Journal of Athletic Training 2014;49(3):345–355
doi: 10.4085/1062-6050-49.3.10

www.natajournals.org

original research

Scapular Muscle-Activation Ratios in Patients With Shoulder Injuries During Functional Shoulder Exercises

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Context: Alterations in scapular muscle activation, which are common with glenohumeral (GH) injuries, affect stability and function. Rehabilitation aims to reestablish activation between muscles for stability by progressing to whole-body movements.

Objective: To determine scapular muscle-activation ratios and individual muscle activity (upper trapezius [UT], middle trapezius [MT], lower trapezius [LT], serratus anterior [SA]) differences between participants with GH injuries and healthy control participants during functional rehabilitation exercises.

Design: Cross-sectional study.

Setting: Laboratory.

Patients or Other Participants: Thirty-nine participants who had GH injuries (n = 20; age = 23.6 ± 3.2 years, height = 170.7 ± 11.5 cm, mass = 74.7 ± 13.1 kg) or were healthy (n = 19; age = 24.4 ± 3.3 years, height = 173.6 ± 8.6 cm, mass = 74.7 ± 14.8 kg) were tested.

Intervention(s): Clinical examination confirmed each participant's classification as GH injury or healthy control. Participants performed 4 exercises (bow and arrow, external rotation with scapular squeeze, lawnmower, robbery) over 3 seconds with no load while muscle activity was recorded.

Main Outcome Measure(s): We used surface electromyography to measure UT, MT, LT, and SA muscle activity. Scapular muscle-activation ratios (UT:MT, UT:LT, and UT:SA) were calculated (normalized mean electromyography of the UT divided by normalized mean electromyography of the MT, LT, and SA). Exercise × group analyses of variance with repeated measures were conducted.

Results: No group differences for activation ratios or individual muscle activation amplitude were found ($P > .05$). Similar UT:MT and UT:LT activation ratios during bow-and-arrow and robbery exercises were seen ($P > .05$); both had greater activation than external-rotation-with-scapular-squeeze and lawnmower exercises ($P < .05$). The bow-and-arrow exercise elicited the highest activation from the UT, MT, and LT muscles; SA activation was greatest during the external-rotation-with-scapular-squeeze exercise.

Conclusions: Scapular muscle activation was similar between participants with GH injuries and healthy control participants when performing the unloaded multiplanar, multijoint exercises tested. High activation ratios during the bow-and-arrow exercise indicate UT hyperactivity or decreased MT, LT, and SA activity. Our GH injury group may be comparable to high-functioning injured athletes. Study results may assist clinicians in selecting appropriate exercises for scapular muscle activation when caring for injured athletes.

***Key Words*:** force couple, glenohumeral joint, rehabilitation, serratus anterior muscle, trapezius muscle

Key Points

- Muscle balance to promote scapular upward rotation, as indicated by muscle-activation ratios, was present and similar between participants with glenohumeral injuries and healthy control participants when performing 4 unloaded multiplanar, multijoint functional exercises.
- Clinicians should use caution when prescribing the bow-and-arrow exercise because it produced high scapular muscle-activation ratios, indicating upper trapezius hyperactivity and decreased middle trapezius, lower trapezius, and serratus anterior activity.
- Exercises that promote activation of the middle trapezius, lower trapezius, and serratus anterior muscles while minimizing upper trapezius hyperactivity are the external rotation with scapular squeeze, lawnmower, and robbery.
- These results may help clinicians to select appropriate exercises for specific scapular muscle activation in injured athletes.

The scapula is integral as a foundational base of support for coordinated functional glenohumeral (GH) joint movements. Proper scapular positioning and movement are products of synchronous firing to achieve optimal length–tension relationships between the primary scapular stabilizers, specifically in muscles that compose the scapular upward rotation force couple: upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and serratus anterior (SA).[1] Functionally, the UT and SA provide the moment arm to create upward rotation of the scapula, whereas the LT provides stability and compression to the inferior angle of the scapula against the thorax to allow for efficient GH movement.[2,3] Theoretically, patients with GH injuries, including subacromial impingement, often exhibit inhibition of or imbalance within and between these scapular muscles during GH movements, which ultimately may lead to scapular dysfunction.[4–13] In particular, altered muscle balance, such as UT overcompensation or hyperactivity, and variable (timing) or insufficient (reduced amplitude) MT, LT, or SA activity occur in individuals with GH injuries.[5,14–16]

