Electromyographic Analysis of Specific Exercises for Scapular Control in Early Phases of Shoulder Rehabilitation

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Background: Restoration of control of dynamic scapular motion by specific activation of the serratus anterior and lower trapezius muscles is an important part of functional rehabilitation. This study evaluated activation of those muscles in specific exercises.

Hypothesis: Specific exercises will activate key scapular-stabilizing muscles in clinically significant amplitudes and patterns.

Study Design: Controlled laboratory study.

Methods: Muscle activation amplitudes and patterns were evaluated in the serratus anterior, upper trapezius, lower trapezius, anterior deltoid, and posterior deltoid muscles with electromyography in symptomatic (n = 18) and asymptomatic (n = 21) subjects as they executed the low row, inferior glide, lawnmower, and robbery exercises.

Results: There were no significant differences in muscle activation amplitude between groups. Muscle activation was moderate across all of the exercises and varied slightly with the specific exercise. The serratus anterior and lower trapezius were activated between 15% and 30% in all exercises. Upper trapezius activation was high (21%-36%) in the dynamic exercises (lawnmower and robbery). Serratus anterior was activated first in the low row and last in the lawnmower and robbery. The upper trapezius and lower trapezius were activated first in the lawnmower and robbery.

Conclusion: These specific exercises activate key scapular-stabilizing muscles at amplitudes that are known to increase muscle strength.

Clinical Relevance: These exercises can be used as part of a comprehensive rehabilitation program for restoration of shoulder function. They activate the serratus anterior and lower trapezius—key muscles in dynamic shoulder control—while variably activating the upper trapezius. Activation patterns depended on scapular position resulting in variability of amplitude and activation sequencing between exercises. Inferior glide and low row can be performed early in rehabilitation because of their limited range of motion, while lawnmower and robbery, which require larger movements, can be instituted later in the sequence.

Keywords: scapula; EMG; rehabilitation; muscle activation

Scapular dyskinesis, with resulting alterations in static scapular position and loss of dynamic control of scapular motion, is commonly found in association with a variety of shoulder injuries.[7,34,36,39,43,56] Dyskinesis results in an increase in anterior tilt, decrease in scapular upward rotation, and an increase in scapular internal rotation.[34,36,38,55] The dyskinetic position and motion have been associated with disruption of coupled scapulohumeral rhythm (SHR),[43] increased tension in the anterior inferior glenohumeral ligament,[57] decreased subacromial space with arm abduction,[20] and decreased supraspinatus muscle activation.[31]

Control of static position and dynamic motion is accomplished by patterned muscle activations that place the scapula in optimal position between the stable base of the trunk and the mobile arm.[42] These activations must be coupled to increase the mechanical advantage of the scapular muscles and also must be specific to the required task.[2,18,34,52] Muscle activation patterns and strength have been shown to be altered in association with shoulder injury.[9,16] Rehabilitation of these alterations is an integral part of shoulder rehabilitation.

Many current shoulder rehabilitation protocols include exercises for restoration of scapular position and motion.

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Most place the emphasis on scapular control early in the rehabilitation sequence. The goals of these protocols are to restore control of the scapula so that it maintains a position of posterior tilt and external rotation—a position collectively termed retraction—as a starting point for rehabilitation of shoulder function.

Many studies have examined the activity of the muscles that stabilize the scapula during rehabilitation.[4,6,11,15,19,37,40,53] These studies have often evaluated exercises that require shoulder motions that would be difficult to achieve in the early phases of a postoperative rehabilitation program such as arm elevation, glenohumeral rotation, or arm forward flexion/scapular retraction. The current study was devised to evaluate exercises that have been previously prescribed to activate key muscles of scapular stabilization, the upper and lower trapezius (LT) and the serratus anterior (SA), during the early phases of rehabilitation for both postoperative and acute nonoperative shoulder injuries.[17,20,30,49]

The primary purpose of this study was to evaluate the amplitude and the sequence of muscle activation of specific exercises in both symptomatic and asymptomatic populations. The objectives were to compare the effect of the exercises between groups of subjects, to evaluate the effect of the exercises on activation amplitude and sequencing, and to determine if the amplitudes were at levels that are considered significant for strengthening muscles. The research hypotheses were that minimal differences would be seen between groups, that activation amplitudes would vary with the specific exercise, and that the amplitudes would be at levels (20%-30% maximal voluntary isometric muscle contractions [MVIC]) that are considered to be effective for moderate muscle strengthening.

