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Surface Electromyographic Analysis of Exercises for the Trapezius and Serratus Anterior Muscles

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Study Design: This study used a prospective, single-group repeated-measures design to analyze differences between the electromyographic (EMG) amplitudes produced by exercises for the trapezius and serratus anterior muscles.
Objective: To identify high-intensity exercises that elicit the greatest level of EMG activity in the trapezius and serratus anterior muscles.
Background: The trapezius and serratus anterior muscles are considered to be the only upward rotators of the scapula and are important for normal shoulder function. Electromyographic studies have been performed for these muscles during active and low-intensity exercises, but they have not been analyzed during high intensity exercises.
Methods and Measures: Surface electrodes recorded EMG activity of the upper, middle, and lower trapezius and serratus anterior muscles during 10 exercises in 30 healthy subjects.
Results: The unilateral shoulder shrug exercise was found to produce the greatest EMG activity in the upper trapezius. For the middle trapezius, the greatest EMG amplitudes were generated with 2 exercises: shoulder horizontal extension with external rotation and the overhead arm raise in line with the lower trapezius muscle in the prone position. The arm raise overhead exercise in the prone position produced the maximum EMG activity in the lower trapezius. The serratus anterior was activated maximally with exercises requiring a great amount of upward rotation of the scapula. The exercises were shoulder abduction in the plane of the scapula above 120° and a diagonal exercise with a combination of shoulder flexion, horizontal flexion, and external rotation.
Conclusion: This study identified exercises that maximally activate the trapezius and serratus anterior muscles. This information may be helpful for clinicians in developing exercise programs for these muscles. *J Orthop Sports Phys Ther 2003;33:247–258.*

Key Words: *scapula, shoulder, strength, upper extremity*

The upper trapezius, lower trapezius, and serratus anterior muscles are considered to be the only upward rotators of the scapula.[39] Therefore, these muscles play an integral part in scapular movement during scapulohumeral rhythm, a motion that has been analyzed by many authors.[2,13,15,20,41] In these studies, the total amount of scapular upward rotation was found to range from 58° to 65° and glenohumeral motion ranged from 103° to 112.5° during full shoulder elevation. There seems to be a consensus as to the general pattern of movement. During the first 30° to 60° of humeral flexion or abduction, the scapula tends to find a position of stability with variable movement between individuals.[20] There is very little upward rotation of the scapula during this period. During midrange of shoulder elevation (from about 80° to 140°) a substantial amount of scapular upward rotation occurs, and then above 140° the amount of rotation decreases.[2]

Scapulohumeral rhythm or scapular position may be altered with different conditions that include increased loading, muscle fatigue, impingement syndrome, instability of the glenohumeral joint, or postural changes.[1,23,25,30–32,34–36] Ludewig and Cook[30] reported that patients with shoulder impingement had increased EMG activity in the trapezius, but had decreased EMG activity in the serratus anterior muscle during shoulder elevation in the scapular plane. It is not known whether weakness or changes in motor recruitment of the serratus anterior and trapezius muscles is the cause or the result of impingement. One goal of shoulder rehabilitation

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should be to restore normal scapulohumeral rhythm and that may require exercises focusing on the trapezius and serratus anterior muscles.

Electromyographic analysis of the trapezius and serratus anterior muscles has been performed during active humeral elevation and during rehabilitation-type exercises.[3,4,8,9,11,13–15,18,20,28,30–33,35,36,38,43] Generally, the studies report increasing EMG activity in the trapezius and serratus anterior as the shoulder is actively elevated to end range.

A variety of exercises have been recommended for strengthening the serratus anterior and trapezius muscles based on the level of EMG activity. Moseley et al[38] performed an EMG study of the shoulder muscles in 9 subjects during 16 different exercises, each repeated 10 times at low intensity. They found that rowing and the military press produced maximum EMG activity in the upper trapezius. For the middle trapezius, they identified 4 exercises that they considered optimal: horizontal extension with the glenohumeral joint in neutral or external rotation, shoulder extension, and rowing. Shoulder abduction, rowing, and horizontal extension with the glenohumeral joint in neutral or external rotation all qualified as optimal exercises for the lower trapezius based on the EMG levels. The exercises suggested for strengthening the serratus anterior muscle were shoulder flexion or abduction and shoulder abduction in the plane of the scapula.

Hintermeister et al[18] performed an EMG study of the shoulder using elastic bands for resistance during 7 exercises performed at a relatively low load. They recommended a shoulder shrug exercise for the upper trapezius muscle, a seated rowing exercise for the trapezius muscles, and a forward punch exercise (scapular protraction) for the serratus anterior muscle.

Serratus anterior muscle activity during selected rehabilitation exercises was studied by Decker et al.[11] All the exercises were performed with the arm below shoulder height with resistance provided by body weight, elastic cords, or dumbbells. The intensity of each exercise was not precisely controlled. A serratus anterior punch exercise (scapular protraction), shoulder elevation in the plane of the scapula, push-ups with maximum scapular protraction, and an exercise called the dynamic hug (scapular protraction) consistently elicited serratus anterior muscle EMG activity greater than 20% of a reference contraction.

None of the EMG studies that have evaluated exercises for the trapezius and serratus anterior muscles were performed with well-controlled high-intensity exercises. In addition, the muscle tests that produced the maximum voluntary isometric contraction for normalization of the data were not identified in some studies. If identified, it was often questionable whether the tests were actually adequate to produce maximum EMG activity of the muscle.

