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original research

Serratus Anterior and Lower Trapezius Muscle Activities During Multi-Joint Isotonic Scapular Exercises and Isometric Contractions

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Context: Proper scapular function during humeral elevation, such as upward rotation, external rotation, and posterior tilting of the scapula, is necessary to prevent shoulder injury. However, the appropriate intensity of rehabilitation exercise for the periscapular muscles has yet to be clarified.

Objective: To identify the serratus anterior, lower trapezius, infraspinatus, and posterior deltoid muscle activities during 2 free-motion exercises using 3 intensities and to compare these muscle activities with isometric contractions during quadruped shoulder flexion and external rotation and abduction of the glenohumeral joint.

Design: Cross-sectional study.

Setting: Health Science Laboratory.

Patients or Other Participants: A total of 16 uninjured, healthy, active, male college students (age = 19.5 ± 1.2 years, height = 173.1 ± 6.5 cm, weight = 68.8 ± 6.6 kg).

Main Outcome Measure(s): Mean electromyographic activity normalized by the maximal voluntary isometric contraction was analyzed across 3 intensities and 5 exercises. Intraclass correlation coefficients were calculated for electromyographic activity of the 4 muscles in each free-motion exercise.

Results: Significant interactions in electromyographic activity were observed between intensities and exercises ($P < .05$). The quadruped shoulder-flexion exercise activated all 4 muscles compared with other exercises. Also, the modified robbery free-motion exercise activated the serratus anterior, lower trapezius, and infraspinatus compared with the lawn-mower free-motion exercise. However, neither exercise showed a difference in posterior deltoid electromyographic activity.

Conclusions: Three intensities exposed the nature of the periscapular muscle activities across the different exercises. The free-motion exercise in periscapular muscle rehabilitation may not modify serratus anterior, lower trapezius, and infraspinatus muscle activities unless knee-joint extension is limited.

Key Words: upper extremity, shoulder joint, overhead performance

Key Points

- Modulation of electromyographic activity of the serratus anterior and lower trapezius muscles varied with multi-joint free-motion exercises though exercise intensity was increased.
- No increase in the electromyographic activity of the lower trapezius was found in the lawn-mower exercise despite increasing intensity.
- Isometric shoulder flexion in the quadruped position showed the highest amplitude of electromyographic activity of the serratus anterior and lower trapezius muscles compared with the free-motion exercises.

Periscapular muscles have been intensively studied for the purposes of injury prevention and rehabilitative exercise in patients with asymptomatic and symptomatic shoulders. These include symptomatic patients with shoulder impingement syndrome and rotator cuff injury.[1–13] The scapula acts as the base from which kinetic force and energy are transferred to the distal segments of the upper extremity, especially in overhead athletes.[14] Also, the stability of the scapula enables the rotator cuff muscles to be maximally activated.[15] For instance, the empty-can position at 90° of abduction (ABD) of the glenohumeral (GH) joint in the scapular plane increased ABD resistance when the scapular position was retracted by a clinician with forearm pressure on the medial scapular border.[15]

The appropriate functional scapular motions of upward rotation, posterior tilt, and external rotation increase the width of the subacromial space during humeral elevation, whereas a lack of proper scapular function, so-called *scapular dyskinesis*, increases the translation of the humeral head and alters scapular position and motion in both static and dynamic applications.[2,16–18] A shoulder rehabilitation exercise program must emphasize the external rotation, posterior tilting, and upward rotation of the scapula.[19] Moreover, current researchers have advocated that the serratus anterior (SA) and lower trapezius (LT) muscles be reconditioned even before the rotator cuff muscles for symptomatic shoulders of overhead athletes.[20] However, the effects of exercise intensity on conditioning these muscles has yet to be investigated. Most, if not all, previous authors used 1 intensity to compare periscapular muscle activities across a variety of scapular exercises.[1,3,5,12,21–23] Although using 1 level of intensity may allow researchers to compare a certain amount of muscle activity across different exercises, the modulation in muscle activity cannot be fully determined with experimental paradigms using only 1 intensity. Some muscle activation may not increase proportionally as the level of exercise intensity increases, and different compensation from other muscles often occurs during the same movement with different intensities.[24]

Free-motion exercises that simultaneously extend the knee joints, hip joints, and trunk, such as the lawn-mower and robbery exercises, were analyzed for scapular muscle activity to identify the amounts of scapular retraction and depression. Exercises with multi-joint movement such as these activated the SA and LT by approximately 30% of maximum voluntary isometric contraction (MVIC) without providing information about exercise intensity.[2] The sequential motion inherent in these exercises, which transfer forces from the lower to upper extremities and follow a proximal-to-distal progression, has been of interest to clinicians for shoulder rehabilitation exercise programming.[17,25] However, researchers have not yet identified how different intensities of such multi-joint isotonic exercises affect the activities of the SA and LT muscles. Therefore, the purpose of our study was to identify the muscular activity of the SA and LT at different levels of intensity during the lawn-mower, robbery, and quadruped shoulder-flexion (QSF) exercises.

METHODS

None of the prior studies determined the optimal intensity needed for the lawn-mower and robbery exercises to activate the SA and LT. Thus, we selected 40% of MVIC, which was previously identified as optimal for shoulder external-rotator muscle exercise; participants who performed the same exercise with either 10% or 70% of MVIC could not achieve the necessary activation of the infraspinatus and instead activated the deltoid.[24,26] Consequently, we measured the amount of SA, LT, infraspinatus (IS), and posterior deltoid (PD), activity during external rotation (ER) of the shoulder during isometric contractions. Furthermore, previous investigators found no difference in the amount of SA and LT electromyographic (EMG) activity between the lawn-mower and robbery exercises.[2] We modified the robbery exercise for less of a kinetic link with the lower extremity and finished at 90° of shoulder ABD and ER, whereas the lawn-mower exercise was used with the original motion in which knees, hips, and trunk are simultaneously extended with less shoulder ABD. Because of the modified-robbery motion, which mimicked the arm during the cocking phase of overhead-throwing, we also measured shoulder ABD at 90° during isometric contractions. In addition, we compared LT activity in as much shoulder flexion as possible in the quadruped position because previous researchers demonstrated the greatest LT EMG activity during humeral elevation above the head in the prone position.[21]

Participants

A total of 16 active male college students (age = 19.5 ± 1.2 years, height = 173.1 ± 6.5 cm, weight = 68.8 ± 6.6 kg) volunteered to be tested in this study. All volunteers belonged to Osaka University of Health and Sport Sciences and gave informed consent to the procedures as approved by the University's Committee for the Protection of Human Subjects, which also approved the study. Participants indicated no history of neurologic or physiologic deficits in the upper body on a preliminary screening questionnaire. Each person was tested for approximately 1 hour on 1 day at a randomly assigned test time, and all tests were conducted in the Health Science Laboratory at Osaka University of Health and Sport Sciences. None of the participants had previously performed any of the exercises used in this study.

Clinical Measures

This study measured the activity of 4 different muscles during 2 currently recommended scapular rehabilitation exercises and compared those levels with the activation levels achieved with flexion, ER, and ABD of the GH joint during isometric contraction. First, isometric contractions of ER and ABD of the shoulder were conducted with a Kin-Com isokinetic dynamometer (model 500-H; Chattanooga Corporation, Chattanooga, TN). Participants next performed the QSF exercise using an isometric contraction at the maximal end of active range of motion. Finally, participants performed 2 free-motion exercises with dumbbells, the lawn-mower and the robbery, as described by Kibler et al.[2] To ensure that all participants performed both exercises similarly, auditory cues for movement were given by a metronome with a frequency of 0.75 Hz, or 45 beats per minute.