In addition to improving muscle strength, current shoulder rehabilitation programs aim to reestablish scapular mobility and stability by emphasizing coordinated and synchronous activation of the muscles that compose the scapular upward-rotation force couple for stabilization. To accomplish this, rehabilitation exercises focus on increasing strength and promoting proper firing between muscles of a force couple, initially using single-plane motions to target activation of the LT, MT, and SA while simultaneously minimizing activation of the UT.[4,5,14,16–22] When an individual gains sufficient scapular strength and control, clinicians may begin to incorporate more functional rehabilitation exercises using multiple planes and body segments in the kinetic chain, such as the hip and trunk, to facilitate correct shoulder muscle activation and function needed for activity-specific movements.[1,23] As multiplanar, multisegmental exercises are integrated, clinicians should be aware of and maintain appropriate activation between muscles that compose the scapular upward-rotation force couple (UT, LT, SA).

Although clinicians are incorporating this functional approach to shoulder rehabilitation into practice, information regarding scapular muscle activation relative to other muscles (eg, other scapular muscles in a force couple) in a ratio is primarily based on a theoretical framework without supporting data. Limited information is available about coordinated activation between the scapular stabilizing muscles (ie, activation ratio of muscles in a force couple) during the performance of more functional rehabilitation exercises in healthy individuals and in those with shoulder injuries. Cools et al[14] recommended rehabilitation exercises to restore scapular muscles in the upward-rotation force couple in relation to one another; however, the exercises were more appropriate for use very early in a rehabilitation program. Kibler et al[23] evaluated muscle-activation properties during multiplanar and multijoint rehabilitation exercises that are considered more functional (low row, inferior glide, lawnmower, and robbery) in symptomatic versus asymptomatic participants and found no differences in muscle-activation amplitude between groups among all exercises performed, yet sufficient amplitudes to elicit moderate strengthening were present. These studies show inconsistencies in how the UT, MT, LT, and SA activate in patients with GH injuries and illustrate the need to further examine how upward-rotation force-couple muscles activate relative to one another, reflected as a ratio, during multiplanar, multijoint functional rehabilitation exercises.

From a clinical perspective, it is important to understand scapular muscle activation and associated ratios in individuals with GH injuries so that the most effective rehabilitation exercises can be prescribed to restore and maintain scapular stability through the progression to more complex rehabilitation exercises. Therefore, the purpose of our study was to determine UT:MT, UT:LT, and UT:SA activation ratio differences between participants with GH injuries and healthy control participants during 4 multiplanar, multisegmental (ie, functional) rehabilitation exercises: bow and arrow (BA), external rotation with scapular squeeze (ERSS), lawnmower, and robbery (Figures 1–4). We also examined individual muscle activation of the UT, MT, LT, and SA between groups during the BA, ERSS, lawnmower, and robbery exercises. We hypothesized that individuals with GH injuries would exhibit imbalances within scapular muscle-activation ratios representative of the commonly reported scenario[5,14–16] of higher UT and lower MT, LT, and SA activation.

METHODS

Design

We used a cross-sectional design. The independent variables were group (GH injury, healthy control) and functional exercise (BA, ERSS, lawnmower, robbery). The dependent variables included normalized muscle activation (percentage of maximal voluntary isometric contraction [% MVIC]) using mean electromyography (EMG) from the UT, MT, LT, and SA. The normalized values also were used to calculate scapular muscle-activation ratios (UT:MT, UT:LT, UT:SA).

Participants

We recruited participants of convenience via word of mouth and advertisements posted in a university setting. Thirty-nine individuals were tested (Table 1). A priori power analysis indicated this group size was adequate to establish acceptable power. A total of 20 (10 male, 10 female) participants had GH injuries based on clinical examination results, and 19 (10 male, 9 female) participants were asymptomatic and considered healthy controls with no history of shoulder injury requiring restriction of activities. Most of the participants with GH injuries (17 of 20) presented with GH instability and secondary subacromial impingement or labral injuries. The remaining 3 participants had rotator cuff injuries. The GH injury group had higher (ie, more disability and symptoms) Disabilities of Arm, Shoulder, and Hand (DASH) scores than the healthy control group ($P < .01$; Table 1), confirming that although they maintained active lifestyles, their injuries negatively affected health-related quality of life.