The purpose of this study was to identify which of several exercises performed at a high level of intensity elicited the greatest levels of EMG activity in the trapezius and serratus anterior muscles.

METHODS

Subjects

Thirty volunteers (10 male and 20 female) whose ages ranged from 22 to 46 years (mean = 27.2 years) participated in the study. The subjects filled out a short history form and were excluded from the study if they had shoulder problems such as tendonitis, adhesive capsulitis, instability, or impingement. Participants signed consent forms approved by the University of South Dakota Institutional Review Board and the Rocky Mountain University of Health Professions Institutional Review Board.

Instrumentation

Using a bipolar configuration, 2 silver/silver chloride disposable surface recording electrodes (Medicotest A/S, Ølstykke, Denmark), each with a pickup diameter of 10 mm, were connected with cables to an 8-channel Noraxon Myosystem 1200 EMG system (Noraxon USA, Inc., Scottsdale, AZ). The Myosystem 1200 has a sensitivity of ±100 nV, a differential input impedance of greater than 10 MΩ, a common mode rejection ratio (CMRR) of greater than 100 dB at 60 Hz, and a frequency response of 10 to 500 Hz. The Myosystem 1200 was interfaced with the computer via a 16-channel, 12-bit A/D card (Computer Boards, Inc., Middleboro, MA). The sampling rate was set at 1000 Hz per channel.

All data were stored on a Gateway Solo 9300LS personal computer (Gateway Inc., Poway, CA) and data were processed and analyzed using the MyoResearch 2.02 software (Noraxon USA, Inc., Scottsdale, AZ).

Procedures

Electromyographic data were collected from the muscles of the right shoulder of each subject. The upper, middle, and lower trapezius, and serratus anterior muscles were evaluated during the 10 different exercises illustrated in Figures 1 to 10.

For electrode placement over the upper trapezius, the shoulder was positioned in 90° of abduction. Two electrodes were placed so that they ran parallel to the muscle fibers and positioned so that 1 electrode was superomedial and 1 inferolateral to a point 2 cm lateral to one-half the distance between the C7 spinous process and the lateral tip of the acromion.[17,26]

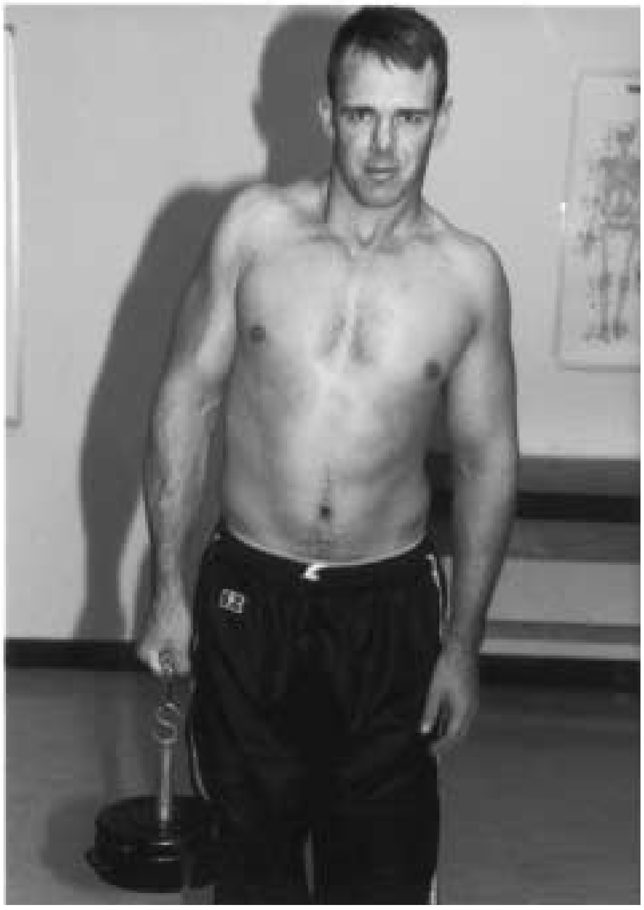

FIGURE 1. Unilateral shoulder shrug in the standing position.

FIGURE 2. Unilateral row in the prone position.

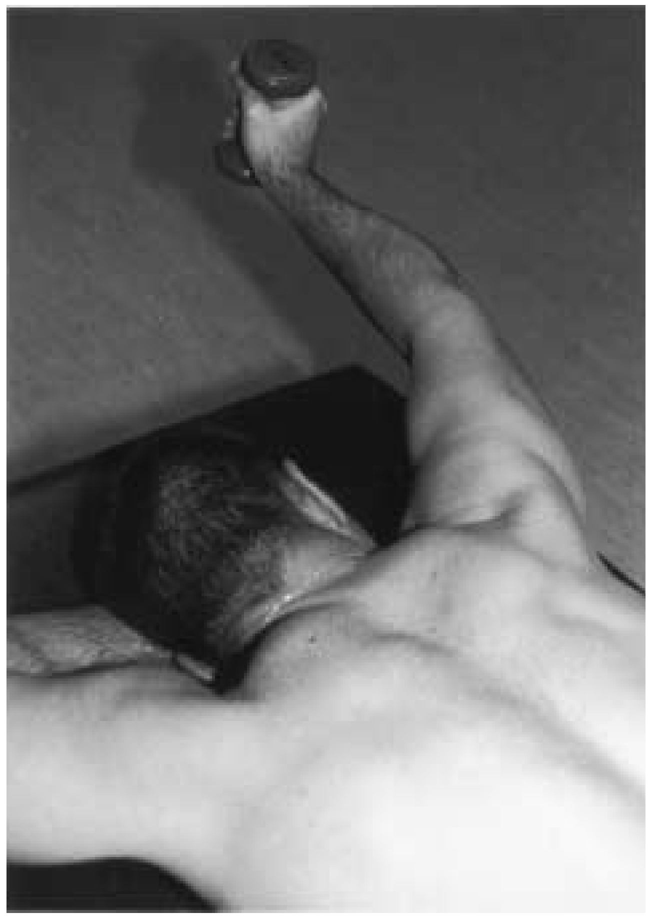

FIGURE 3. Arm raise above the head with the upper extremity in line with the lower trapezius muscle fibers in the prone position.