MATERIALS AND METHODS

Subjects

Thirty-nine subjects (age, 29.62 ± 6.69 years; height, 173.82 ± 7.86 cm; weight, 76.64 ± 14.77 kg) were studied. Eighteen (9 male, 9 female) subjects who were asymptomatic for shoulder pain (age, 27.3 ± 4.4 years; height, 172 ± 6.3 cm; weight, 72.7 ± 14.4 kg) had no history of shoulder injury requiring restriction of activities nor demonstrated scapular dyskinesis on clinical examination. Twenty-one (13 male, 8 female) symptomatic subjects (age, 31.6 ± 7.7 years; height, 175 ± 8.9 cm; weight, 80 ± 14.6 kg) who were patients of the senior author (W.B.K.) had a diagnosis by clinical examination and/or imaging (radiographs, magnetic resonance imaging (MRI) as appropriate) of impingement (n = 9), labral injury (n = 5), or rotator cuff tendinopathy (n = 7), and demonstrated scapular dyskinesis (altered scapular position at rest and/or motion upon dynamic arm elevation) on clinical examination. These subjects were consecutive patients who consented to enroll in the study and were to be placed in a comprehensive rehabilitation program for their injury that emphasized scapular control as the first stage of rehabilitation.[25] All subjects took part in the study before beginning the rehabilitation program. A subject was excluded from this study if he or she had any neurological disorders or had previous shoulder surgery. Subjects read and signed an Institutional Review Board–approved informed consent form that described the research procedure before participating in the study.

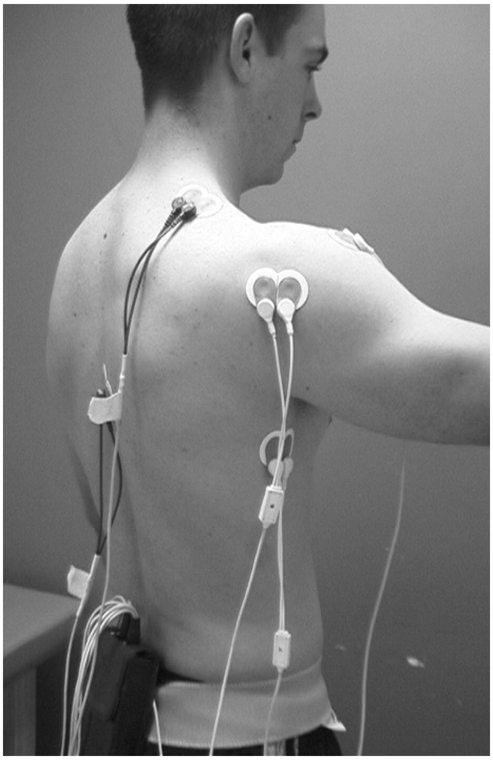

Figure 1. Electrode set-up indicating placement for surface electromyography electrodes.

Electrode Placement

The skin surface was prepared by shaving any hair overlying the skin, lightly debriding the skin with fine sandpaper, and vigorously cleaning with an alcohol swab prior to electrode placement to minimize skin impedance.[5] Bipolar surface electrodes (Medicotest, Olstykke, Denmark) were placed on 3 scapulothoracic muscles (the upper trapezius [UT], LT, and SA) and 2 scapulohumeral muscles (anterior deltoid [AD] and posterior deltoid [PD]) using previously published standardized methods.[10,59] The 3 scapulothoracic muscles were chosen because they are considered to be the most important muscles in the force couples that control scapular position and motion.[2,52] The deltoid muscle was chosen to reflect arm movement. Each electrode was made of Ag/AgCl with an interelectrode distance of 2 cm. The surface electrodes were connected to a belt amplifier that was attached around the subject's waist (Figure 1). The dominant arm was tested in each of the asymptomatic subjects, while the injured arm was tested in the symptomatic subjects.

TABLE 1
MVIC Test Positions for Normalization of EMG[a]

Muscle	Electrode Placement[10]	Position[24]
Scapular muscles		
Upper trapezius	Electrodes placed 2 cm apart on the upper back halfway between C7 spinous process and the acromion process.	Subject: Shoulders placed in shrugged position. Examiner: One hand placed over upper trapezius between neck and acromion. Subject: Isometrically shrugged resisting shoulder depression.
Lower trapezius	Electrodes placed 2 cm apart on an oblique angle, 5 cm down from the scapular spine and outside the medial border of the scapula.	Subject: Prone with arm passively placed to 180° of flexion Examiner: One hand placed on back below scapula and one hand placed over distal humerus above elbow. Subject: Isometrically forward flexed resisting extension.
Serratus anterior	Electrodes placed 2 cm apart just below the axilla at the level of the inferior angle of the scapula (medial to the latissimus dorsi).	Subject: Arm forward flexed to 130°. Examiner: One hand placed over dorsal arm and one hand placed on lateral scapula for stability. Subject: Isometrically flexed resisting forward extension.
Shoulder muscles		
Anterior deltoid	Electrodes placed 2 cm apart approximately 4 cm below the clavicle running parallel with the muscle fibers.	Subject: Arm placed in abduction, slight flexion, and slight external rotation. Examiner: One hand placed on belly of biceps brachii and one hand placed on superior scapula for stability. Subject: Isometrically forward flexed and abducted resisting extension and adduction.
Posterior deltoid	Electrodes placed 2 cm apart and 2 cm below the lateral border of the scapular spine and placed in an oblique direction toward the humerus so they ran parallel to the muscle fibers.	Subject: Arm placed in abduction, slight extension, and slight internal rotation. Examiner: One hand placed on distal triceps above olecranon process and one hand placed on superior scapula for stability. Subject: Isometrically extended and abducted resisting flexion and adduction.

