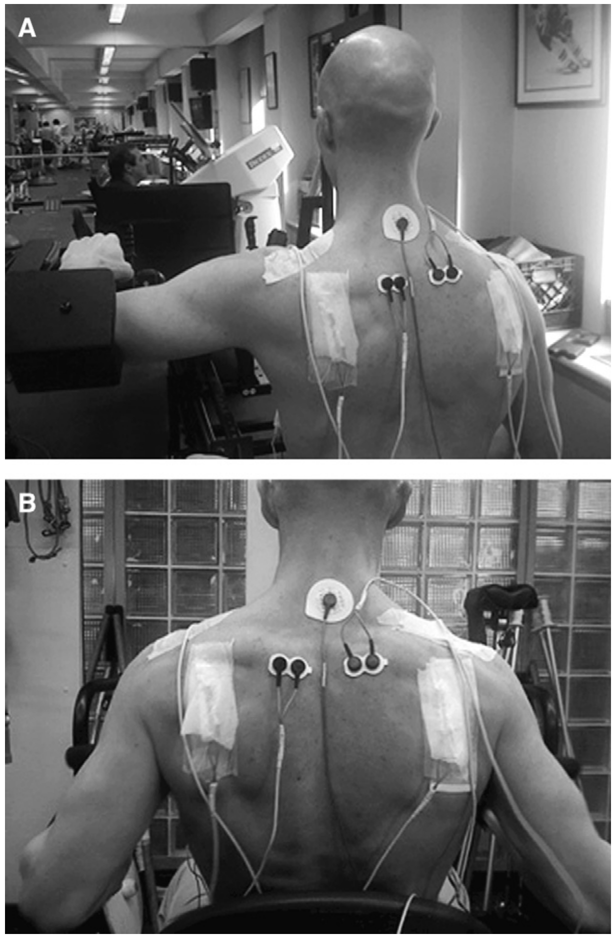

Figure 1 **(A)** A study volunteer demonstrates the positioning of the extremity before testing initiation and of the electromyographic leads for data collection while seated during the testing of glenohumeral internal and external rotation. **(B)** The volunteer demonstrates a posterior view of the position of electrodes and form for isokinetic rowing.

Results

Internal rotation

Maximal contractions

During maximal internal glenohumeral rotation, EMG activity of the pectoralis major was higher than activity in the serratus anterior from 90° to 60° (65% vs 35% MVC, $P < .05$) and from 60° to 30° (51% vs 19% MVC, $P < .01$), but was not different from 30° to 0° (37% vs 42% MVC, $P = .9$; Fig. 2). EMG activity in the pectoralis major was not different from activity in the middle trapezius in any of the three phases of motion (65% vs 67% MVC, 51% vs 34% MVC, and 37% vs 44% MVC, respectively). For the pectoralis major, EMG activity was lower for the final one-third of the motion compared with the initial two-thirds of the motion ($P < .05$). By contrast, middle trapezius and serratus anterior activity was lowest in the middle phase of the motion (60° to 30°; $P < .01$).

Submaximal contractions

EMG activity for the 3 phases of motion during submaximal internal rotation was not different between the pectoralis major (28%, 20%, 18% MVC), middle trapezius (26%, 13%, 37% MVC), and serratus anterior (21%, 14%, 30% MVC; muscle effects $P = .1$-.83; Fig. 3). Pectoralis major activity was higher for the initial phase of motion (90°-60°) compared with the rest of the motion ($P < .01$). Middle trapezius and serratus anterior activity was lowest for the middle phase of the motion ($P < .001$).

External rotation

Maximal contractions

Paradoxically, during maximal glenohumeral external rotation, contractions infraspinatus activity through each