All participants underwent a musculoskeletal examination that included special tests for subacromial impingement (painful arc,[24] Neer test,[24,25] infraspinatus test, and Hawkins-Kennedy test[24,26]), rotator cuff injuries (cross-body adduction, drop-arm test,[27] infraspinatus strength test,[27] and empty-can test[24]), GH instability (apprehension test,[25] relocation test,[28] anterior release,[28] and sulcus sign), and labral injuries (crank test,[29] anterior slide test,[29] Speed test,[30] biceps load I test,[31] and biceps load II test[30]). Participants were classified into the GH injury group if they had at least 3 positive special tests for the aforementioned injuries and responded *yes* to at least 2 of the following 3 questions: (1) Do you experience weakness, throbbing pain, pain with motion, and/or pain with overhead activities? (2) Do you feel looseness and/or instability in your shoulder? and (3) Do you experience sensations of clicking, popping,

Figure 1. Bow-and-arrow exercise.

cracking, snapping, and/or catching? Exclusion criteria for the GH injury group included self-report or clinical examination of any of the following: surgery on the test extremity within 12 months of testing, neurovascular disorder, lack of available range of motion needed for testing (130° of shoulder abduction and flexion), or current GH joint symptoms that could not be classified into the injury group described.

We matched healthy control participants to participants with GH injuries for sex, height, mass, race, and upper extremity dominance. Participants were considered *healthy* if they exhibited full, pain-free range of motion and function in the test extremity. However, participants were excluded from the healthy group if they self-reported surgery on the test extremity within 12 months before testing, neurovascular disorder, lack of available range of motion needed for testing (130° of shoulder abduction and flexion), or any injuries sustained to the test extremity within the 6 months before testing. All participants provided written informed consent, and the A.T. Still University–Arizona Institutional Review Board approved the study.

Instrumentation

Electromyography. Surface electromyographic activity was recorded simultaneously from the UT, MT, LT, and SA during 4 functional rehabilitation exercises using an EMG acquisition system (Myosystem 1200; Noraxon USA, Inc, Scottsdale, AZ). We used a single-ended amplifier with an impedance greater than 10 MΩ, gain of 1000, fourth-order Butterworth filter with a cutoff frequency of 10 to 500 Hz, and common-mode rejection ratio of 130 dB. A receiver with a sixth-order filter that had a gain of 2 and total gain of 2000 was used to further amplify the signal. The signal was passed to a computer through a 16-channel NorBNC connector system and a 12-bit analog-to-digital card (Noraxon USA, Inc). The sampling rate was 1000 Hz. The EMG files were stored on the computer, and MyoResearch software (version MR-XP 1.07; Noraxon USA, Inc) was used for processing and analysis.

Accelerometer. A triaxial accelerometer (NeuwGhent Technology, LaGrangeville, NY) was used to track upper extremity movements during the functional exercises. The accelerometer measured $\pm 5g$ in each axis (x, y, and z) with a bandwidth of 500 Hz and sensitivity of 200 mV/g. One lead per axis was connected into NorBNC analog input channels and into a personal computer where they were displayed using the MyoResearch software. The accelerometer signals were synchronized with EMG data and later used to mark the start and end of the concentric phase for each functional exercise.

Procedures

All testing was performed in a research laboratory during a single test session. Upon arrival at the laboratory, participants signed an informed consent form and complet-

Figure 2. External-rotation-with-scapular-squeeze exercise.

ed a patient demographic form, health history form, and the DASH patient outcomes instrument. The primary investigator (C.R.M.), who is an athletic trainer, performed a musculoskeletal shoulder examination on all participants to determine their placement into the GH injury or healthy control group.