[a] MVIC, maximal voluntary isometric muscle contractions; EMG, electromyography.

Electromyography Collection

A Noraxon Telemyo unit (Noraxon USA Inc, Scottsdale, Arizona) transmitted all raw electromyography (EMG) data at 1000 Hz via a telemetry pole (transmitting frequency, 905-928 MHz) to its receiver unit. This device had a common mode rejection ratio of 90 dB. The gain for the surface electrodes was set at 2000. All data were recorded, stored, and analyzed using Datapac 2002 Version 3.11 software (Run Technologies, Mission Viejo, California) on a PC-type computer.

Maximal Voluntary Isometric Contractions

Two MVICs for each muscle were performed for normalization of EMG data[23,24] (Table 1) to provide a reference of electrical activity for each muscle. All EMG data were reported as a percentage of the MVIC (%MVIC). Each MVIC was sustained for a period of 5 seconds for each of the 2 trials.

Exercise Protocol

Each subject was allowed to familiarize himself or herself with the 4 exercises before testing. The 4 exercises studied were inferior glide (IG) (Figure 2), low row (LR) (Figure 3), lawnmower (LM) (Figure 4), and robbery (RB) (Figure 5).[§] These exercises are named after the general arm and body postures and motions that are used in performing them. An external trigger controlled by one of the investigators marked each exercise trial for data analysis. The same investigator instructed the subject, verbally counted the 3-second time period for each exercise, and controlled the external trigger to demark the beginning and ending of each repetition. To help control for accuracy, the trigger was depressed 2 seconds before beginning the repetition and 1 second after the termination of the repetition. The subjects were observed during data collection and given verbal feedback to maintain proper exercise technique. Each subject was instructed to move from the beginning to the end range within 3 seconds of time. An examiner counted aloud the 3 seconds for each trial while another examiner watched technique. Each exercise was performed for 8 repetitions. If a subject did not perform a repetition correctly, additional repetitions were performed.

Inferior Glide

The IG (Figure 2) is an isometric exercise that emphasizes humeral head depression and scapular retraction.[17,20] The

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[§] Video supplements showing the 4 exercises are available online for this article at http://ajsm.sagepub.com/supplemental.

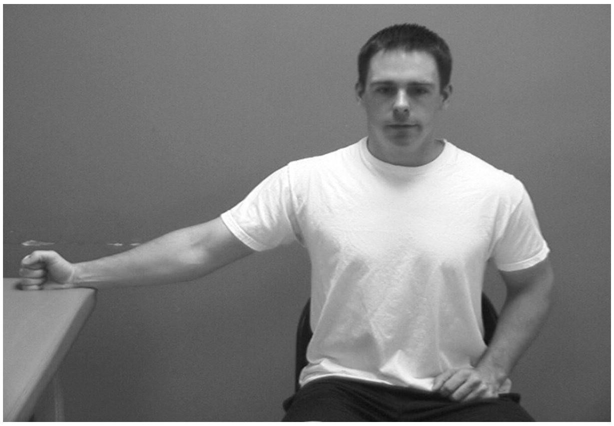


Figure 2. Inferior glide exercise.

scapular muscles primarily targeted for this exercise were the SA and LT. Each subject was placed in an upright sitting position with the test arm abducted to 90° with fist clenched on a firm supportive surface. Each subject was instructed to apply pressure with his or her fist in the direction of arm adduction and instructed to inferiorly depress their scapula and hold this position for 5 seconds.

Low Row

The LR (Figure 3) is an exercise that emphasizes scapular external rotation and posterior tilt.[30] The scapular muscles primarily targeted in this exercise were the SA and LT. For this study, the LR was performed as an isometric exercise, although progressions can be instituted to make it a dynamic isotonic exercise. Each subject stood in front of an immovable surface. Subjects placed their hand on the anterior edge of the surface with palm facing posteriorly. Subjects were instructed to extend their trunk and push their hand maximally against the surface in the direction of shoulder extension and instructed to retract and depress the scapula; the isometric contraction was performed for 5 seconds.

Lawnmower

The LM (Figure 4) is a multijoint exercise that mobilizes joints in a diagonal pattern from the contralateral leg through the trunk to the ipsilateral arm.[30] These multijoint exercises use force-dependent integrated muscle activation patterns to coordinate the motions of connected joints[41] and to produce efficient and stable distal joint positions through the production of interactive moments.[44] They have been found to generate higher gains in strength than single joint exercises because of the facilitation of the force-dependent patterns by increase in neurological activity.[33] This exercise used the motion of hip/trunk extension, trunk rotation, and scapular retraction to activate the muscles to assist in positioning the scapula in retraction.[30]

Targeted muscles for the LM exercise were the SA and LT. Although the SA is often characterized as a scapular protractor, when the scapula is in a position of external rotation, a major component of scapular retraction, the SA is oriented to maintain this position. This is demonstrated by high and early levels of activation as is seen in cocking (scapular external rotation) in baseball,[16,21] tennis,[26] and arm elevation.[3] It is also shown by the fact that scapular position in long thoracic nerve palsy is one of internal rotation and anterior tilt, which is more characteristic of loss of external rotation control.