FIGURE 4. Shoulder horizontal extension with external rotation in the prone position.

For the middle trapezius, the electrodes were placed parallel to the muscle fibers between the spine of the scapula and thoracic spine. One electrode was placed medial and 1 lateral to a point 3 cm lateral to the second thoracic spinous process.[10] For the lower trapezius, the shoulder was positioned in 90° of flexion and the electrodes were placed on an oblique vertical angle with 1 electrode superior and 1 inferior to a point 5 cm inferomedial from the root of the spine of the scapula.[10] For the serratus anterior, the shoulder was abducted to 90° and the electrodes were placed vertically along the midaxillary line at rib levels 6 through 8.[6] A common reference electrode was placed over the C7 spinous process.

FIGURE 5. Shoulder external rotation with the shoulder abducted 90° and the elbow flexed 90° in the prone position with the elbow supported on the table.

FIGURE 6. Shoulder abduction in the plane of the scapula above 120° in the standing position.

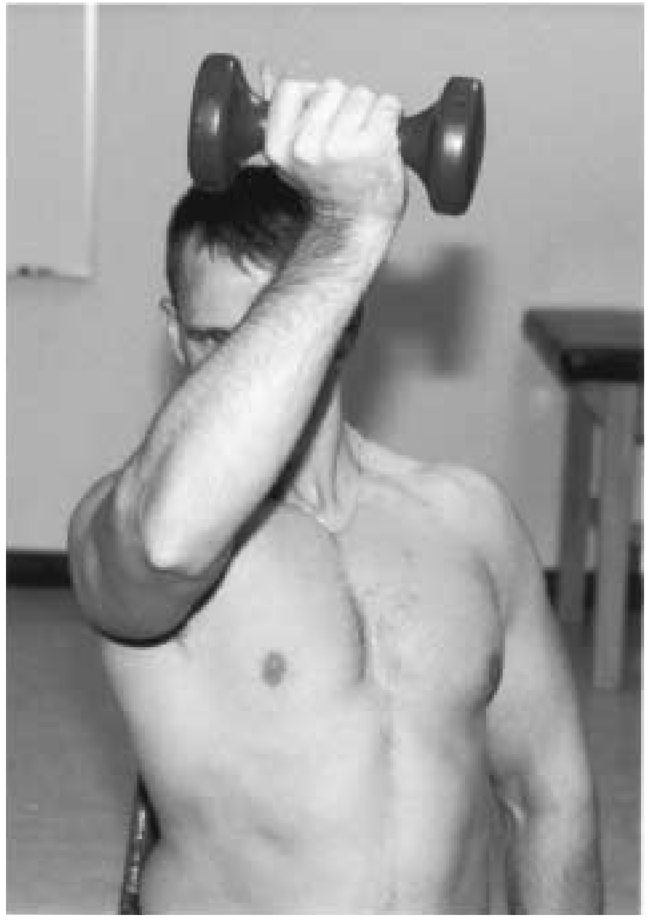

FIGURE 7. Diagonal exercise with a combination of shoulder flexion, horizontal flexion, and external rotation in the sitting position.

FIGURE 8. Shoulder abduction in the plane of the scapula below 80° in the standing position.

All sites for electrode placements were prepared by abrading the skin with fine sandpaper and cleansing the area with 70% isopropyl alcohol. Shaving of hair was performed if necessary. The electrode pairs were then applied with a center-to-center interelectrode distance of 30 mm. The skin impedance was checked with an ohm meter attached to the snap of each electrode pair and was acceptable for the study if less than 5000 Ω.[10]

For normalization of the EMG data, muscle-testing positions as outlined for the trapezius and serratus anterior muscles by Kendall et al,[24] as well as 5 other

FIGURE 9. Bilateral scapular protraction with the shoulder horizontally flexed to about 45° and the elbows flexed to about 45° in the supine position.