The EMG preparation included shaving the skin surface to remove any overlying hair and cleaning the skin with a 70% isopropyl alcohol swab to minimize skin impedance. We used self-adhesive, Ag-AgCl surface electrodes with a 10-mm diameter and 10-mm interelectrode distance (Noraxon USA, Inc). Bipolar surface electrodes were placed on the skin overlying the scapular muscles (UT, MT, LT, and SA), and the reference electrode was placed on the ipsilateral clavicle of the test extremity. The anatomic placement of electrodes was parallel to the fiber direction of each muscle at the following locations: UT electrodes were placed half the distance between the spine (C7 vertebra) and acromion process over the muscle belly, MT electrodes were placed horizontally at half the distance between the spine (approximately T3-5) and vertebral border of the scapula in line with the scapular spine, LT electrodes were placed obliquely between the lower thoracic spine (approximately T8-12) and scapular spine approximately 5 to 7 cm inferior to the vertebral border of the scapula, and SA electrodes were placed obliquely over the lower fibers of the SA on the lateral thoracic cage at the level of the inferior scapula and anterior to the latissimus dorsi border just below the axilla with the upper extremity elevated approximately 120°.[32] Correct placement of all electrodes on the test extremity was confirmed by monitoring activity during isolated muscle testing of the specific muscle and by EMG signal identification on an oscilloscope (version MyoResearch MR-XP 1.07; Noraxon, USA, Inc). After confirming proper electrode placement, we recorded using standardized manual muscle testing procedures.[33] Before each test, the myoelectric signal was calibrated with the participant in a relaxed, seated position to establish baseline EMG activity. During MVIC tests on the test extremity, participants were instructed to resist with maximal effort against the investigator's manual resistance for 5 seconds. The average of 3 MVICs for each muscle was used for EMG normalization during data processing.

After MVIC tests, the accelerometer was secured at the wrist of the test extremity using an elastic band. Participants were given instruction and feedback (oral and visual) regarding successful completion of the concentric phase for each functional exercise, and practice repetitions were allowed until the participants were comfortable with the functional exercise. Each participant performed the concentric phase for the 4 functional rehabilitation exercises while EMG data were collected on the test extremity. The order in which functional exercises were performed was balanced among participants.

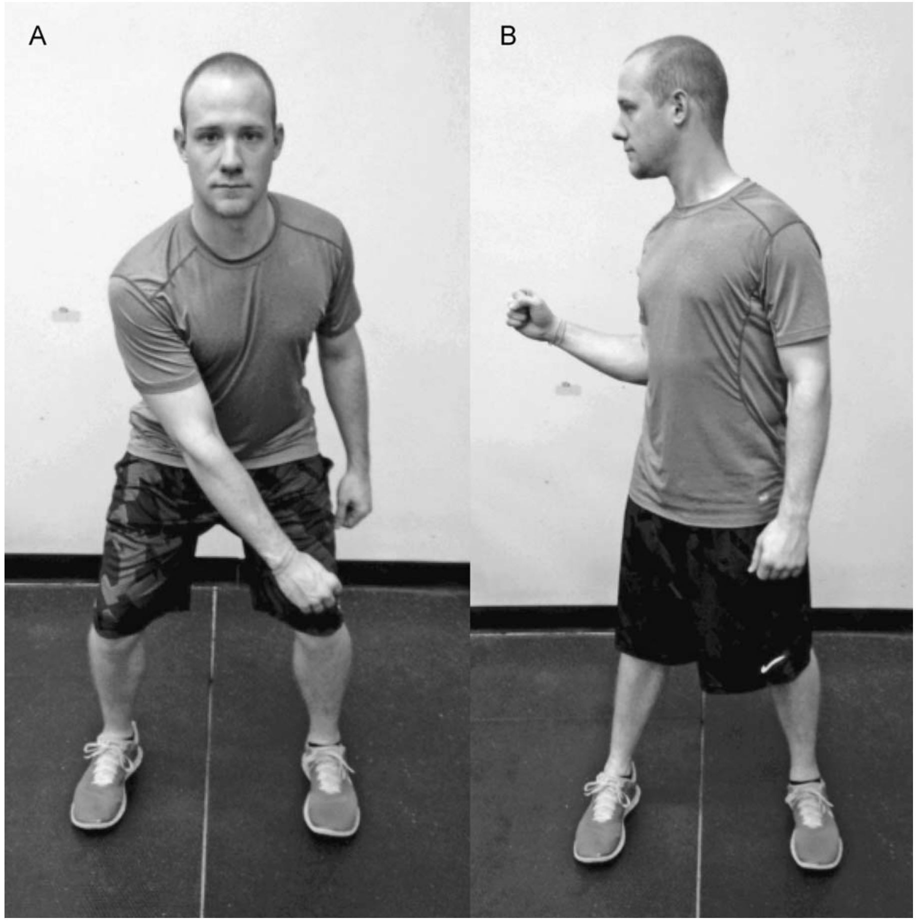

Figure 3. Lawnmower exercise.