Electrode Placement

Raw EMG amplitudes of the SA, LT, IS, and PD were collected in each testing session. To measure EMG amplitudes, bipolar surface electromyogram silver electrodes (model Delsys Bagnoli-4; Delsys Inc, Natick, MA) with a bar length of 10 mm, a width of 1 mm, and a distance of 1 cm between active recording sites were used. Electrodes for the SA, LT, and PD muscles were placed according to a previous report,[2] whereas the electrode for the IS muscle was placed according to another study.[24] The electrodes were placed as follows: SA, below the axilla at the level of the inferior angle of the scapula; LT, at an oblique angle 5 cm down from the scapular spine and just outside the medial border of the scapula; PD, at an oblique direction parallel to the muscle fibers of the deltoid muscles at the lateral border of the scapular spine. An electrode was also placed on the IS just below the scapular spine and at the middle of the IS fossa of the scapula.[24] The EMG electrodes were preamplified and routed through the EMG mainframe, which further amplified (×1000) and band-pass filtered (20–450 Hz) the signals. A metal reference electrode was placed between the LT and IS electrodes. To ensure that EMG activities were analyzed similarly between participants, an electronic goniometer (Biometrics Ltd, Newport, UK) was attached to the elbow on the lateral side of the arm being tested.

Procedures

For the controlled isometric measurement of ER of the GH joint, participants stood upright, with the shoulder flexed and abducted 30° in the scapular plane, elbow flexed to 90°, and forearm pronated to 90°. The load cell was tilted

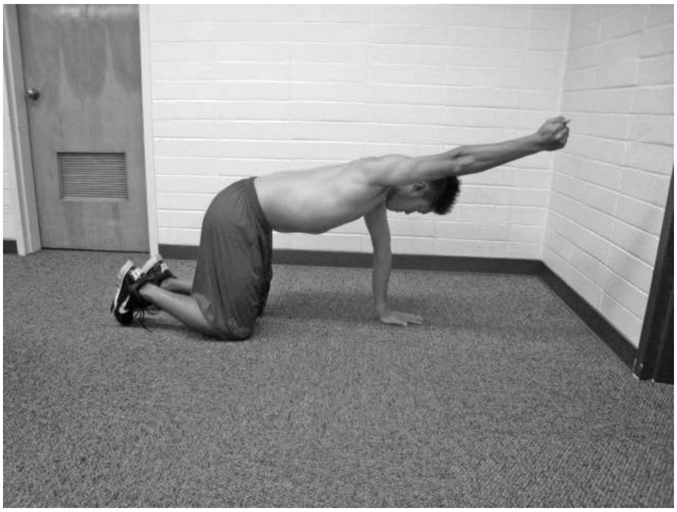


Figure 1. Quadruped shoulder flexion. Participants knelt in the quadruped position and performed isometric contractions at 180° of glenohumeral flexion or with as much flexion as possible.

20° from the horizontal position, and the height of the load cell was adjusted for the person based on his height. The grip position on the lever arm was also adjusted from the olecranon of the elbow placed on the load cell for each individual. Participants were instructed to concentrate on ER of the GH joint and to minimize substitution.

For the next controlled measurement of ABD of the GH joint, participants were seated, with the shoulder abducted to 90° and internally rotated 90° in the coronal plane, elbow extended 0°, and forearm in the neutral position. The height of the load cell was adjusted for the height of the person's shoulder.

Each individual performed an MVIC of ER of the GH joint at 0° of rotation followed by 20%, 30%, and 40% MVIC using the isokinetic dynamometer. Each participant also performed an MVIC of ABD at 90° of GH joint elevation, followed by contractions at 20%, 30%, and 40% MVIC. For both controlled measurements, each person performed 3 trials of each isometric contraction for 4 seconds with a rest interval of 20 seconds. To accurately produce a certain amount of torque during the performance of isometric contractions, individuals were given ongoing visual feedback on the torque generated using the monitor of a personal computer in front of him.[27]

To measure QSF, the participant knelt in the quadruped position (hips and knees flexed to 90°) and performed an MVIC at 180° of GH flexion or with as much flexion as possible. The shoulder was rotated consistently such that the thumb was pointing upward toward the ceiling (Figure 1). To ensure that an MVIC was performed, the person grasped a dumbbell, and the forearm was further pushed by the same examiner until the participant was barely able to maintain the arm in a flexed position. This contraction was held for 4 seconds. After maximal testing, the individual held a dumbbell of 3%, 5%, and 7% of body weight (BW) in the same QSF position for 4 seconds each.

For the first free-motion exercise, the lawn mower, the participant performed a dumbbell exercise in a diagonal pattern from the contralateral leg through the trunk to the ipsilateral arm. This free-motion exercise simultaneously used the motions of knee, hip, and trunk extension, as well as ipsilateral trunk rotation and scapular retraction.[2] At the start of the exercise, while in the quarter-squat position with the feet parallel, shoulder-width apart, and the body slightly forward and flexed, he grasped the dumbbell in front of the contralateral knee. The participant then pulled the dumbbell by extending the knee and hip, rotating the trunk, and flexing the elbow to 90° until the scapula maximally retracted. At the end of the exercise, the forearm was supinated (Figure 2). The participant performed the exercise with dumbbells of 3%, 5%, and 7% BW.

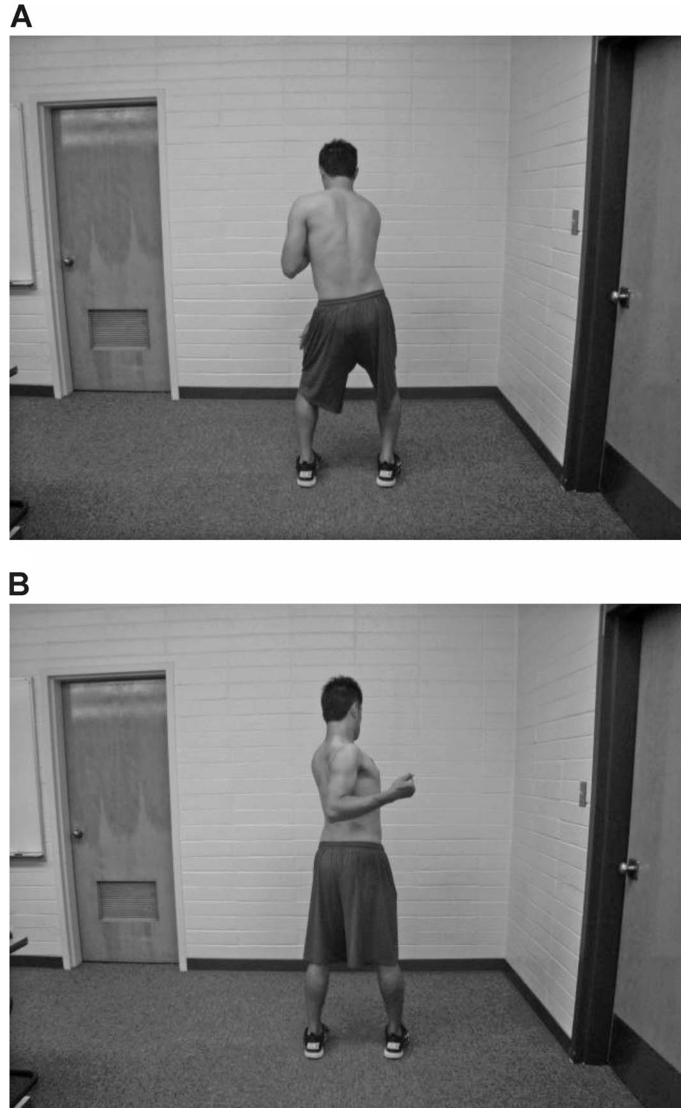
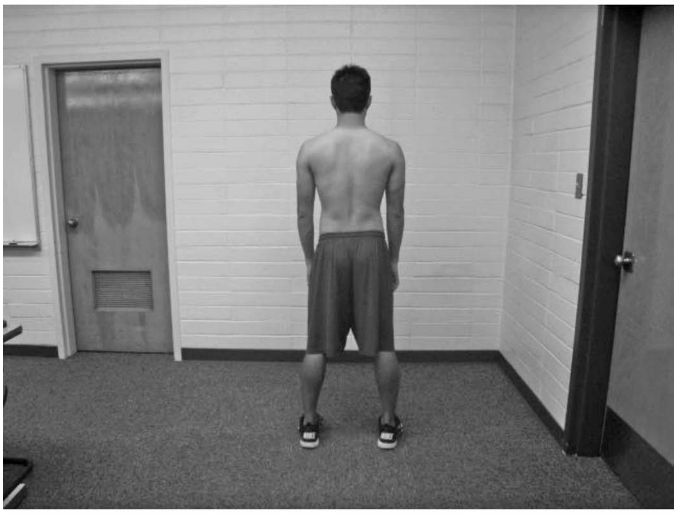