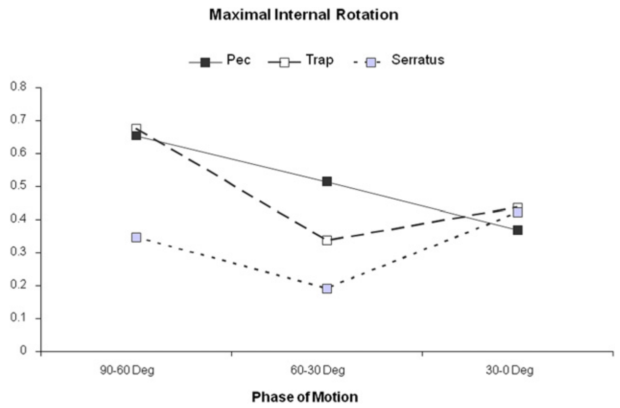

Figure 2 Pectoralis major *(Pec)*, middle trapezius *(Trap)*, and serratus anterior *(Serratus)* activity (% maximal voluntary contractions) during maximal isokinetic internal rotation. Friedman tests were used for effect of muscle and phase of motion, with Wilcoxon sign rank tests for pairwise comparisons with Bonferroni corrections. Effect of muscle: 90°-60°, $P = .05$; Pec > Serratus, $P < .05$; 60°-30°, $P = .02$; Pec > Serratus, $P < .05$; 30°-0°, $P = .94$. Effect of phase of motion: Pec, $P = .04$; 90°-60° and 60°-30° > 30°-0°, $P < .05$; Trap, $P < .001$; 90°-60° > 60°-30°, $P < .05$; Serratus, $P = .002$; 90°-60° and 30°-0° > 60°-30°, $P < .05$. The range bars show the standard deviation.

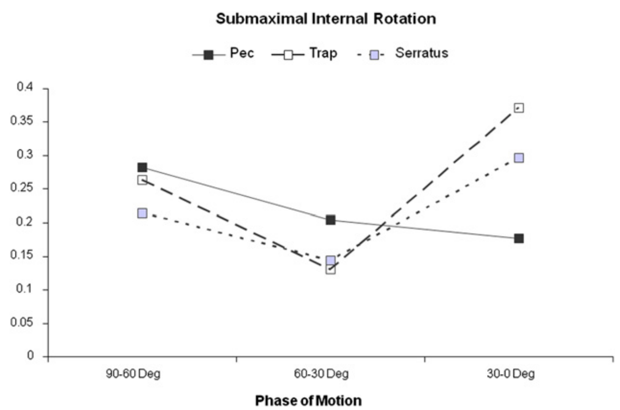

Figure 3 Pectoralis major *(Pec)*, middle trapezius *(Trap)*, and serratus anterior *(Serratus)* activity (% maximal voluntary contractions [MVC]) during submaximal isokinetic internal rotation (50% MVC). Friedman tests were used for effect of muscle and phase of motion, with Wilcoxon sign rank tests for pairwise comparisons with Bonferroni corrections. Effect of muscle: 90°-60°, $P = .57$; 60°-30°, $P = .83$; 30°-0°, $P = .1$. Effect of phase of motion: Pec, $P = .002$;, 90°-60° and 60°-30° > 30°-0°, $P < .05$; Trap, $P < .001$; 90°-60° and 30°-0° > 60°-30°,$P < .05$; Serratus, $P < .001$; 30°-0° > 60°-30°, $P < .05$.

phase of motion (47%, 41%, 37% MVC) was lower ($P < .01$) than activity in both the middle trapezius (109%, 95%, 99% MVC) and serratus anterior (91%, 88%, 81% MVC; Fig 4). None of the 3 muscles showed any differences in EMG activity between the three phases of motion (0°-30°, 30°-60°, 60°-90°).

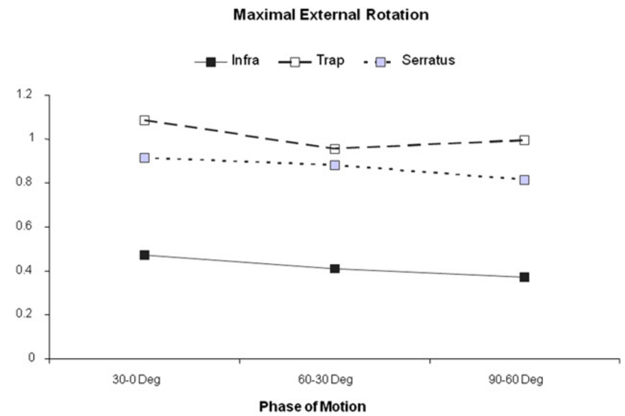

Figure 4 Infraspinatus *(Infra)*, middle trapezius *(Trap)*, and serratus anterior *(Serratus)* activity (% maximal voluntary contractions) during maximal isokinetic external rotation. Friedman tests were used for effect of muscle and phase of motion, with Wilcoxon sign rank tests for pairwise comparisons with Bonferroni corrections. Effect of muscle: 90°-60°, $P = .003$; Trap and Serratus > Infra, $P < .05$; 60°-30°, $P < .001$; Trap and Serratus > Infra, $P < .05$; 30°-0°, $P < .001$; Trap and Serratus > Infra, $P < .05$. Effect of phase of motion: Infra, $P = .65$; Trap, $P = .83$; Serratus, $P = .07$.