Figure 3. Low row exercise.

For this study, subjects began the exercise with their trunk flexed and rotated to the contralateral side from the instrumented arm with their hand at the level of their contralateral patella. Subjects were instructed to rotate the trunk toward the instrumented arm and extend the hip and trunk to a vertical orientation while simultaneously placing their instrumented arm at waist level and retracting their scapula so that they try to place an “elbow into their back pocket” position. Body movement was smooth, but the retraction position was to be completed with a strong

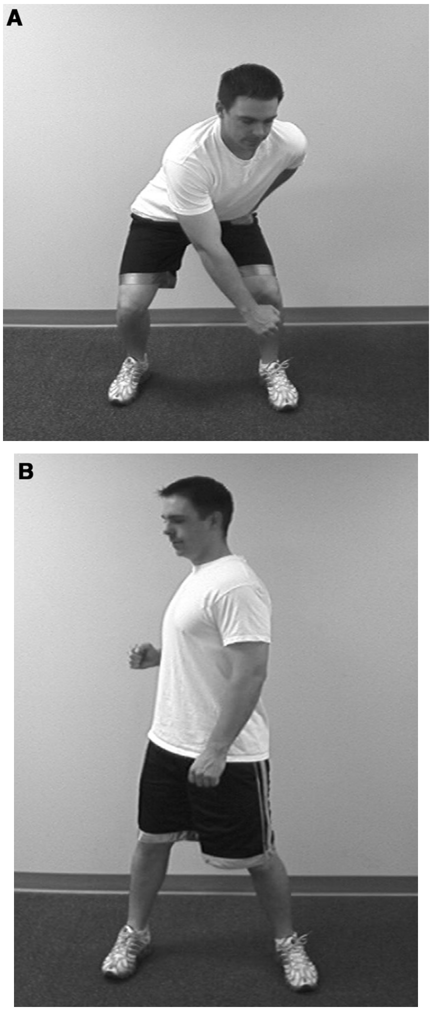


Figure 4. Lawnmower exercise. A, starting position. B, end position.

contraction of the muscles. For the study, no resistance from tubing or weights was used.

Robbery

The RB (Figure 5) is a multijoint exercise that uses hip/trunk extension and bilateral arm motion to achieve scapular retraction.[30] For this study, each subject began in a standing position with the trunk flexed to approximately 40° to 50° with arms forward flexed and palms facing the thighs. While keeping the elbows close to the body, each subject moved into trunk and arm extension and flexed the elbows so palms were facing up and away from the body while simultaneously pinching both scapulae toward his or her back pockets with a strong 5-second contraction.

Data Reduction

Muscle Activation Amplitude. The amplitude values were smoothed using root mean square (RMS). The highest 500-millisecond window for each muscle was used to represent 100% MVIC.[45] Subjects performed 2 maximal contractions for a total of 5 seconds each with 60 seconds of rest between each maximal trial. A resting standing file was obtained for 5 seconds that was used to identify baseline background activity that was removed before normalization.[45]

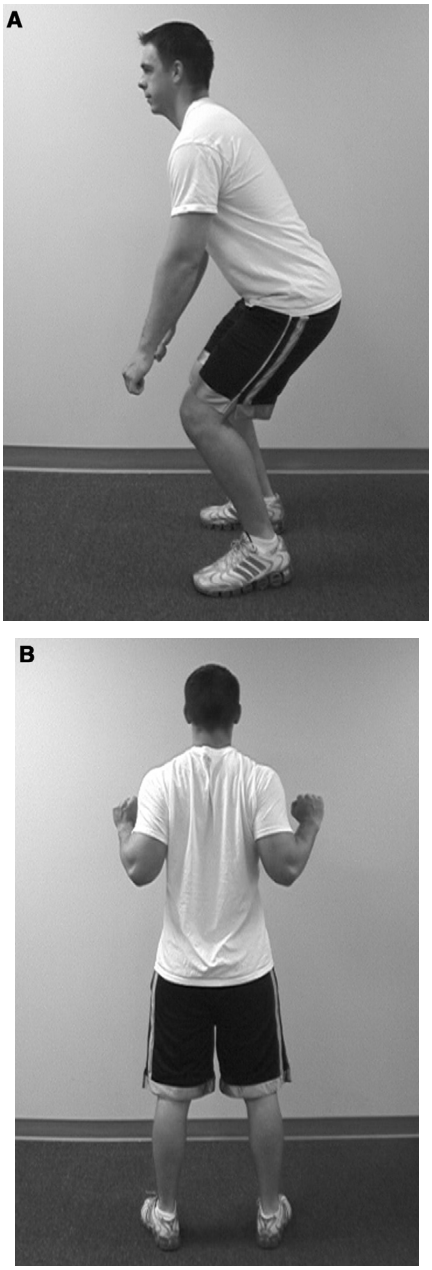


Figure 5. Robbery exercise. A, starting position. B, end position.