Figure 2. A and B, Lawn-mower exercise. Participants performed the free-motion exercise using a dumbbell in a diagonal pattern from the contralateral leg through the trunk to the ipsilateral arm.

For the second free-motion exercise, the robbery, the person stood upright and used hip and trunk extension and bilateral arm motion to achieve ER of the GH joint and maximal scapular retraction.[2] At the start of the exercise, in a standing position with the trunk slightly forward and flexed, the elbow extended, and the palms facing the thighs, he grasped a dumbbell in front of the ipsilateral groin area. While keeping the elbows close to the body, the participant moved into trunk extension and flexed the elbows to 90° so the palms were facing up and away from the body while

A



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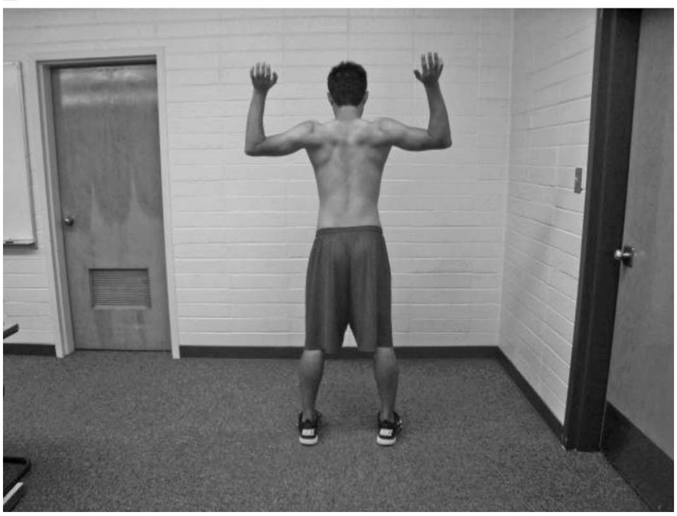

Figure 3. A and B, Robbery exercise. Participants performed the free-motion exercise using a dumbbell in a bilateral arm motion to achieve external rotation of the glenohumeral joint and maximal scapular retraction.

simultaneously abducting and externally rotating the arm at 90° and maximally retracting the scapulae (Figure 3). The person performed the exercise with dumbbells of 3%, 5%, and 7% BW.

Each individual performed the lawn-mower and robbery exercises for 10 consecutive repetitions and followed auditory cues for each repetition. A metronome with a frequency of 0.75 Hz or 1.5 seconds per movement was used to standardize the speed of exercise. Before each free-motion exercise, the participant performed several practice repetitions to ensure familiarity with the upcoming test condition before formal data collection.

Data Management and Analyses

Input signals of EMG activities and joint angles were recorded using a data-collection system (model MP100 Data Acquisition System; Biopac System, Inc, Goleta, CA) with a sampling rate of 2000 Hz; all data were stored in a computer for offline analyses. The root mean square values of the EMG signal for the SA were normalized to the MVIC of the corresponding muscle in ABD of the GH joint, whereas the root mean square of the EMG signal for the LT was normalized to the MVIC of the corresponding muscle in QSF. Additionally, the root mean squares of the EMG signals for the IS and PD were normalized to the MVIC of the corresponding muscles in ER of the GH joint. In each trial of free-motion exercise, data consisted of the EMG activity as a dependent variable measured by the joint angles from the initial movement for 1 second during the concentric contraction (Figure 4). Also, each EMG activity from the third to the ninth trials, a total of 7 trials in each free motion of the lawn-mower and robbery exercises, was analyzed. The data for the EMG activity at each percentage of MVIC during the isometric contractions in ER, ABD, and QSF were analyzed for a 1-second postisometric contraction for a duration of 2 seconds.

For data analyses of the EMG activity of the muscles across the exercise conditions, a 3 × 5 (intensity × exercise) repeated-measures analysis of variance design, with participants crossed with intensity and exercise, was used to examine differences for each dependent variable. Where appropriate, the simple main effect and the Tukey honestly significant different post hoc test were used to measure any significant difference for each EMG activity.[28] All statistical tests were performed at the .05 level of probability. Also, intraclass correlation coefficients (ICCs) were calculated for each intensity in both the lawn-mower and robbery exercises, using the dependent variable of the root mean square values of the EMG signal for each measured muscle. A within-subject (subject × trial) analysis of variance design was used to calculate the ICCs.

RESULTS

Serratus Anterior Muscle

Mean values (± standard deviations) for SA EMG activities are shown in Table 1. For SA, the mean ICC [2,1] was 0.71 of a person's true score for the lawn-mower exercise and 0.93 for the robbery exercise. The ICCs for the SA during the lawn-mower and robbery exercises are presented in Table 2.