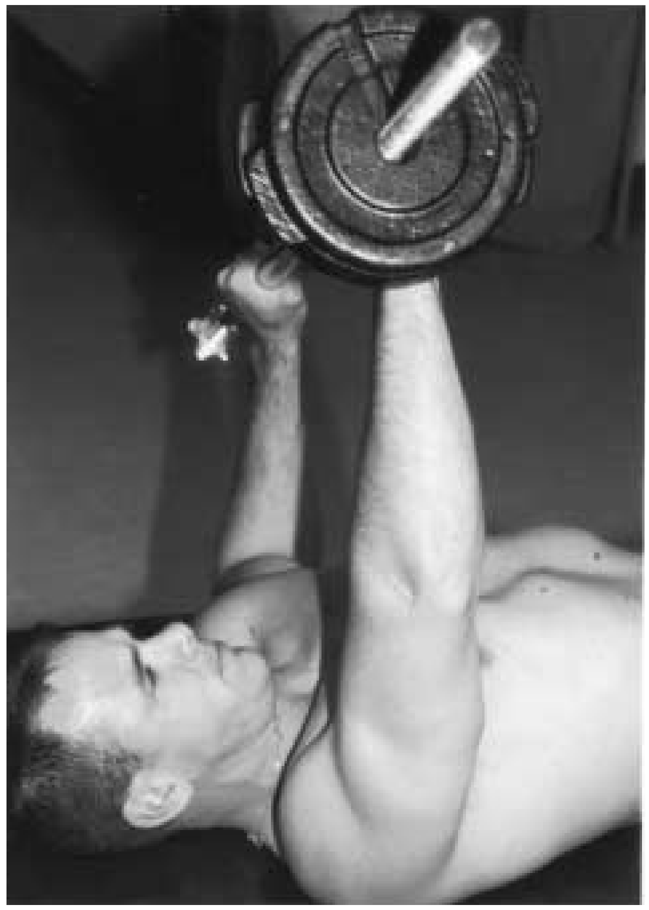

FIGURE 10. Unilateral shoulder press with full scapular protraction with the shoulder flexed to 90° and the elbow fully extended in the supine position.

muscle test positions were analyzed to determine which test produced the maximum EMG activity for each muscle. For the upper trapezius muscle, there were 3 different muscle tests that produced maximum EMG activity in subjects. Two of the tests were resisted shoulder shrug or shoulder abduction to 90° with the head and neck rotated to the opposite side and side-bent to the same side in both cases. A third muscle test was performed with the shoulder flexed to 125°. Two muscle tests were found to produce maximum EMG activity in the middle and lower trapezius. The muscle tests were performed in the prone position with either the shoulder horizontally extended and externally rotated, or with the arm raised overhead in line with the lower trapezius muscle fibers.[24] The maximum EMG amplitudes for the serratus anterior were produced with a muscle test either with the shoulder flexed to 125° or abducted to 125° in the plane of the scapula. The muscle test that produced the maximum EMG amplitude in each muscle for each subject was then considered the maximum voluntary isometric contraction (MVIC) for that muscle.

Within each subject, the EMG values for each muscle during each exercise were normalized as a percentage of the highest EMG value produced by that muscle during a MVIC. The EMG data for the exercises were then expressed as percent maximum voluntary isometric contraction (% MVIC).

For each exercise, the 5-repetition maximum (RM) was determined for each subject prior to the testing session. That intensity level which is in the range of about 85% to 90% of maximum lifting capacity was used during EMG data collection.[5] During EMG data collection, each exercise was performed 3 times at a slow movement rate of 5 seconds for each concentric phase of the exercise. A metronome set at a rate of 1 beat per second was utilized to control the speed of each repetition.

The exercise sequence for each subject was determined by simple random selection by drawing each exercise from a box. Ten subjects performed the exercises a second time on the same day after a 15-minute rest period to analyze test-retest reliability of the EMG recordings.

The raw EMG data were full-wave rectified and processed using a root-mean-square algorithm with a

20-ms moving window. A 2-second time period from 1 of the 3 repetitions during each muscle test or exercise, where the rectified, smoothed EMG amplitude was the greatest, was quantified by the computer. The data resulting from this time period were utilized for analysis of each muscle test performed for normalization and for each exercise.

Data Analysis

The SPSS Base 10.0 for Windows (SPSS Inc., Chicago, IL) computer program was used for data analysis. An intraclass correlation coefficient ($ICC_{3,1}$) was used to determine the same-day test-retest reliability of the EMG recordings.[42]

A repeated-measures analysis of variance (ANOVA) was applied when analyzing the data to determine if there were significant differences in EMG activity for specific muscles during the exercises. A separate ANOVA was performed for each of the 4 muscles, with the independent variable being exercise with 10 levels of comparison. A least significant difference (LSD) pairwise multiple comparison analysis was performed to determine the significance of the differences among pairs of means. An alpha level of 0.05 was applied to all the data in determining significant differences.

TABLE 1. Mean (±SD) EMG activation of the upper trapezius expressed as a percentage of maximum voluntary isometric contraction (MVIC) for 10 shoulder exercises. Corresponding intraclass correlation coefficients (ICC) for the EMG measurements are also provided for each exercise.

	Exercise	% MVIC	ICC
1.	Unilateral shoulder shrug	119 ± 23*	0.81
2.	Shoulder abduction in the plane of the scapula above 120°	79 ± 19†	0.80
3.	Arm raise overhead in line with the lower trapezius muscle fibers	79 ± 18†	0.89
4.	Shoulder abduction in the plane of the scapula below 80°	72 ± 19†	0.75
5.	Shoulder horizontal extension with external rotation	66 ± 18†	0.83
6.	Diagonal exercise with shoulder flexion, horizontal flexion, and external rotation	66 ± 10†	0.81
7.	Unilateral row	63 ± 17†	0.91
8.	Shoulder external rotation at 90° of abduction	20 ± 18‡	0.91
9.	Unilateral shoulder press	7 ± 3	0.30
10.	Bilateral scapular protraction	7 ± 5	0.94

* Significantly greater than exercises 2 through 10 ($P \leq 0.05$).
† No significant difference between exercises 2 through 7, but they all are significantly greater than exercises 8 through 10 ($P \leq 0.05$).
‡ Significantly greater than exercises 9 and 10 ($P \leq 0.05$).