The raw data were filtered to a bandwidth of 20 to 500 Hz. The data were then smoothed using an RMS filter and time constant of 100 milliseconds using Datapac 2002 Version 3.11 software (Run Technologies). For each subject, the mean EMG activity from the 4 middle trials during an exercise was averaged to represent the mean muscular activity for a particular exercise. The middle 4 clean trials were used to minimize fatigue and error in performance. If an improper movement time or technique occurred during data collection, another trial was substituted for data analysis. The mean muscular

TABLE 2
Average Amplitude EMG Activity All Subjects (N = 39) by Exercises[a]

	Inferior Glide	Low Row	Lawnmower	Robbery	Differences Between Exercises
Upper trapezius	8.1 (5.9)	10.4 (8.1)	21.8 (15.7)	31.6 (16.7)	RB > all others LM > IG, LR
Lower trapezius	19.4 (26.6)	15.4 (11.6)	30.5 (19.2)	27.0 (20.8)	LM = RB > LR
Serratus anterior	23.4 (19.6)	28.2 (20.8)	25.5 (21.4)	20.9 (16.8)	None
Anterior deltoid	4.6 (2.4)	16.6 (13.3)	5.5 (3.6)	7.4 (5.5)	LR > all others
Posterior deltoid	8.6 (6.0)	42.4 (23.2)	16.2 (10.6)	14.0 (9.2)	LR > all others
Differences between muscles	SA > UT, AD, PD LT = all others	PD > UT, LT, AD PD = SA SA > UT, LT	UT = LT = SA LT > AD, PD PD > AD	UT = LT = SA > AD UT = LT > PD	

[a] Data are given in means (standard deviations). EMG, electromyography; RB, robbery; LM, lawnmower; IG, inferior glide; LR, low row; SA, serratus anterior; UT, upper trapezius; AD, anterior deltoid; PD, posterior deltoid; LT, lower trapezius.

activity, reported as percentage of MVIC for each subject, was used for later statistical analysis to determine EMG amplitude differences between exercises.

Muscle Activation Timing. A resting standing file was obtained for 5 seconds after performance of the 2 MVICs that was used for determining baseline background activity such as heartbeat and was removed before normalization. To determine onset of muscular activity during each exercise, a threshold to determine onset time was performed using a reference interval of relative quiescent activity of 100 milliseconds as a baseline. Onset of muscular activity was determined when the muscular activity elevated above the reference interval by 3 standard deviations and remained above this level for at least 100 milliseconds.[22] Each muscular event as determined by the onset algorithm was visually inspected by an investigator to ensure muscular onset validity.[12] Common irregularities present in this particular data set requiring visual inspection included heart beat artifacts not accounted for by filtering, electrode movement artifact, and successive muscular activities where muscle activity did not return to a resting baseline. The first 4 valid trials were averaged to represent the respective onset times of each muscle for all exercises. Muscle onset times were analyzed relative to the onset time of the AD.[58] All muscle onsets were compared to the anterior deltoid onset time by subtracting the onset time of each muscle from the anterior deltoid onset time. The IG exercise was not included in this portion of the analysis due to inactivity of the AD in greater than 50% of the trials.

Statistical Analysis

Muscle Activation Amplitudes. Two within-factor (exercise and muscle) and 1 between-factor (group) analysis of variance (ANOVA) was used to determine if there was a difference between groups and exercises in EMG amplitudes in each muscle. The dependent measure was %MVIC amplitude of each muscle studied. The independent variables were the 4 exercises (IG, LR, LM, and RB) and 5 muscles instrumented. Additionally, the 2 groups (asymptomatic and symptomatic) were independent variables. A .05 α level was chosen a priori to denote statistical significance for these comparisons. For any significant difference, a Bonferroni post hoc analysis with a .05 α level to denote significance was used for follow-up analysis.

Muscle Activation Timing. Four separate 1 within-factor (muscle) and 1 between-factor (group) ANOVAs were performed for each exercise to determine sequence of muscular onset. The muscle within variable had 5 levels (UT, LT, SA, AD, and PD) while the between factor had 2 levels (asymptomatic and symptomatic). The dependent measure was onset of muscle activation in milliseconds relative to anterior deltoid. A .05 α level was chosen a priori to denote statistical significance for these comparisons.