Submaximal contractions

During submaximal external rotation contractions, infraspinatus activity was lower than serratus anterior activity for all 3 phases of the motion (27% vs 52% MVC, 31% vs 60% MVC, 39% vs 57% MVC; all $P < .01$; Fig 5) and lower than middle trapezius activity for the middle phase of the motion (31% vs 68% MVC, $P < .05$). None of the 3 muscles showed any differences in EMG activity between the 3 phases of motion.

Scapular retraction (supinated row)

During maximal isometric scapular retraction in the supinated row position, there was no difference in EMG activity between the middle trapezius (61% MVC), serratus anterior (35% MVC), pectoralis major (33% MVC), and infraspinatus (48% MVC; effect of muscle $P = .34$). During submaximal isotonic scapular retraction (supinated rowing motion), middle trapezius activity (70% MVC), serratus anterior activity (26%), and infraspinatus activity (59%) were all higher than pectoralis major activity (13%, all $P < .01$).

Glenohumeral rotation vs scapular retraction

Middle trapezius activity during maximal scapular retraction (supinated row) was not different from its activity during maximal internal rotation (61% vs 81% MVC; $P = .18$) and was actually lower than its activity during maximal external rotation (61% vs 117% MVC; $P < .01$). Middle trapezius activity during submaximal scapular retraction was higher

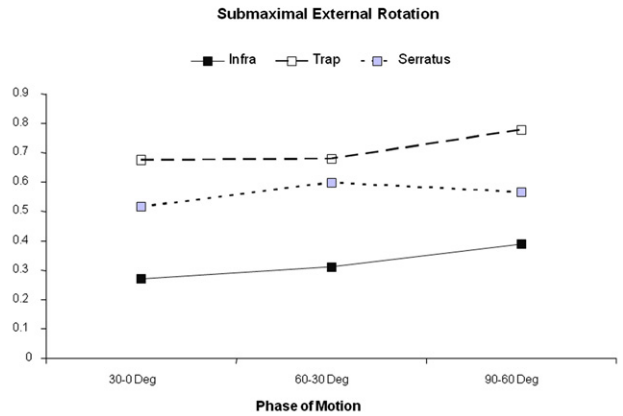

Figure 5 Infraspinatus *(Infra)*, middle trapezius *(Trap)*, and serratus anterior *(Serratus)* activity (% maximal voluntary contractions) during submaximal isokinetic external rotation. Friedman tests were used for effect of muscle and phase of motion, with Wilcoxon sign rank tests for pairwise comparisons with Bonferroni corrections. Effect of muscle: 90°-60°, $P = .009$; Serratus > Infra, $P < .05$; 60°-30°, $P = .009$, Trap and Serratus > Infra, $P < .05$; 30°-0°, $P = .019$; Serratus > Infra, $P < .05$. Effect of phase of motion: Infra, $P = .27$; Trap, $P = .78$; Serratus, $P = .65$.

than its activity during submaximal internal rotation (70% vs 36% MVC; $P < .05$) but was not different from its activity during submaximal external rotation (70% vs 65% MVC, $P < .68$). Of note, the activity for the middle trapezius during glenohumeral rotation is the peak value during the full range of motion, and therefore, values are higher than the values for each of the 3 phases of motion in Figs. 2 to 5.

Discussion

The results of this study highlight the important contribution of the scapular stabilizers to glenohumeral rotational kinematics. During glenohumeral internal rotation, EMG activity in the middle trapezius and serratus anterior was, for the most part, not different from activity in the pectoralis major. During glenohumeral external rotation, EMG activity in the middle trapezius and the serratus anterior was actually higher than activity in the infraspinatus. Although the teres minor may be a more substantial contributor to external rotation at this position, we did not expect that the infraspinatus would be less active in the middle trapezius. Thus, activity in the selected scapular stabilizers was similar to or higher than activity in the selected prime movers. It was also apparent that the scapular stabilizers were more active during the initiation and termination of glenohumeral internal rotation than in the middle phase of the motion. By contrast, pectoralis major activity was lowest in the terminal phase of internal rotation. For external rotation, muscle activity did not vary systematically through the range of motion.