The BA exercise is used in strength and fitness training and theoretically promotes MT, LT, and SA activation, but to our knowledge, muscle activity during this functional exercise has not been studied (Figure 1). We were interested in examining muscle activation during this exercise because it incorporates the kinetic chain by requiring hip and thoracic spine rotation before upper extremity movements. Participants began the exercise with both upper extremities elevated to 90° of forward flexion, with their feet placed together, and facing forward. They externally rotated the hip on the same side as the test extremity while simultaneously retracting the scapula of the test extremity and rotating the torso around the thoracic spine. Emphasis was placed on keeping the test extremity on a level plane throughout the entire movement and squeezing the scapulae together without scapular elevation at the end of motion.

The ERSS exercise, which is supposed to target LT activation while minimizing UT activation, was performed standing with the test extremity resting at the side in 90° of elbow flexion (Figure 2).[14] Participants maximally externally rotated the hip on the same side as the test extremity while externally rotating the test extremity, keeping it at the side and attempting to place the elbow in the back pocket. Emphasis was placed on squeezing the scapulae together at the end of the exercise.

The lawnmower exercise is a multijoint functional exercise that mobilizes joints in a diagonal pattern from the contralateral lower extremity through the trunk to the ipsilateral upper extremity (Figure 3).[23] The targeted muscles for the lawnmower exercise were the LT and SA.[23] Participants began the exercise with the trunk flexed and rotated to the contralateral side of the test extremity and with the hand of the test extremity at the level of the contralateral patella. They rotated the trunk toward the test extremity and extended the hip and trunk to a vertical position while simultaneously placing the test extremity at waist level and retracting the scapula to place the elbow in the back pocket.[23] Attention was focused on squeezing the scapulae together at the end of the exercise.

The robbery exercise is a multijoint functional exercise that uses hip and trunk extension and bilateral upper extremity motion to achieve scapular retraction through activation of the MT (Figure 4). Participants began the exercise in a standing position with the trunk flexed 40° to 50° with the upper extremities forward flexed and palms facing the thighs. While keeping the elbows close to the body, they extended the trunk and upper extremities and flexed the elbows so their palms were facing up and away from their bodies. Emphasis was placed on squeezing the scapulae together toward the back pockets.[23]

The concentric phase of each exercise was performed over 3 seconds. A digital metronome (Korg USA, Melville, NY) set to 60 beats per minute and oral prompts were used to control the exercise movement speed of the concentric phase to ensure a 3-second period. Exercises were