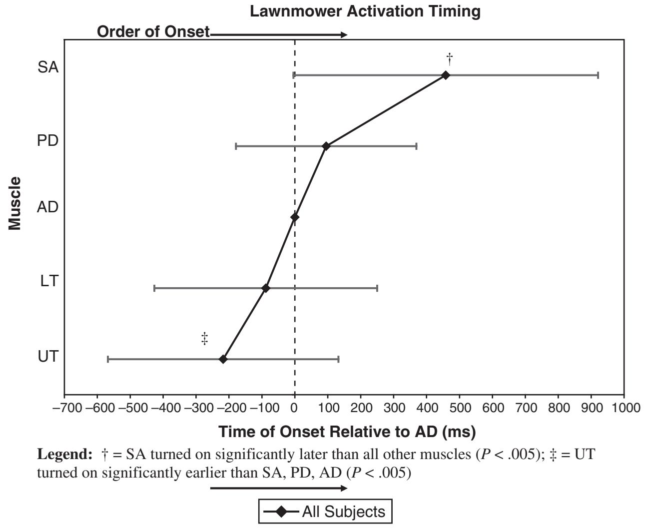
RESULTS

Muscle Activation Amplitude

The ANOVA model revealed that sphericity could not be assumed, and a Greenhouse-Geisser correction was used to interpret all results. There were no significant differences found between groups in EMG amplitudes ($P = .42$; $\eta^2 = .13$), indicating both injured and uninjured subjects generated the same amplitude level of the muscles instrumented. A significant interaction between exercise and muscle was found, indicating that particular exercises activated certain muscles to a greater extent than other muscles with the groups (injured and noninjured) pooled together ($P < .001$; $\eta^2 > .99$). Bonferroni post hoc correction for multiple comparisons converted the α level to $P \leq .0011$ for a pair-wise comparison to be considered significant. The post hoc significant differences between exercises and within exercises are depicted in Table 2.

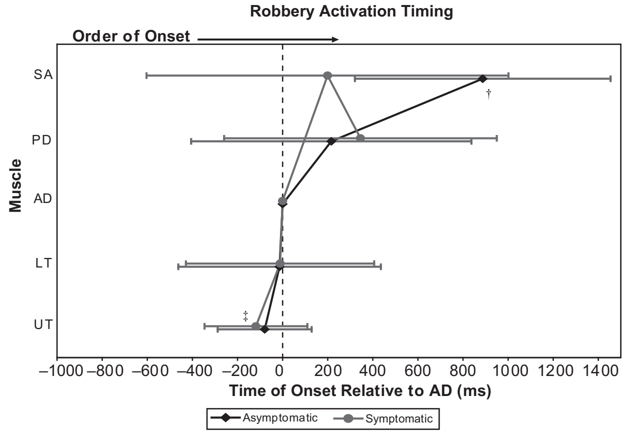
Muscle Activation Timing

Low Row. No significant differences were found in muscle onset activation ($P = .13$; $\eta^2 = .46$) between asymptomatic and symptomatic subjects during the LR. Similarly, there were no significant differences in onset time for all muscles involved when subjects were pooled. Mean onset times and corresponding standard deviations (SD) relative to the AD were as follows: PD = –52 ± 125 milliseconds, SA = –47 ± 126 milliseconds, UT = 1.7 ± 200 milliseconds, and LT = 10.7 ± 171 milliseconds.



Legend: † = SA turned on significantly later than all other muscles ($P < .005$); ‡ = UT turned on significantly earlier than SA, PD, AD ($P < .005$)

Figure 6. Activation timing of lawnmower exercise. †Serratus anterior (SA) turned on significantly later than all other muscles ($P < .005$). ‡Upper trapezius (UT) turned on significantly earlier than SA, posterior deltoid (PD), and anterior deltoid (AD) ($P < .005$).



Legend: † = Asymptomatic Subjects: Serratus anterior activated significantly later than upper trapezius, lower trapezius, and anterior deltoid ($P < .0025$); ‡ = Symptomatic Subjects: Upper trapezius activated significantly earlier than the posterior deltoid ($P < .0025$)

Figure 7. Activation timing of robbery exercise. †Asymptomatic subjects: Serratus anterior (SA) activated significantly later than upper trapezius (UT), lower trapezius (LT), and anterior deltoid (AD) ($P < .0025$). ‡Symptomatic subjects: UT activated significantly earlier than the posterior deltoid (PD) ($P < .0025$).

Lawnmower. There were no significant differences in muscle onset activation between subject groups during the LM exercise ($P = .25$; $\eta^2 = .35$). A significant main effect for muscle order was found when subjects were pooled (F = 21.199; degree of freedom [df] = 4; $P < .001$). Bonferroni post hoc analysis revealed that the SA was the last muscle to activate ($P < .005$), and the UT activated earlier than the AD, PD, and SA ($P < .005$) (Figure 6).

Robbery. During the RB exercise, a significant difference in sequence was found between asymptomatic and symptomatic subjects (F = 4.060; df = 4; $P = .004$). Bonferroni post hoc analysis revealed that in asymptomatic subjects, the SA activated significantly later than the UT, LT, and AD ($P < .0025$). In the symptomatic group, the UT was activated significantly earlier than the PD ($P < .0025$) (Figure 7).

DISCUSSION

The results from this study confirm that these specific exercises activated the UT, LT, and SA in clinically significant amplitudes and that there were minimal differences between the groups. Muscle activation below 20% is considered clinically low, and activity between 20% and 40% is considered clinically moderate.[13] A moderate level of muscle activation is adequate to retrain neuromuscular control for scapula and glenohumeral musculature, especially in the initial phases of rehabilitation.[28,37] The data also show that the muscles are activated in different sequences by different exercises.