RESULTS

Reliability

The same-day test-retest ICCs for EMG recordings from 10 subjects are documented in Tables 1 through 4 for each muscle during each exercise. The reliability of the EMG recordings was generally excellent (0.91–0.98) when the muscles worked as prime movers, except for the recordings for the upper trapezius where the scores were less (0.81–0.89). Often, reliability was less when the muscle worked as a synergist or antagonist during the exercise rather than a prime mover.

Electromyography Exercise Data

The EMG activity of each muscle during each exercise, as well as the significant differences between exercises, are displayed in Tables 1 through 4. Examples of the raw EMG recordings are displayed in Figures 11 and 12.

DISCUSSION

The scapular upward rotator muscles are essential for normal movement and function of the shoulder girdle.[39] Therefore, it is important to be able to effectively strengthen the trapezius and serratus anterior muscles during rehabilitation of patients with

TABLE 2. Mean (±SD) EMG activation of the middle trapezius expressed as a percentage of maximum voluntary isometric contraction (MVIC) for 10 shoulder exercises. Corresponding intraclass correlation coefficients (ICC) for the EMG measurements are also provided for each exercise.

	Exercise	% MVIC	ICC
1.	Arm raise overhead in line with the lower trapezius muscle fibers	101 ± 32*	0.91
2.	Shoulder horizontal extension with external rotation	87 ± 20†	0.98
3.	Unilateral row	79 ± 23†	0.97
4.	Unilateral shoulder shrug	53 ± 25‡	0.86
5.	Shoulder abduction in the plane of the scapula above 120°	49 ± 16‡	0.80
6.	Shoulder abduction in the plane of the scapula below 80°	47 ± 16‡	0.82
7.	Shoulder external rotation at 90° of abduction	45 ± 36‡	0.87
8.	Diagonal exercise with shoulder flexion, horizontal flexion, and external rotation	21 ± 9	0.83
9.	Unilateral shoulder press	12 ± 10	0.27
10.	Bilateral scapular protraction	7 ± 3	0.86

* Significantly greater than exercises 4 through 10 ($P \leq 0.05$).
† No significant difference between exercises 2 and 3, but both are significantly greater than exercises 4 through 10 ($P \leq 0.05$).
‡ No significant difference between exercises 4 through 7, but they are all significantly greater than exercises 8 through 10 ($P \leq 0.05$).

TABLE 3. Mean (±SD) EMG activation of the lower trapezius expressed as a percentage of maximum voluntary isometric contraction (MVIC) for 10 shoulder exercises. Corresponding intraclass correlation coefficients (ICC) for the EMG measurements are also provided for each exercise.

Exercise	% MVIC	ICC
1. Arm raise overhead in line with the lower trapezius muscle fibers	97 ± 16*	0.96
2. Shoulder external rotation at 90° of abduction	79 ± 21†	0.96
3. Shoulder horizontal extension with external rotation	74 ± 21‡	0.92
4. Shoulder abduction in the plane of the scapula above 120°	61 ± 19§	0.98
5. Shoulder abduction in the plane of the scapula below 80°	50 ± 21§	0.94
6. Unilateral row	45 ± 17§	0.80
7. Diagonal exercise with shoulder flexion, horizontal flexion, and external rotation	39 ± 15	0.94
8. Unilateral shoulder shrug	21 ± 10	0.05
9. Unilateral shoulder press	11 ± 5	0.20
10. Bilateral scapular protraction	5 ± 2	0.70

* Significantly greater than exercises 3 through 10 ($P \leq 0.05$).
† Significantly greater than exercises 5 through 10 ($P \leq 0.05$).
‡ Significantly greater than exercises 6 through 10 ($P \leq 0.05$).
§ No significant difference between exercises 4 through 6, but they are all significantly greater than exercises 7 through 10 ($P \leq 0.05$).

TABLE 4. Mean (±SD) EMG activation of the serratus anterior expressed as a percentage of maximum voluntary isometric contraction (MVIC) for 10 shoulder exercises. Corresponding intraclass correlation coefficients (ICC) for the EMG measurements are also provided for each exercise.

Exercise	% MVIC	ICC
1. Diagonal exercise with shoulder flexion, horizontal flexion, and external rotation	100 ± 24*	0.94
2. Shoulder abduction in the plane of the scapula above 120°	96 ± 24*	0.96
3. Shoulder abduction in the plane of the scapula below 80°	62 ± 18†	0.93
4. Unilateral shoulder press	62 ± 19†	0.98
5. Shoulder external rotation at 90° of abduction	57 ± 22†	0.89
6 Bilateral scapular protraction	53 ± 28†	0.80
7. Arm raise overhead in line with the lower trapezius muscle fibers	43 ± 17†	0.68
8. Unilateral shoulder shrug	27 ± 17	0.85
9. Unilateral row	14 ± 6	0.97
10. Shoulder horizontal extension with external rotation	9 ± 3	0.96

* No significant difference between exercises 1 and 2, but both are significantly greater than exercises 3 through 10 ($P \leq 0.05$).
† No significant difference between exercises 3 through 7, but they are all significantly greater than exercises 8 through 10 ($P \leq 0.05$).

shoulder pathology. The EMG data presented may assist physical therapists in developing exercise programs that will optimally activate the trapezius and serratus anterior muscles.

Exercises for the Upper Trapezius

The shoulder shrug exercise produced the most EMG activity in the upper trapezius (119% MVIC) (Figure 1). Moseley et al[38] also performed a shrug exercise, but it was not listed as one of their top 5 exercises for recruitment of the upper trapezius muscle. They found that rowing (Figure 2) produced the maximum EMG amplitude in the upper trapezius, whereas in this present study, rowing produced an amplitude of only 63% MVIC. The rowing exercise was performed in the same position in both studies, so it is not clear why there is such a discrepancy. Intramuscular fine-wire electrodes were used in their study as compared to surface electrodes in this study. The exercises were also performed at a higher intensity in this present study. Hintermeister et al[18] performed scapular exercises using an elastic cord for resistance and also found that the shoulder shrug produced maximum EMG activity in the upper trapezius.