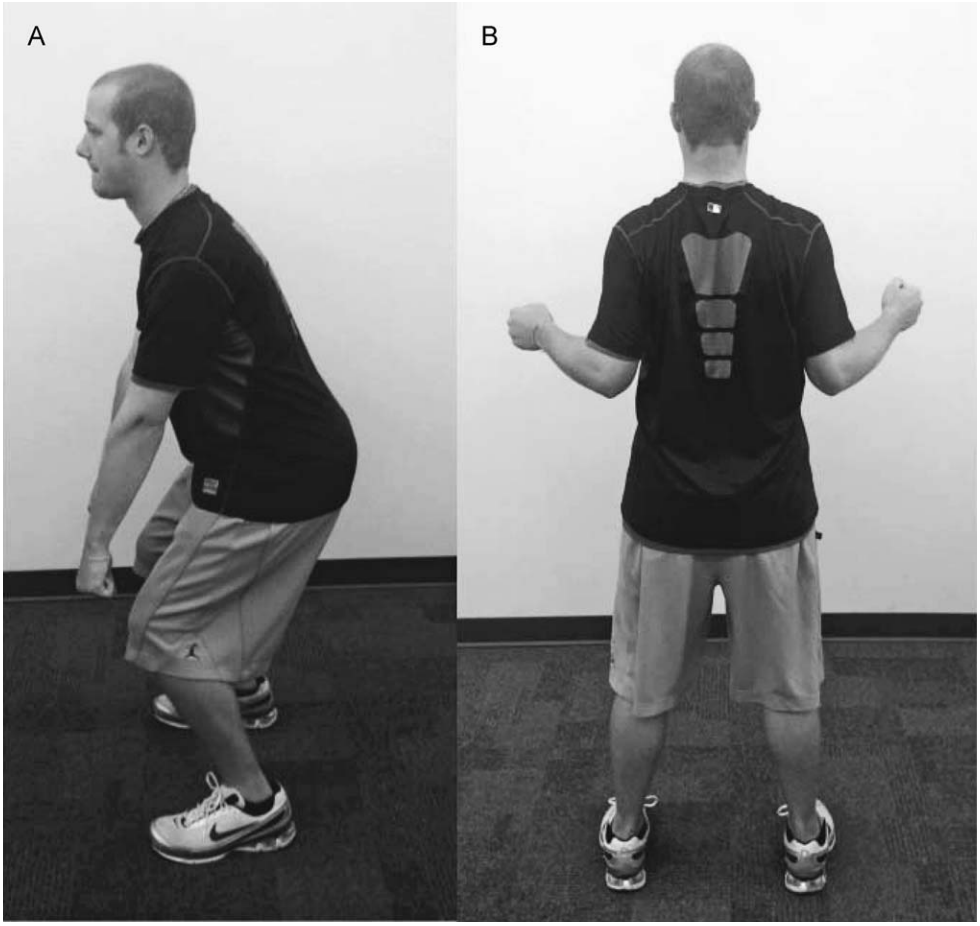

Figure 4. Robbery exercise.

performed unloaded, using only the body mass of the participants as resistance. Participants performed 5 acceptable repetitions of each functional exercise while EMG and accelerometer data were recorded on the test extremity. Only repetitions that were performed correctly (form, movement, and speed) and were within the middle 3 repetitions were used in analyses.

Data Reduction

Using the MyoResearch software, raw EMG data were full-wave rectified (ie, linear envelope detection), integrated with a sixth-order Butterworth filter, and smoothed over a 15-millisecond moving window. We averaged the peaks of 3 MVICs for each muscle and used them for normalizing EMG in the functional exercise trials. The mean EMG data for each muscle during the concentric phase of each exercise were normalized as a percentage of MVIC. Accelerometer data from the x, y, and z axes were synchronized with the EMG data in MyoResearch and used to mark the start and end of the concentric phase of each exercise repetition. Data were exported as a spreadsheet and imported to SPSS (version 19.0; IBM Corporation, Somers, NY) for data analysis.

Data Analysis

Descriptive and inferential analyses were performed on collected data. One-way analyses of variance were used to determine whether demographic variables (age, height, mass, DASH scores) differed between groups. Before analyses, normalized EMG data were evaluated for outliers and sphericity using the Kolmogorov-Smirnov test.

Scapular muscle-activation ratios were calculated by dividing normalized EMG values of the UT by normalized EMG values of the MT, LT, and SA to generate ratios

Table 1. Demographic Information of Participants Tested by Group (Mean ± SD)

	Group		
	Glenohumeral Injury (n = 20)	Healthy Control (n = 19)	Total (N = 39)
Age, y	23.6 ± 3.2	24.4 ± 3.3	24.0 ± 3.2
Height, cm	170.7 ± 11.5	173.6 ± 8.6	172.1 ± 10.2
Mass, kg	74.7 ± 13.1	74.7 ± 14.8	74.7 ± 13.8
Disabilities of the Arm, Shoulder, and Hand score	13.4 ± 10.0[a]	0.58 ± 1.1	7.2 ± 9.6

[a] $P < .01$.

Table 2. Scapular Muscle-Activation Ratios During Functional Exercises Between Groups[a]