Muscle Activation Amplitudes

Scapular motion is a composite of 3 individual motions—upward/downward rotation around a horizontal axis perpendicular to the plane of the scapula; internal/external rotation around a vertical axis through the plane of the scapula; and anterior/posterior tilt around a horizontal axis in the plane of the scapula—and 2 translations that are characterized by scapular elevation/depression and clavicular protraction/retraction.[36,38] All of the motions and translations are important in allowing the scapula to perform its roles in normal SHR. To avoid impingement with arm elevation, the scapula must posteriorly tilt and externally rotate in addition to upward rotation.[34,36,38] To maximize ball and socket glenohumeral kinematics and maintain joint stability, all motions and translations must be coordinated to maintain the glenoid as a congruent socket for the moving humeral head and maximize concavity/compression.[29] Finally, the scapula must externally rotate and posteriorly tilt during arm use to maximize activation of the muscles, such as the supraspinatus, that originate on the scapula.[31,51]

Other studies have identified the UT, LT, and SA as the most important muscles in providing scapular control by creating force couples that move and stabilize the scapula.[2,14,52] The SA and LT make up the crucial lower force couple responsible for control of inferior stabilization as well as work with the UT to control retraction and general scapular stabilization.[2,52] The SA is activated between 20% and 40% MVIC, LT is activated 15% MVIC, and the UT is activated between 15% and 26% MVIC in nonresisted active shoulder elevation movements.[4,19] These values are in the same general range as the activations seen in this study, giving evidence that the muscles are being activated to the appropriate levels that they would be used in routine functional tasks.

Studies have determined that LT and SA are well activated by many types of exercises. Some studies have involved scapular retraction and depression.[20,27] Others have used positions of weightbearing and shoulder protraction[11,35] or scapular upward rotation.[40] The levels of activation in these studies have been higher, even beyond 100% MVIC, and may be helpful in gaining ultimate strength.

The exercises evaluated in this study do not place the humerus in positions such as active forward elevation or shoulder abduction, which would exacerbate the symptoms of patients with shoulder pain caused by impingement. Nonresisted scapular control exercises, such as the maneuvers tested in this study, could be implemented early in rehabilitation. The activation levels found in this study were lower, suggesting these are probably best suited for the early to middle phases of shoulder rehabilitation to help initiate activation of the scapula-stabilizing muscles.

The IG and LR are closed-chain isometric exercises. These types of exercises are usually considered to be safe in early rehabilitation phases because of their limited range of motion and control of joint loads.[20] These exercises were effective in activating the key muscles responsible for depressing and retracting the scapula. In this study, SA was activated above 20% MVIC in both exercises. The LT was activated at a lower amplitude in the IG. The IG exercise also creates shoulder adduction forces, which have been shown to create widening of the subacromial space.[20] This position may allow patients with impingement to perform exercises in functionally related positions that will activate the specific muscles that can help decrease the symptoms.

The PD was activated to the greatest degree during the LR. The LR elicited more than 40% MVIC from the PD, which is consistent with the PD's role as a shoulder extensor. The SA (28% MVIC) was activated significantly more than the UT (10% MVIC) during the LR exercise. This level of SA activation suggests that this would be a favored exercise in early rehabilitation in patients in whom SA activity needs to be emphasized and UT needs to be deemphasized—a common rehabilitation problem in patients who have a resting posture or dynamic motion of "shrugging" or excessive scapular elevation. Although other posterior shoulder musculature such as teres minor, infraspinatus, and latissimus dorsi were not instrumented, it is a reasonable assumption that this exercise would be good for general strengthening of the entire posterior shoulder musculature.

The dynamic exercises—LM and RB—activated all 3 scapular muscles to similar amplitudes generally in the moderate category of 20% to 40% but did not selectively activate one scapular muscle over another. Scapular muscle activation was significantly greater than AD muscle activation during the dynamic exercises. These exercises can be used in the middle phases of rehabilitation, as they activate scapular musculature near levels used for functional overhead activities.[8,39] Because they require larger ranges of motion and generate more loads, they should be used when anatomic healing and adequate range of motion are present in either nonoperative or postoperative rehabilitation. Both exercises can be done in multiple planes of motion and with varying amounts of resistance. The LT is found to be frequently weak in patients with shoulder injury[8,39] and is often difficult to strengthen. The LM exercise activates the LT in larger amplitudes and can be used to effectively begin strengthening of this important muscle.

There was no significant difference in activation intensity in response to the exercise stimulus between the asymptomatic and symptomatic groups. This is probably due to the limitations on motion, load, and exercise intensity in the study. The positions and motions were chosen to decrease impingement and shear, and the repetitions were relatively low. This is in distinction to studies that show differential activation amplitudes in injured and noninjured patients when they are actively involved in sports[16,47,48] or in activities above shoulder levels.[34] However, this is in agreement with other studies that have shown that alterations in periscapular muscle activation are not associated with specific glenohumeral joint pathologic changes.[4,51] This is probably due to the fact that the current thought on scapular dyskinesis is that it is most commonly caused by inhibition of muscle activation by feedback from an injured or painful joint, and the positions or motions employed in this study eliminated the pain, allowing the muscle activation to occur with minimal inhibition.[46] Because the muscle activations were similar in both groups, both asymptomatic and symptomatic groups may benefit from this type of exercise program for rehabilitation and conditioning.