Analysis of the results indicated a significant interaction in SA EMG activities between intensities and exercises ($F_{8,120} = 7.28$, $P < .01$, effect size [ω^2] = 0.17). Specifically, for QSF, we observed differences in the mean values of EMG activities across different intensities (56.3% versus 78.3% and 88.1% at 3%, 5%, and 7% BW, respectively) (the critical value of the Tukey honestly significant difference [D_{Tukey}] = 7.0%, $P < .05$). In contrast, for the lawn-mower exercise, a difference in the mean values of EMG activities was shown between 3% and 7% BW (12.9% and 21.7%, respectively), whereas no difference was noted between 3% and 5% BW or between 5% and 7% BW. Similarly, the robbery exercise demonstrated a difference between 3% and 7% BW (48.1% versus 67.0%, respectively), whereas no difference was evident between 3% and 5% BW or between 5% and 7% BW. For ER, no difference was shown across any of the 3 intensities. However, for ABD, we observed differences in the mean values of EMG activities between 20% and 40% MVIC (27.7% and 41.8%, respectively) and between 30% and

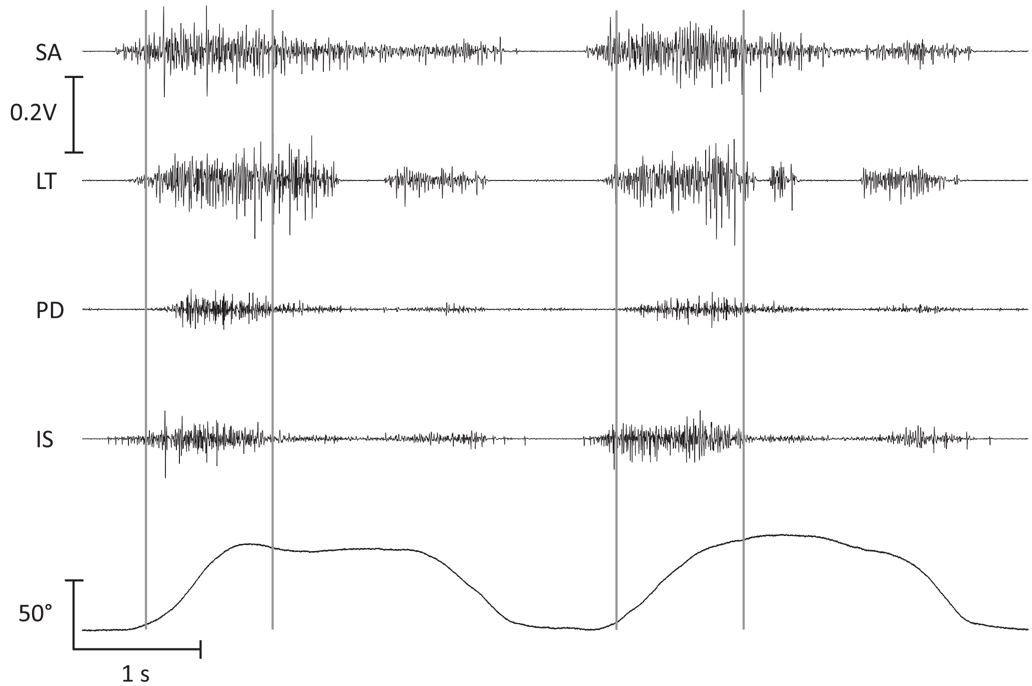

Figure 4. Typical raw electromyographic traces of serratus anterior (SA), lower trapezius (LT), posterior deltoid (PD), and infraspinatus (IS) muscle activity during the robbery exercise with a dumbbell of 7% of body weight. For the angle trace (below), an electronic goniometer was attached to the elbow on the lateral side of the arm being tested. Concentric contractions are shown on the up-slope portion, and eccentric contractions are shown on the down-slope portion. Electromyographic activity (root mean square) was measured by the angles of the elbow joint from the initial movement for 1 second during the concentric contraction.

40% MVIC (33.2% and 41.8%, respectively) but no difference between 20% and 30% MVIC.

With regard to the mean values of EMG activities across different exercises at each intensity, each mean value for QSF was greater than that for the lawn-mower exercise at the corresponding intensity ($D_{\text{Tukey}} = 13.6\%$, $P < .05$). In contrast, no difference was demonstrated in the mean value between the QSF and the robbery exercise at 3% BW, but differences were evident between these exercises at 5% and 7% BW (78.3% for QSF versus 60.4% for robbery and 88.1% for QSF versus 67.0% for robbery, respectively).

For the lawn-mower exercise, the mean EMG activity was less than that for the robbery exercise at each corresponding intensity (12.9%, 15.6%, and 21.7% for the lawn mower versus 48.1%, 60.4%, and 67.0% for the robbery at 3%, 5%, and 7% BW, respectively). Similarly, the mean values for the lawn-mower exercise were significantly smaller than those for the ABD (27.7%, 33.2%, and 41.8% ABD at 20%, 30%, and 40% MVIC, respectively). However, compared with ER, we found no difference in mean values between the lawn-mower exercise at 3% BW and ER at 20% MVIC, whereas significant differences in mean values were shown between the lawn-mower exercise at 5% BW and ER at 30% MVIC (15.6% and 8.1%, respectively) and between the lawn-mower exercise at 7% BW and ER at 40% MVIC (21.7% and 12.5%, respectively).

For the robbery exercise, the mean EMG activity was significantly greater than for ER and ABD at each corresponding intensity. For ER, the mean values were significantly smaller than for ABD at each corresponding intensity (6.2%, 8.1%, and 12.5% for ER versus 27.7%, 33.2%, and 41.8% for ABD at 20%, 30%, and 40% MVIC, respectively; Figure 5).

Table 1. Serratus Anterior Electromyography Activity[a] (Mean ± SD)

Exercise or Motion	Intensity, % 3	5	7
Quadruped shoulder flexion	56.3 ± 20.9	78.3 ± 29.1	88.1 ± 33.4
Lawn mower	12.9 ± 6.03	15.6 ± 7.15	21.7 ± 10.7
Robbery	48.1 ± 15.5	60.4 ± 15.7	67.0 ± 18.7
External rotation	6.18 ± 4.52	8.08 ± 6.40	12.5 ± 10.0
Abduction	27.7 ± 10.4	33.2 ± 12.5	41.8 ± 15.8

[a] Normalized by the maximum isometric voluntary contraction.

Lower Trapezius Muscle

Mean values (± standard deviations) for LT EMG activities are shown in Table 3. For LT, the mean ICC [2,1] was 0.86 of a participant's true score for the lawn-mower exercise and 0.81 for the robbery exercise. The ICCs for the LT during the lawn-mower and robbery exercises are presented in Table 4.

Analysis of the results indicated a significant interaction in LT EMG activities between intensities and exercises ($F_{8,120} = 4.72$, $P < .01$, $\omega^2 = 0.11$). Specifically, for QSF,

Table 2. Intraclass Correlation Coefficients [2,1] of the Root Mean Square Values of Electromyographic Signals for the Serratus Anterior Muscle