Exercises for the Middle Trapezius

For the middle trapezius, the prone arm raise overhead (101% MVIC) and shoulder horizontal extension with external rotation (87% MVIC) were exercises that produced maximum EMG activity (Figures 3 and 4). These were performed in the same positions that Kendall et al[24] recommend for muscle testing of the middle and lower trapezius. Moseley et al[38] found maximum EMG activity in the middle trapezius during horizontal extension with neutral or lateral rotation.

Exercises for the Lower Trapezius

The optimal exercise for activating the lower trapezius was the arm raise overhead in line with the lower trapezius muscle fibers and with the subject in the prone position (97% MVIC) (Figure 3). This exercise was performed in the same position as the muscle test that produced a MVIC for normalization. There are no other studies that have analyzed this exercise with EMG.

Some patients may have shoulder pathology that would make the above exercise contraindicated due to the elevated position of the humerus. An alternative exercise that produced high levels of EMG activity (79% MVIC) in the lower trapezius was prone shoulder external rotation at 90° of abduction (Figure 5). Ballantyne et al[4] previously demonstrated that external rotation of the shoulder at 90° of abduction

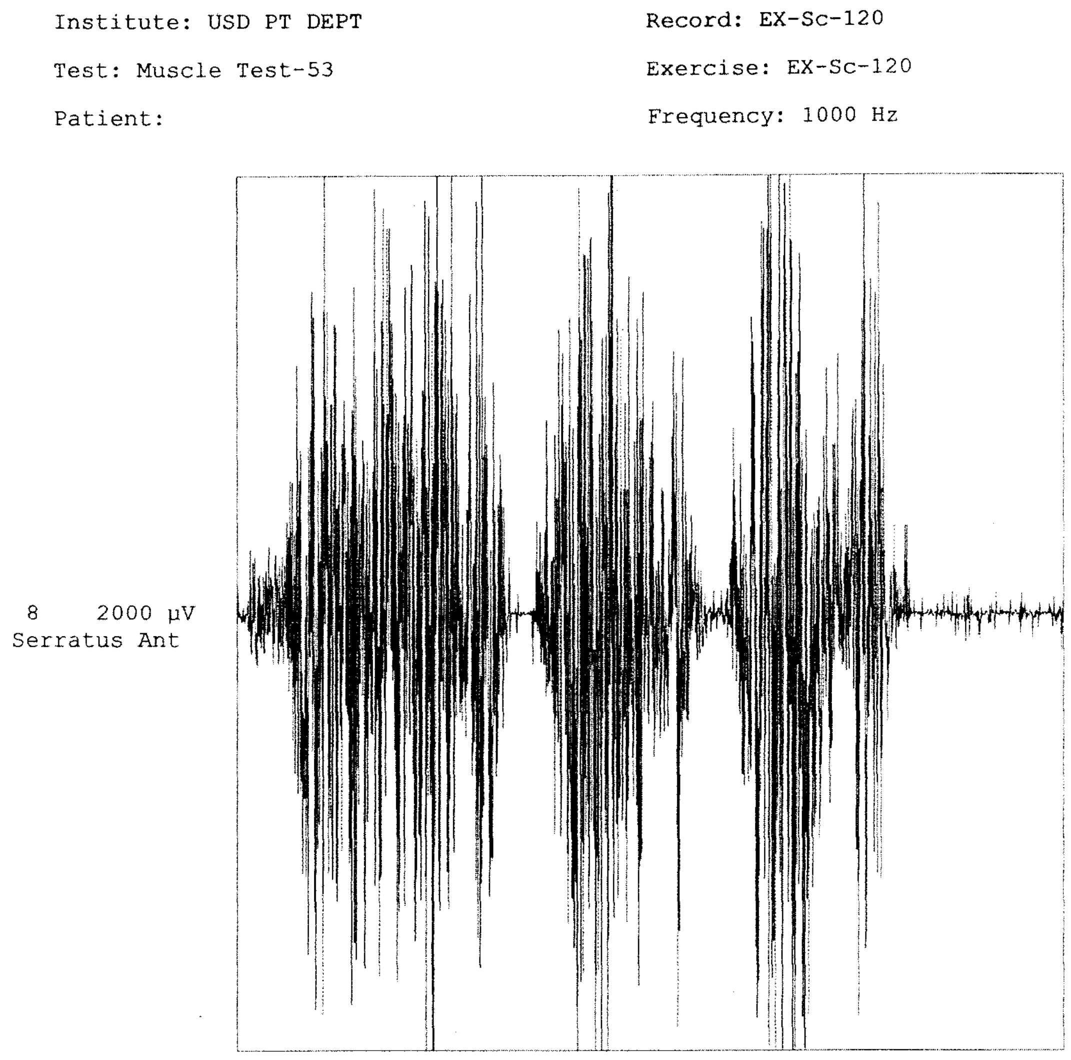

FIGURE 11. Raw EMG recording of the activity in the serratus anterior muscle during shoulder abduction in the plane of the scapula above 120°. Three contractions with a total range of 0–2000 µV.

elicited considerable activity in the lower trapezius muscle. This exercise causes maximum depression of the scapula and isolates the lower trapezius from the upper (20% MVIC) and middle trapezius (45% MVIC) better than any other exercise.