Muscle Activation Timing

These data show that muscles can be activated in patterns that reflect the task presented to them. Even though the desired scapular position at the end of each exercise was qualitatively the same position of scapular retraction, the starting position and motion of the scapula in the exercise were different for each exercise.

This is especially demonstrated by the activation of the SA. When the scapula was placed in a position of retraction at the start of the exercise, such as during the LR, SA was activated early. When the scapula started in a more protracted position and the subject moved into a position of retraction, the SA was typically the last to be activated, as seen during the LM and RB exercises. The amplitude of activation was not statistically different in either situation. This indicates the capability of both types of exercises to meaningfully activate the SA but may be used at different times in rehabilitation, depending on tissue healing and required limitations on position and motion.[31,49,50]

When comparing the 2 subject groups, the SA turned on significantly later compared with the UT, LT, and AD in the asymptomatic subjects during the RB exercise (Figure 7). When shoulder function has been compromised due to shoulder injury, the SA may activate sooner during this exercise to establish a greater base of control for the arm as it moves to the terminal position.[34-36] This is consistent with Glousman's findings of early SA activity in injured throwers.[16] The explanation of why it only showed up in the bilateral activation may relate to the fact that, of all the periscapular muscles, only SA is not coupled in activation with its contralateral mate.[1,49]

The trapezius muscles also showed task-specific behavior. When the arm was initially placed in a closed-chain supported position that did not require active scapular suspension, as in the LR exercise, UT and LT were activated later in the exercise. However, in the open-chain active exercises that required movement of the arm and scapula for active repositioning, UT and LT were activated first. If UT activation is to be initially discouraged, such as in patients with significant UT substitution (the "shrug") upon arm elevation, these exercises should be implemented in later phases of rehabilitation.[9,54]

A guideline for progression of these exercises may be formulated by combining the muscle activation and onset data. The most common clinical finding in scapular dyskinesis associated with most shoulder injuries is the prominence of the inferior angle or medial border of the scapula.[32] This pattern is associated with SA and LT weakness and alteration of activation sequencing that consists of increased UT activation and delayed LT activation.[8] For this clinical scenario, the isometric LR and IG exercises should be employed first to activate the SA and LT in safe arm positions with no impingement and minimal joint shear. These exercises also allow those patients with UT substitution patterns to deemphasize this muscle. The dynamic exercises follow a sequenced pattern of muscle activation that requires larger motions and positions that generate more joint shear. They can be used later in rehabilitation when these motions and positions are safe to maximize early dynamic control of scapular motion and serve as a base for more vigorous exercises.

Limitations

Surface EMG was used to collect muscle activity during each of the exercises performed. While surface EMG has been deemed reliable,[10] there may have been some area of muscle not represented, such as the middle fibers of the SA. Subjects tested during this study were separated into 2 groups: noninjured controls and injured patients; the subjects were not matched by height, weight, or body composition. These factors could have impeded the EMG output, which in turn could have affected the comparison between the 2 groups.

This study examined both isometric and isotonic concentric contractions, which may have elicited variations in the muscle activity due to changing speed and length of the muscles tested. There was an attempt to control the rate of the dynamic exercises through verbal counting by an examiner; however, exact control of the arm motion was not provided. Another issue is intensity of isometric muscle contraction producing differing loads. We instructed all subjects in a similar manner; however, a percentage of maximum isometric force was not controlled for.

During this study, we evaluated 3 scapular muscles thought to be most important for dynamic scapular control and most frequently focused upon during shoulder and scapula rehabilitation. Other muscles such as the rhomboids, levator scapulae, and the pectoralis minor, which also attach to the scapula, may play significant roles in dynamic scapular control. The limited number of muscles tested in this study did not allow for accurate analysis of proximal to distal muscle activation.[36] Future investigations may consider evaluating other muscles or exercises as well.

SUMMARY

The exercises evaluated in this study are effective in activating key scapular muscles in task-specific patterns at moderate levels of intensity, which are consistent with physiologic activation sequences. These characteristics suggest that the exercises may be used in the early and middle phases of comprehensive shoulder rehabilitation protocols to establish scapular control as a stable base for glenohumeral function. These exercises activate muscles in positions and motions that place the scapula in a stable position for the tasks of throwing or lifting and may form a basis for more advanced return to play protocols. Because they are effective in both asymptomatic and symptomatic populations, they may be used in both rehabilitation protocols and conditioning programs. However, only 4 exercises were investigated out of a large number of shoulder exercises. Other exercises may also develop the activation intensities and task-specific timing that produce the biomechanically advantaged scapular position.

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