Exercise	Intensity, % 3	5	7
Lawn mower	0.64	0.75	0.73
Robbery	0.90	0.93	0.95

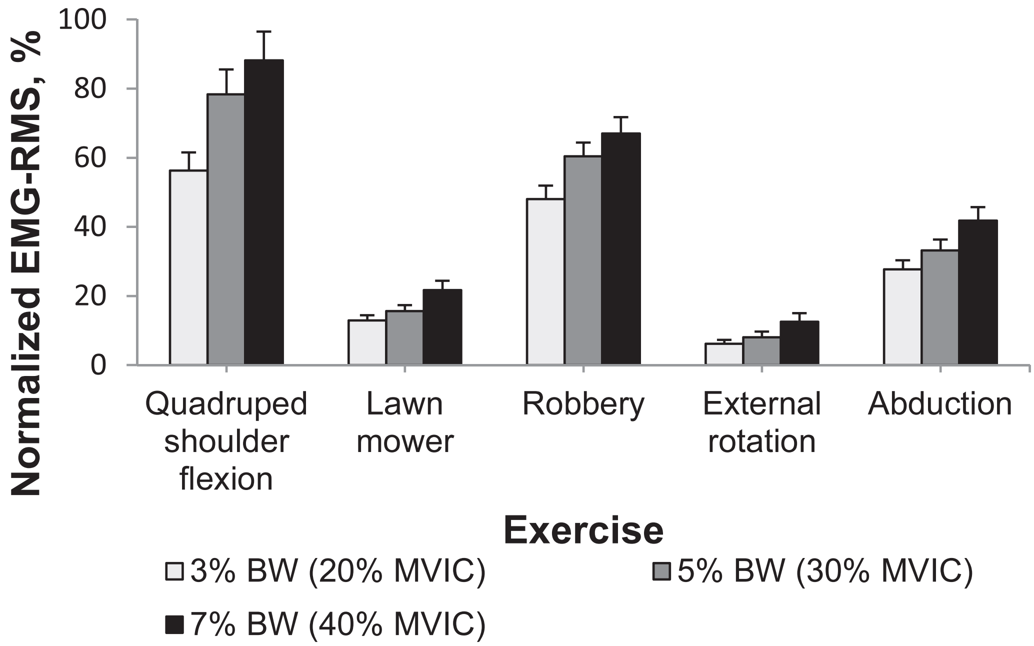

Figure 5. Mean values of normalized serratus anterior electromyographic (EMG) activity across different exercises at each intensity. Intensities were set by the dumbbell of body weight (BW) for the quadruped shoulder flexion, lawn-mower, and robbery exercises and by the percentage of maximum isometric voluntary contraction for external rotation and abduction of the glenohumeral joint during isometric contraction. Note that there was no difference in the muscle activity between the quadruped shoulder-flexion and robbery exercises at the intensity of 3% BW, whereas there were significant differences between these exercises at 5% and 7% BW ($P < .05$). Abbreviations: MVIC, maximum voluntary isometric contraction; RMS, root mean square.

mean values of EMG activities were different as the intensity increased (69.4%, 79.6%, and 86.9% at 3%, 5%, and 7% BW, respectively) ($D_{\text{Tukey}} = 5.9\%$, $P < .05$). In contrast, no difference in the mean values of EMG activities was observed for the lawn-mower exercise across the different intensities. For the robbery exercise, mean values differed between 3% and 5% BW (36.0% versus 43.2%, respectively) and between 3% and 7% BW (36.0% versus 46.7%, respectively), whereas no difference was noted between 5% and 7% BW.

For ER, we found significant differences in the mean values between 20% and 40% MVIC (24.7% versus 41.6%, respectively) and between 30% and 40% MVIC (29.4% versus 41.6%, respectively) but no difference between 20% and 30% MVIC. However, for ABD, the mean values differed between 20% and 40% MVIC (33.4% versus 46.3%, respectively), but not between 20% and 30% MVIC or between 30% and 40% MVIC.

Table 3. Lower Trapezius Electromyography Activity[a] (Mean ± SD)

Exercise or Motion	Intensity, %		
	3	5	7
Quadruped shoulder flexion	69.4 ± 17.8	79.6 ± 9.58	86.9 ± 12.6
Lawn mower	29.4 ± 17.5	28.6 ± 15.8	28.8 ± 14.9
Robbery	36.0 ± 11.6	43.2 ± 12.6	46.7 ± 12.5
External rotation	24.7 ± 12.5	29.4 ± 12.2	41.6 ± 17.8
Abduction	33.4 ± 15.7	40.6 ± 15.7	46.3 ± 19.1

[a] Normalized by the maximum isometric voluntary contraction.

Across different exercises, the mean values of LT EMG activities for QSF were greater than those of the other exercises at each corresponding intensity ($D_{\text{Tukey}} = 13.2\%$, $P < .05$). For the lawn-mower exercise, the mean values at 5% and 7% BW were significantly smaller than those for the robbery exercise (28.4% and 28.8% for the lawn mower versus 43.2 and 46.7% for the robbery, respectively), whereas no difference was evident between these 2 exercises at 3% BW (Figure 6).

Infraspinatus Muscle

Mean values (± standard deviation) for IS EMG activities are shown in Table 5. For IS, the mean ICC [2,1] was 0.76 of a participant's true score for the lawn-mower exercise and 0.79 for the robbery exercise. The ICCs for the IS during the lawn-mower and robbery exercises are presented in Table 6.

Analysis of the results indicated a significant interaction in the IS EMG activities between intensities and exercises ($F_{8,120} = 24.20$, $P < .01$, $\omega^2 = 0.44$). Specifically, for QSF and the robbery exercise, the mean values of EMG activities significantly increased when intensity increased

Table 4. Intraclass Correlation Coefficients [2,1] of the Root Mean Square Values of Electromyographic Signals for the Lower Trapezius Muscle

Exercise	Intensity, %		
	3	5	7
Lawn mower	0.86	0.86	0.86
Robbery	0.80	0.76	0.88

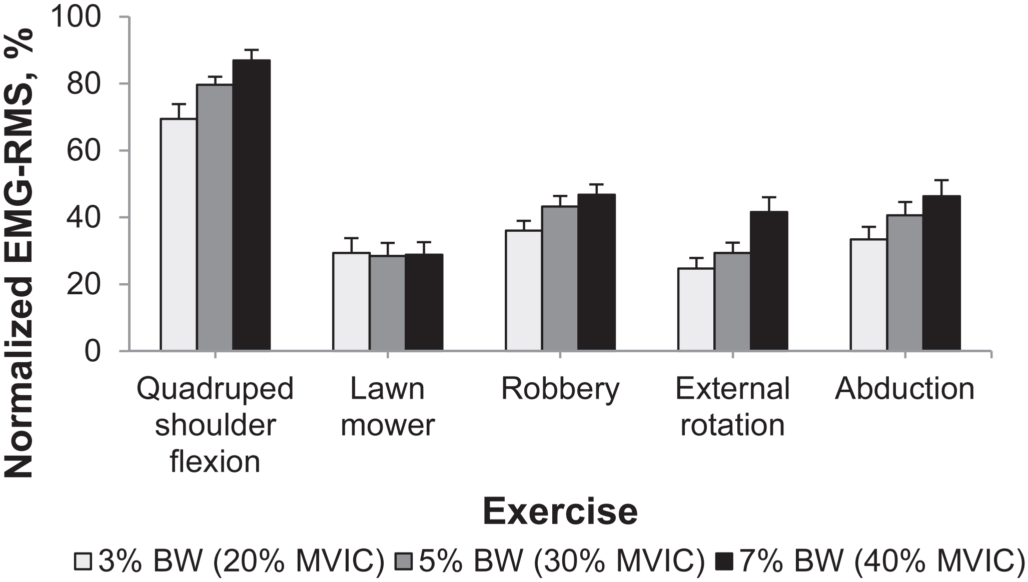

Figure 6. Mean values of normalized lower trapezius electromyographic (EMG) activity across different exercises at each intensity. Note that there was no difference in muscle activity across the different intensities for the lawn-mower exercise, but there were differences between 3% and 5% body weight (BW) and between 3% and 7% BW for the robbery exercise ($P < .05$). Abbreviations: MVIC, maximum voluntary isometric contraction; RMS, root mean square.

(19.3%, 29.9%, and 41.5% for the QSF and 24.0%, 36.2%, and 44.7% for the robbery at 3%, 5%, and 7% BW, respectively) ($D_{Tukey} = 3.6\%$, $P < .05$). In contrast, for the lawn-mower exercise, the mean values of EMG activities did not differ with intensity. For ER and ABD, the mean values of EMG activities significantly increased when intensity increased (12.6%, 18.5%, and 30.7% for ER and 11.5%, 16.9%, and 21.5% for ABD at 20%, 30%, and 40% MVIC, respectively).