A third exercise that produced relatively high EMG activity (74% MVIC) in the lower trapezius was shoulder horizontal extension with external rotation (Figure 4). Moseley et al[38] reported EMG activity of 63% MVIC with this exercise. They identified shoulder abduction from 90° to 150° as the optimal exercise for activating the lower trapezius (68% MVIC). However, in this present study, it was found that shoulder abduction in the plane of the scapula above 120° (Figure 6) produced EMG activity of 61% MVIC and was rated as the fourth best exercise.

Rowing exercises have been recommended for strengthening the trapezius muscle.[18,38] Moseley et al[38] recorded EMG activity of 112% MVIC for the upper trapezius, 59% MVIC for the middle trapezius, and 67% MVIC for the lower trapezius during rowing. Hintermeister et al[18] found that rowing activated the trapezius muscles the best when the humerus was first abducted to 90°. In this present study, the prone rowing exercise created 79% MVIC in the middle trapezius, 63% MVIC in the upper trapezius, and 45% MVIC in the lower trapezius. Therefore, it was not found to be an optimal exercise for activating the trapezius muscle as a whole. However, rowing may be the exercise of choice for activating the trapezius in early stages of rehabilitation if a patient should not be performing shoulder elevation.

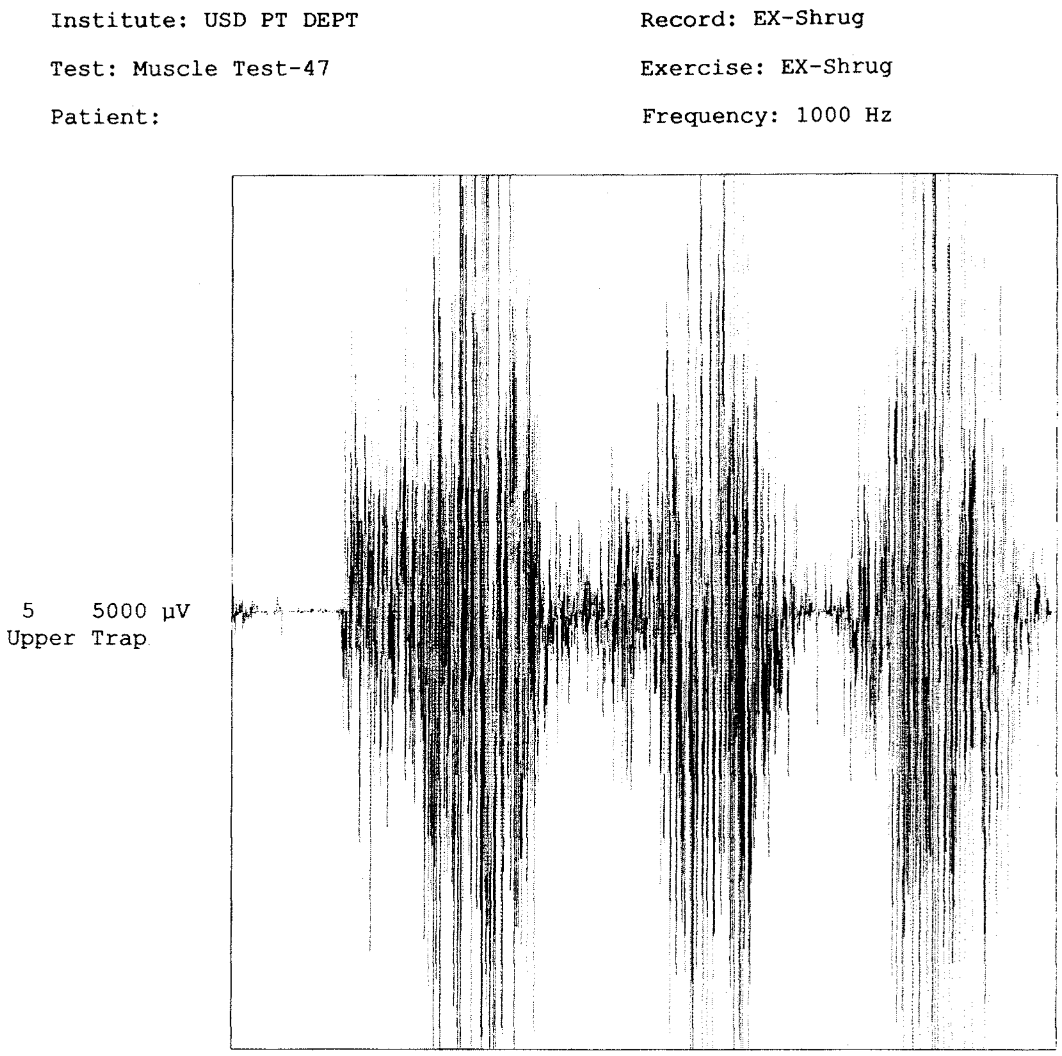

FIGURE 12. Raw EMG recording of the activity in the upper trapezius muscle during the unilateral shoulder shrug exercise. Three contractions with a total range of 0–5000 µV.