The high level of activity noted in the scapular stabilizers during glenohumeral rotation supports that glenohumeral rotation is a coupled rather than an isolated motion. We should therefore consider these muscles as couples, rather than differentiating their function as prime movers and stabilizers. Because these muscles work in a coupled fashion, rehabilitation should be directed as such rather than trying to perform ‘‘isolated,’’ muscle-focused exercise. Previous studies have described the activity of the scapular and glenohumeral rotators during dynamic high-speed motions such as the pitching motion[7-9] and tennis strokes.[11,18]

With regard to baseball pitching, Gowan et al[7] found that amateur pitchers demonstrated significantly higher EMG signals in the muscles of the rotator cuff, whereas professional pitchers demonstrated higher EMG signals in the scapular stabilizers, indicating that proficiency required effective scapular stabilization. With regard to tennis strokes, Ryu et al[18] demonstrated high activity in the serratus anterior during both the serve and forehand motions. During the tennis serve, Kibler et al[11] showed the importance of proper sequencing of muscle activations, with the scapular stabilizers activated before the glenohumeral rotators. Together, these studies[7-9,11,18] highlight the importance of the scapular muscles during complex shoulder motions.

The present study examined the relationship between the scapular stabilizer muscles and the glenohumeral rotators during less complex isolated glenohumeral motions to specifically quantify the role of the scapular stabilizers in glenohumeral motion. Qualitatively the results are in agreement with the previous pitching and tennis stroke studies[7-9,11,18] showing high activity in the scapular muscles during glenohumeral internal and external rotation. Quantitatively, the present study highlights that during isolated glenohumeral internal and external rotation, the scapular muscles (serratus anterior and middle trapezius) are working as hard, or harder, than the rotators (infraspinatus and pectoralis major). These findings have important implications for rehabilitation of shoulder injuries, indicating that equal emphasis should be placed on retraining the scapular muscles and the glenohumeral rotators.

The intimate relationship between the scapular stabilizers and glenohumeral rotators has also been highlighted by recent studies on the selective fatigue of muscle groups. McQuade et al[13,16,19] demonstrated altered scapulohumeral kinematics after scapulothoracic muscle fatigue, and concluded that shoulder fatigue affects the way in which the scapula moves concomitantly with the humerus and that fatigue tends to result in increased motion of the scapula. Similarly, Tyler et al[21] demonstrated that fatigue in the scapular retractors decreased glenohumeral internal and external rotation strength. Ebaugh et al[5] examined the effects of an external rotational fatigue protocol on scapulothoracic and glenohumeral kinematics. They reported that fatigue of the external rotators not only decreases external rotation of the humerus but also leads to less posterior tilt of the scapula in the midranges of motion.

Considering that in the present study the scapular stabilizers were more active than the infraspinatus during external rotation, it is possible that fatigue in the scapular stabilizers precedes fatigue in the external rotators during external rotation exercises. The subsequent alteration in scapula-humeral kinematics may have implications for injury. For example, weakness in the scapular retractors was recently demonstrated in adolescent baseball pitchers with throwing-related pain.[20]

An important limitation in the present study is that a limited number of muscles were studied for each movement: infraspinatus for external rotation, pectoralis major for internal rotation, and middle trapezius and serratus for scapular stabilization. The proximity of the teres major and minor to the infraspinatus was a factor in choosing only 1 muscle in this region and dictated that infraspinatus activity was monitored by fine wire instead of surface electrodes. Although the subscapularis is an important internal rotator, monitoring the subscapularis requires fine wire electrodes, and these are somewhat technically challenging and tedious to place. We therefore decided that surface EMG of the pectoralis would be sufficient for the limited purpose of assessing internal rotation activity. The middle trapezius was chosen as the primary scapular retractor because it is the target muscle for the supinated rowing exercise, which is commonly used in rehabilitation and training. Further, the serratus and middle trapezius were chosen to minimize the ‘‘crosstalk’’ that can potentially occur with surface EMG measurements (eg, upper trapezius and supraspinatus).[1] An additional limitation is that function of the scapular stabilizers during isokinetic glenohumeral internal and external rotation may be different from their function during a multisegmental dynamic movement such as throwing a ball.

Conclusions

Our study showed that the scapular stabilizers were functioning at a similar or higher intensity than the glenohumeral rotators during internal and external rotation. This highlights the importance of training the scapular stabilizers and including force-coupling techniques in upper extremity athletes and in patients with rotator cuff pathology.

Disclaimer

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