The mean values for QSF were significantly greater than those for the lawn-mower exercise at each corresponding intensity (19.3%, 29.9%, and 41.5% for QSF versus 9.2%, 9.3%, and 11.1% for the lawn mower at 3%, 5%, and 7% BW, respectively) and for ABD (11.5%, 16.9%, and 21.5% at 20%, 30%, and 40% MVIC, respectively) ($D_{Tukey} = 7.7\%$, $P < .05$). In contrast, we saw no difference in mean values between QSF and the robbery exercise at each corresponding intensity. Also, for the lawn-mower exercise, the mean EMG activity was significantly less than those for the robbery exercise at each corresponding intensity (9.2%, 9.3%, and 11.1% for the lawn mower versus 24.0%, 36.2%, and 44.7% for the robbery at 3%, 5%, and 7% BW, respectively). For ER, the mean EMG activity was significantly greater than for ABD at 40% MVIC (30.7% for ER versus 21.5% for ABD), whereas no differences were found between these exercises at 20% and 30% MVIC (Figure 7).

Table 5. Infraspinatus Electromyographic Activity[a] (Mean ± SD)

Exercise or Motion	Intensity, % 3	5	7
Quadruped shoulder flexion	19.3 ± 9.93	29.9 ± 13.0	41.5 ± 19.0
Lawn mower	9.22 ± 3.63	9.28 ± 3.29	11.1 ± 3.68
Robbery	24.0 ± 6.64	36.2 ± 11.3	44.7 ± 13.8
External rotation	12.6 ± 3.43	18.5 ± 4.88	30.7 ± 8.38
Abduction	11.5 ± 6.59	16.9 ± 11.3	21.5 ± 14.3

[a] Normalized by the maximum isometric voluntary contraction.

Posterior Deltoid Muscle

Mean values (± standard deviation) for PD EMG activities are shown in Table 7. For PD, the mean ICC [2,1] was 0.88 of a participant's true score for the lawn-mower exercise and 0.79 for the robbery exercise. The ICCs for the PD during the lawn-mower and robbery exercises are presented in Table 8.

Analysis of the results indicated a significant interaction in EMG activity between intensities and exercises ($F_{8,120} = 20.21$, $P < .01$, $\omega^2 = 0.39$). Specifically, for QSF, the mean values of EMG activities significantly increased when intensity increased (48.4%, 70.1%, and 83.8% at 3%, 5%, and 7% BW, respectively) ($D_{Tukey} = 6.2\%$, $P < .05$). In contrast, for the lawn-mower exercise, no difference in the mean values of EMG activity was noted across the different intensities. For the robbery exercise, the mean value at 3% BW was significantly smaller than the value at 7% BW (31.6% versus 37.9%, respectively). For ER, mean values differed between 20% and 40% MVIC (9.3% versus 22.9%, respectively) and between 30% and 40% MVIC (14.6% versus 22.9%, respectively). For ABD, the mean EMG activity significantly increased when intensity increased

Table 6. Intraclass Correlation Coefficient [2,1] of the Root Mean Square Values of Electromyographic Signals for the Infraspinatus Muscle

Exercise	Intensity, % 3	5	7
Lawn mower	0.81	0.77	0.70
Robbery	0.82	0.72	0.83

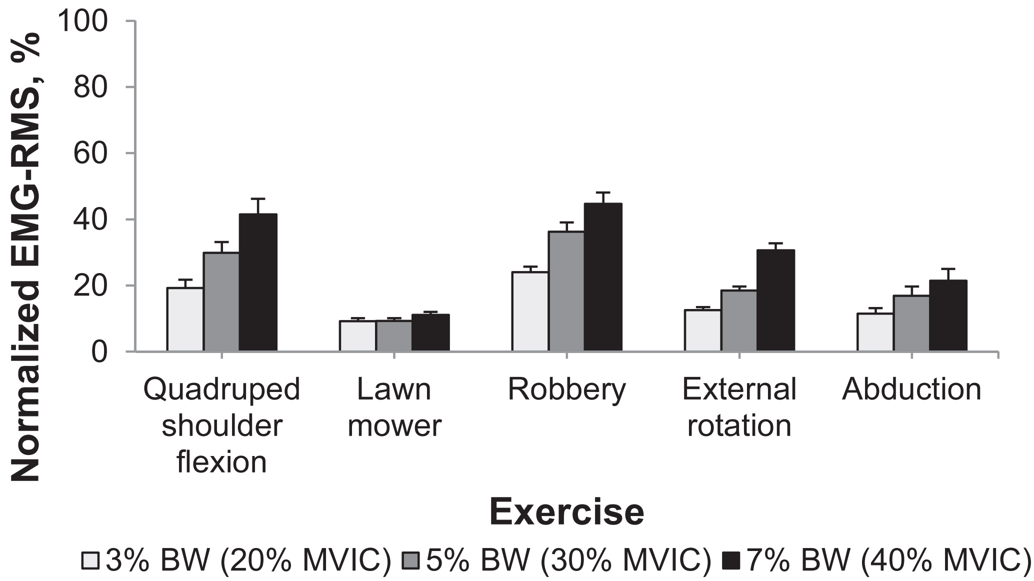

Figure 7. Mean values of normalized infraspinatus electromyographic (EMG) activity across different exercises at each intensity. Note that no difference in muscle activity occurred between the quadruped shoulder-flexion and robbery exercises at each corresponding intensity. However, the electromyographic activity for the quadruped shoulder-flexion and robbery exercises was greater than for the lawn-mower exercise at each corresponding intensity ($P < .05$). Abbreviations: BW, body weight; MVIC, maximum voluntary isometric contraction; RMS, root mean square.

(31.4%, 41.7%, and 49.5% at 20%, 30%, and 40% MVIC, respectively) as would be expected.

Across exercises, mean EMG activity differed between the QSF and lawn-mower exercises at 5% BW and 7% BW (70.1% for QSF versus 36.1% for the lawn mower and 83.8% for QSF versus 32.0% for the lawn mower, respectively) ($D_{Tukey} = 16.2\%$, $P < .05$) but not between these exercises at 3% BW. Mean values for QSF were significantly greater than those for the robbery exercise, ER, and ABD at each corresponding intensity.

For the lawn-mower exercise, significant differences were identified in the mean EMG activity between the lawn-mower exercise at 3% BW and ER at 20% MVIC (38.2% for the lawn mower versus 9.3% for ER) and between the lawn-mower exercise at 5% BW and ER at 30% MVIC (36.1% lawn mower versus 14.6% ER), whereas no difference occurred between the lawn-mower exercise at 7% BW and ER at 40% MVIC. For the robbery exercise, mean EMG activity differed between the robbery exercise at 3% BW and ER at 20% MVIC (31.6% robbery versus 9.3% ER) and between the robbery exercise at 5% BW and ER at 30% MVIC (37.5% robbery versus 14.6% ER). For ER, the mean values of EMG activities were significantly smaller than those for ABD at each corresponding intensity (9.3%, 14.6%, and 22.9% versus 31.4%, 41.7%, and 48.5% at 20%, 30%, and 40% MVIC, respectively; Figure 8).