Exercises for the Serratus Anterior

Exercises that create upward rotation of the scapula were found to produce much more EMG activity in the serratus anterior than straight scapular protraction exercises. A diagonal exercise with a combination of shoulder flexion, horizontal flexion, and external rotation (100% MVIC) and shoulder abduction in the plane of the scapula above 120° (96% MVIC) generated the highest levels of EMG activity in the serratus anterior (Figures 6 and 7). Moseley et al[38] also found that shoulder elevation exercises from 120° to 150° produced maximum EMG activity in the serratus anterior. The diagonal exercise reduces the activity in the trapezius muscle, therefore, the serratus anterior muscle has to carry more of the load. An advantage of this exercise for the serratus anterior muscle is that patients with impingement problems may be able to perform this exercise more easily than a shoulder abduction exercise.

Exercise in the plane of the scapula was performed below 80° and above 120° to avoid a range of motion where shoulder impingement would most likely occur (Figures 6 and 8). Exercise below 80° produced significantly less EMG activity (62% MVIC) in the serratus anterior when compared to exercise above 120° (96% MVIC). This is not surprising because the majority of upward rotation of the scapula occurs in ranges between 80° and 140° during shoulder abduction.[2] Many patients with impingement may be able to exercise in the plane of the scapula above 120° as long as the painful arc of movement is avoided.

Many authors recommend scapular protraction exercises for serratus anterior muscle strengthening.[11,18,22,40,44] In this present study, 2 protraction-type exercises were evaluated. The first exercise was a bilateral scapular protraction exercise (Figure 9) fashioned after the dynamic hug exercise studied by Decker et al.[11] This exercise produced EMG activity in the serratus anterior that was 53% MVIC. The second exercise was a supine unilateral shoulder press exercise with full scapular protraction to end range which produced 62% MVIC (Figure 10). This activity level was consistent with what we found during manual muscle testing using scapular protraction at 90° of shoulder flexion (57% MVIC).

Decker et al[11] performed scapular protraction-type exercises using moderate resistance with an elastic cord and found the activity in the serratus anterior to be at the 31%-MVIC level for a serratus anterior punch (protraction) exercise and a dynamic hug exercise (protraction). Hintermeister et al[18] followed a similar protocol to that of Decker et al[11] and also used elastic cords for resistance. They found a forward punch exercise to produce 49% MVIC in the serratus anterior. It is not completely clear why these exercises do not activate the serratus anterior to a greater degree, however, it is evident that these exercises do not produce adequate upward rotation of the scapula, which seems to be a very important factor for optimal activation of the muscle.

Simultaneous Activation of the Trapezius and Serratus Anterior

Because the trapezius and serratus anterior muscles work synergistically to produce upward rotation of the scapula, the 2 exercises that best activated the 2 muscles simultaneously were identified. Performing this type of exercise may be important in teaching proper motor recruitment of the trapezius and serratus anterior muscles if the goal is to improve scapular upward rotation and scapulohumeral rhythm. The first exercise was the prone arm raise overhead, which produced EMG activity in the 3 parts of the trapezius that ranged from 79% to 101% MVIC and activation levels in the serratus anterior that could not be reliably measured (Figure 3). The second exercise was shoulder abduction in the plane of the scapula above 120°, which produced EMG activity ranging from 49% to 79% MVIC in the 3 parts of the trapezius and 96% MVIC in the serratus anterior (Figure 6).

Limitations

Research has demonstrated that as active tension increases in a muscle, there is a linear or near-linear increase in the EMG amplitude during isometric contractions.[19,29,37,46] In this study, concentric contractions were evaluated and it must be recognized that there may have been changes in the EMG recording due to changing muscle length and speed of contraction.[12] This is always a concern when performing EMG to evaluate exercises. However, it has been demonstrated that there is a near-linear relationship between force production and the EMG recording with concentric or eccentric contractions if the velocity of contraction is kept constant.[7,27] The speed of contraction or muscle shortening in this study was controlled as much as possible with the use of a metronome during the exercises.

Most authors feel that surface EMG is appropriate for superficial muscles.[6,10,12] The surface EMG signal is a good representation of the activity of the whole muscle. It also has been found that the reliability of the surface EMG signal is better than analyzing activity with intramuscular fine-wire electrodes.[17,21,27] However, cross-talk may be a limitation when using surface electrodes during EMG recordings, especially when analyzing small muscles.[16,45] We feel that cross-talk was not a significant problem in this study because we analyzed large superficial muscles.

Conclusions drawn about activation levels during some exercises for the trapezius and serratus anterior may not be valid because of unreliable EMG measurements, especially when the muscles were acting as synergists or antagonists. There were several exercises in which the ICC scores for the EMG recordings for a certain muscle dropped below 0.80 and, therefore, the exercise must be interpreted with caution. However, this limitation does not affect the major findings reported in this paper because the reliability was generally good to excellent.

Because these results were obtained by studying subjects without pathology of the shoulder girdle, rather than patients with shoulder problems, caution is warranted in extrapolating these findings to a patient population.

CONCLUSION

The results would suggest that the upper trapezius is best activated with the shoulder shrug exercise. The middle trapezius demonstrated the greatest amount of EMG activity with 2 exercises: shoulder horizontal extension with external rotation and the overhead arm raise exercise in the prone position. For the lower trapezius, the overhead arm raise in the prone position produced the most EMG activity. Shoulder external rotation at 90° of humeral abduction is also an excellent exercise for activating the lower trapezius. Shoulder abduction in the plane of the scapula above 120° or a diagonal exercise with shoulder flexion, horizontal flexion, and external rotation that require a great amount of upward rotation of the scapula produced the greatest activation of the serratus anterior. Shoulder abduction in the plane of the scapula above 120° is also an excellent exercise for coactivation of the trapezius and serratus anterior. Scapular protraction exercises often used for exercising the serratus anterior produced EMG activity that was relatively low.

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