Table 7. Posterior Deltoid Electromyography Activity[a] (Mean ± SD)

	Intensity, %		
Exercise or Motion	3	5	7
Quadruped shoulder flexion	48.4 ± 7.28	70.1 ± 8.09	83.8 ± 9.30
Lawn mower	38.2 ± 4.98	36.1 ± 5.42	32.0 ± 4.66
Robbery	31.6 ± 4.59	37.5 ± 5.29	37.9 ± 5.45
External rotation	9.30 ± 1.24	14.6 ± 2.03	22.9 ± 2.34
Abduction	31.4 ± 4.63	41.7 ± 5.93	49.5 ± 6.84

[a] Normalized by the maximum isometric voluntary contraction.

DISCUSSION

We examined 2 scapulothoracic and 2 scapulohumeral muscles during currently recommended multi-joint isotonic scapular exercises and isometric contractions with dumbbells of 3% to 7% BW performed by uninjured, active male college students. We also compared muscular activity during the open kinetic chain exercise of ER and ABD of the GH joint at 20% to 40% MVIC. These intensities were selected to measure the activity of the SA and LT muscles based on previous research that identified 40% MVIC as optimal for shoulder external-rotator muscle exercise.[24]

The SA and LT showed the highest EMG activity during the QSF exercise. The SA is one of the primary muscles responsible for producing the characteristic upward rotation of the scapulohumeral rhythm.[9,10,14] The more the humerus is elevated, the more SA activity is increased.[9,21] Oyama et al[12] examined 6 scapular-retraction exercises with a variety of shoulder angles in the prone position, including 120° of ABD with full ER of the GH joint. These authors found that SA activity during a 6-second isometric contraction with no resistance ranged from 9.7% to 21.3% MVIC. The results were much lower than our study, in which SA muscular activity reached 56.3% to 88.1% MVIC in full shoulder

Table 8. Intraclass Correlation Coefficients [2,1] of the Root Mean Square Values of Electromyographic Signals for the Posterior Deltoid Muscle

	Intensity, %		
Exercise	3	5	7
Lawn mower	0.92	0.83	0.87
Robbery	0.78	0.86	0.79

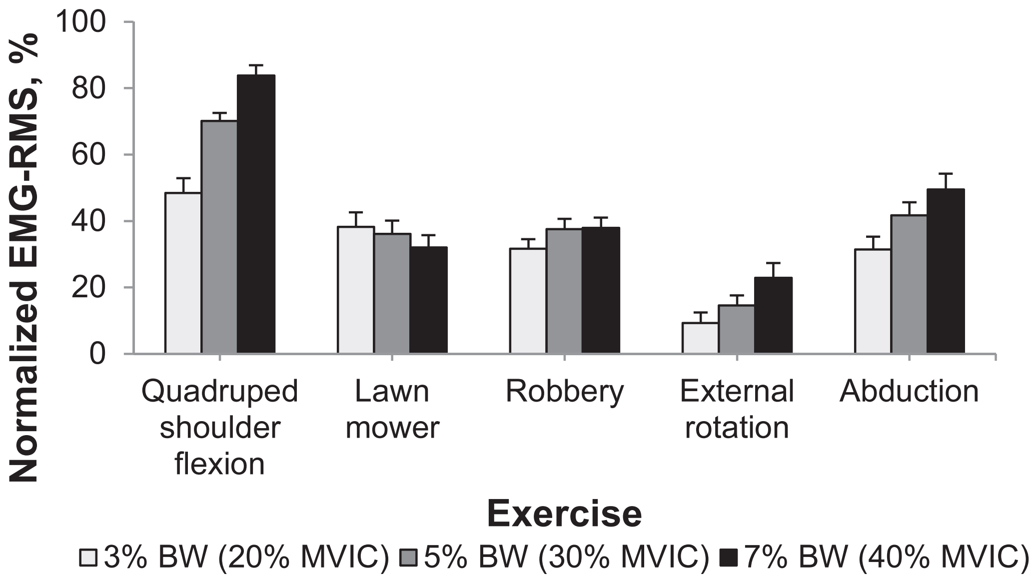

Figure 8. Mean values of normalized posterior deltoid electromyographic (EMG) activity across different exercises at each intensity. Note that for the lawn-mower exercise, no difference in muscle activity was observed across the different intensities, whereas for the robbery exercise, the mean value at 3% body weight (BW) was smaller than that at 7% BW ($P < .05$). Abbreviations: MVIC, maximum voluntary isometric contraction; RMS, root mean square.

flexion, even with dumbbell intensity at 3% to 7% BW. In both studies, the participants fully elevated the humerus against gravity from 90° of shoulder flexion. However, besides the obvious difference that our participants held dumbbells of 3% to 7% BW (equivalent to 2 to 5 kg given the mean BW of 68.8 kg) the 2 investigations differed in several critical ways. First, we did not specifically instruct our participants to retract the scapula. Second, our participants performed shoulder flexion in the quadruped position, compared with the prone position in the previous study. The quadruped position left the trunk unsupported when the humerus was elevated. One hypothesis for this finding is that hip flexion and ipsilateral shoulder flexion resulted in a decrease in proximal stability, which created a need for more SA activation.

The greatest LT EMG activity can be measured during humeral elevation above the head with 120° to 150° of ABD in the prone position.[21,29] Ekstrom et al[21] demonstrated that the position in which the participants elevated the humerus above the head in line with the LT muscle fibers activated the LT up to 97% MVIC. The LT activation reported by Ekstrom et al[21] was 10% greater than in our study (86.9% MVIC) with the intensity at 7% BW during the QSF exercise. Ekstrom et al[21] also measured EMG activity of the upper trapezius (UT) at 79% MVIC for humeral elevation. Instead, we measured the EMG activity of the PD, which was 83.8% MVIC at 7% BW. However, exercises that specifically recruit the UT and the deltoid muscle are not emphasized and are often avoided in rehabilitation programs for injured overhead athletes. This is because hyperactivity of the UT compared with the SA can be associated with *scapular dyskinesis*, which is defined as alterations in static scapular position and lack of dynamic control of scapular motion.[4,7,14,19] Yet hyperactivity of the deltoid reduces the amount of subacromial space as a result of humeral head translation during a superiorly directed shear force in the glenoid fossa.[30,31] Care must be taken when including exercises with higher levels of UT and deltoid activation, particularly in patients with subacromial impingement syndrome.

The subacromial space width can be decreased during abducting muscle contraction compared with adducting contraction.[30] Unlike the anterior or middle deltoid muscles, the PD may have less effect on the alteration of humeral translation.[24,25] Bitter et al[24] demonstrated no difference in the mean PD EMG activity between 40% and 70% MVIC during isometric contraction of ER with ABD, whereas middle deltoid EMG activity increased significantly. The authors suggested that a decrease in the subacromial space was generated by the middle deltoid rather than the PD. Because there is no abducting contraction against gravity in the QSF exercise, the participants progressively increased the mean IS and PD EMG activity while the external resistance intensity increased to 7% BW. It is unlikely that the QSF exercise causes the detrimental translation of the humeral head superiorly. Additionally, the QSF exercise can highly activate the LT with the use of a dumbbell at 7% BW. Although our study revealed a high level of SA activity during the QSF exercise, these findings should be used cautiously in patients with subacromial impingement syndrome because of scapular dyskinesis. Such patients must be encouraged to initially work the SA and LT using lower levels of humeral elevation to minimize the effects of GH impingement.[17,20]

The lawn-mower exercise has been advocated because it uses the kinetic chain sequences of force transferred from the lower extremity to upper extremity.[2,14] Kibler et al[2] demonstrated that participants elicited a mean value of LT EMG activity at 30.5% MVIC during the lawn-mower exercise, regardless of whether they were asymptomatic or symptomatic. We found no difference in the mean value of LT and PD EMG activity across 3 intensities. It is plausible to speculate that the participants progressively activated the lower leg, hip, or trunk muscles when the intensity was increased.

The LT attaches to the medial border of the scapula near the spine of the scapula and plays a crucial role in stabilizing the scapula during humeral elevation.[19] Our findings support those of a previous study[2] in which patients with shoulder impingement emphasized scapular external rotation and posterior tilting, leading to LT activation while performing the lawn-mower exercise. The exercise should be promoted in the early stages of rehabilitation.[2] Our study also supports using resistance up to 7% BW because of the favorable SA activation.

The robbery exercise is another kinetic chain activity originally examined by Kibler et al.[2] We modified the original robbery exercise and asked participants to maintain 90° of ABD, full ER, and scapular retraction at the end of the exercise. The participants used very little knee extension yet used hip and torso extension during the humeral elevation. Unlike previous researchers who reported no difference in SA and LT EMG activity between the lawn-mower and robbery exercises,[2] we found that the modified robbery exercise increased SA and LT activity more than the lawn-mower exercise at all corresponding intensities. The modified robbery exercise may mimic the arm-cocking phase during the overhead baseball pitch and tennis serve, although the angular velocity is different. DiGiovine et al[32] observed SA EMG activity at the 4th rib of 106% MVIC and IS EMG activity of 74% MVIC during the cocking phase. Both values were greater than in any other phase of the pitching motion. The participants in our study demonstrated no difference in mean values for SA EMG activity between QSF and the robbery exercise with the intensity at 3% BW (56.3% and 48.1% MVIC, respectively), and QSF generated more EMG activity than the robbery exercise at both 5% and 7% BW. The robbery exercise generated more IS EMG activity than QSF at 3% and 5% BW intensities. Although participants increased PD EMG activity at 7% BW intensity compared with 3% BW intensity, no differences were observed between the lawn-mower and robbery exercise at any other corresponding intensities.

Previous authors have analyzed scapular muscle EMG activity in different multi-joint exercises incorporating a type of free motion but not in the prone position. In terms of SA activity, for instance, a diagonal exercise, emphasizing not only humeral elevation but also scapular protraction, with the dumbbell in the standing position, increased SA activity nearly 100% MVIC.[21] The forward punch with elastic tubing activated the SA by 48.7% MVIC.[22] Scaption with ER using a dumbbell ranging from 2 to 4 kg activated the SA by 83.8% MVIC during the concentric phase of the exercise.[3] The dynamic-hug exercise with elastic tubing using maximum protraction activated the SA by 109% MVIC, whereas the highest activity for the UT was 51% MVIC across several exercises, such as the forward punch, scaption, and SA punch.[5] A 1-armed row exercise in which the participant bends the torso forward to 30° from the horizontal with 1 knee on a bench, using a low-resistance intensity (3 of 10 on the Borg scale) activated the LT by 39% MVIC.[1] Additionally, bilateral shoulder ER with scapular retraction using the elastic tubing activated the LT by 40% MVIC.[23]

Most, if not all, of the previous investigators qualitatively intervened in different types of exercises or postural positions with a single intensity for muscular activity. However, few quantitatively analyzed muscular activity using different intensities of the same exercise, especially during multi-joint exercises, as in our study. For instance, the modified robbery exercise progressively increased EMG activity by 28% in the SA, 23% in the LT, and 46% in the IS from the intensity of 3% to 7% BW, whereas PD EMG activity in the lawn-mower exercise did not differ across any of the 3 corresponding intensities. The modified robbery exercise should be promoted in the middle stages of rehabilitation because it uses 90° of GH joint abduction.[17]

The GH ER exercise has been well studied and produces high levels of IS activity for stabilizing the GH joint.[33] The amount of IS activity varies depending on the elevation of the GH joint. In the side-lying position, ER from 0° of ABD most effectively activates the IS, whereas in the standing position, an increase in the GH ABD angle may decrease muscle activity.[33] In our study, participants performed isometric contractions at 30° of elevation in the scapular plane with the load cell tilted at 20° from the horizontal in the standing position.[27] Mean IS EMG activity was less than the actual amount of torque produced by the participants at all 3 corresponding intensities: 12.6%, 18.5%, and 30.7% at 20%, 30%, and 40% MVIC, respectively. These results may account for the synergistic effects, such as the teres minor muscle activation or cocontraction of PD activity (or both), which increased significantly as the corresponding intensity was increased.

The highest amount of IS EMG activity during ABD in the scapular plane or scaption is observed at angles between 30° and 60° of elevation, regardless of the amount of load or angular velocity.[34] The participants in our study demonstrated no differences in mean IS EMG activity between ER and ABD, except for 40% MVIC. Based on these results, scaption exercise at up to 60° of ABD with an intensity of 3% BW can be as effective as ER for activating the IS.

Abducting isometric contractions significantly increased for the EMG activity of all 4 muscles measured at 90° of GH ABD with no instruction to retract the scapula across the 3 intensities. Isometric contraction activated the SA more than the lawn-mower exercise did at the middle and high levels of corresponding intensity. At any of the intensity levels used in our study, ABD isometrics produced LT activity similar to that of the robbery exercise. Furthermore, LT activity increased from 90° of ABD during the prone position[21] and progressively increased from 90° of ABD, flexion, or scaption.[29] Based on the results of our study, a certain amount of load held in the hand likely activates the LT to stabilize the instant center of scapular rotation during humeral elevation.[10,19] Shoulder flexion or scaption with ER was reported to activate the UT by 39% to 45% MVIC with a weight of 2 to 4 kg.[3] Therefore, humeral elevation with weight should be used cautiously for patients with hyperactivity of the UT in the scapulohumeral rhythm leading to scapular dyskinesis.

CONCLUSIONS

We quantitatively examined EMG activity of the SA and LT, 2 important muscles responsible for normal scapulohumeral rhythm, during 2 free-motion exercises with dumbbells. Modulation of the muscle activity varied depending not only on exercise intensity but also on the exercise-movement pattern. The QSF exercise showed the highest activity of the SA, LT, and PD compared with the free-motion exercises. Specifically, application of a small amount of external resistance, such as 3% BW, activated the LT muscle approximately 70% MVIC during the QSF exercise, whereas only half or less LT activation occurred at the same intensity during the lawn-mower and robbery exercises.

We modified the robbery exercise with less knee extension and ended it at approximately 90° of ABD and ER of the GH joint. As a result, the SA, LT, and IS muscle activity was significantly greater for the lawn-mower exercise. This modification mimicked the cocking motion of throwing and should be promoted in rehabilitative exercises for overhead athletes. However, patients with a symptomatic shoulder should gain the functional scapular motions of ER, posterior tilting, and upward rotation before they perform exercises including 90° of ABD and ER of the GH joint. Further studies of the robbery exercise are warranted using different angles of shoulder ABD, with or without kinetic chain contributions from the lower extremity. Further research is also warranted to understand the activity of the periscapular muscles during the lawn-mower exercise, which can be compared with the simultaneous bilateral motions required for the robbery exercise. This exercise ends with the shoulder at 90° of abduction and the elbow at 90° of flexion, mimicking the cocking motion of throwing overhead.

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