Scapular Muscle Ratio	Functional Exercise, Ratio ± Standard Error (95% Confidence Interval)				Differences Among Exercises
	Bow and Arrow	External Rotation With Scapular Squeeze	Lawnmower	Robbery	
Upper trapezius : Middle trapezius					
Glenohumeral injury (n = 20)	2.1 ± 0.3 (1.5, 2.6)	0.7 ± 0.2 (0.4, 1.0)	1.2 ± 0.2 (0.9, 1.6)	2.2 ± 0.3 (1.4, 2.9)	Bow and arrow and robbery > external rotation with scapular squeeze and lawnmower
Healthy control (n = 19)	2.1 ± 0.3 (1.6, 2.7)	0.7 ± 0.2 (0.3, 1.0)	0.6 ± 0.2 (0.3, 1.0)	1.3 ± 0.3 (0.6, 2.0)	
Groups combined (N = 39)	2.1 ± 0.2 (1.7, 2.5)	0.7 ± 0.1 (0.4, 0.9)	0.9 ± 0.1 (0.7, 1.2)	1.7 ± 0.2 (1.2, 2.2)	
Effect size	−0.05	0.07	0.74	0.57	
Upper trapezius : Lower trapezius					
Glenohumeral injury (n = 20)	3.7 ± 0.7 (2.4, 5.1)	0.9 ± 0.2 (0.5, 1.2)	1.7 ± 0.3 (1.0, 2.3)	3.5 ± 0.5 (2.6, 4.4)	Bow and arrow and robbery > external rotation with scapular squeeze and lawnmower
Healthy control (n = 19)	3.1 ± 0.7 (1.7, 4.5)	0.7 ± 0.2 (0.3, 1.0)	0.6 ± 0.3 (0.0, 1.3)	1.5 ± 0.5 (0.6, 2.5)	
Groups combined (N = 39)	3.4 ± 0.5 (2.4, 4.4)	0.8 ± 0.1 (0.5, 1.0)	1.2 ± 0.2 (0.7, 1.6)	2.5 ± 0.3 (1.8, 3.2)	
Effect size	−1.03	−1.89	−2.59	−3.43	
Upper trapezius : Serratus anterior					
Glenohumeral injury (n = 20)	7.2 ± 1.4 (4.3, 10.1)	0.8 ± 0.3 (0.1, 1.5)	1.7 ± 0.4 (0.9, 2.5)	3.8 ± 1.2 (1.4, 6.1)	Bow and arrow > robbery, external rotation with scapular squeeze, and lawnmower
Healthy control (n = 19)	3.3 ± 1.5 (0.3, 6.2)	0.8 ± 0.3 (0.1, 1.6)	0.6 ± 0.4 (−0.2, 1.4)	1.9 ± 1.2 (−0.5, 4.4)	
Groups combined (N = 39)	5.2 ± 1.0 (3.1, 7.3)	0.8 ± 0.2 (0.3, 1.3)	1.1 ± 0.3 (0.6, 1.7)	2.9 ± 0.8 (1.2, 4.6)	
Effect size	0.63	−0.04	0.62	0.36	

[a] Differences among exercises occurred at $P \leq .05$.

UT:MT, UT:LT, and UT:SA, respectively. As such, a high ratio value corresponded with more UT activity, and a low ratio value represented less UT activity relative to activation of the MT, LT, or SA. Scapular muscle-activation ratios were analyzed using 4 (exercise) × 2 (group) analyses of variance with repeated measures to examine differences in UT:MT, UT:LT, and UT:SA ratios separately. Independent *t* tests with Bonferroni correction were used for all indicated post hoc analyses.

Individual muscle activation was analyzed using 4 (exercise) × 2 (group) analyses of variance with repeated measures to examine differences in UT, MT, LT, and SA muscles separately. Independent *t* tests with Bonferroni correction and a converted α level of $\leq$.0125 were used for all indicated post hoc analyses. For all analyses, the α level was set a priori at .05. All data were analyzed using SPSS (version 19.0; IBM Corporation).

RESULTS

The EMG data from 1 healthy control participant (female) were removed from the analyses because UT:MT and UT:LT activation ratios values exceeded ±3 SDs on 3 of 4 functional exercises tested. Results of EMG analyses are reported for 20 participants with GH injuries and 19 healthy control participants.

Overall, we found no differences for the UT:MT, UT:LT, or UT:SA activation ratios between the GH injury and healthy control groups for any exercise tested; however, we noted trends toward group differences. We observed differences in scapular muscle-activation ratios and individual muscle activation between exercises.

Results indicated an exercise × group interaction for the UT:MT activation ratio ($F_{3,\ 111} = 3.41$, $P = .02$) and UT:SA activation ratio ($F_{3,\ 111} = 2.72$, $P = .048$), but post hoc analyses failed to detect differences. Post hoc analyses suggested a trend toward a higher UT:MT activation ratio in the GH injury group than in the healthy control group for the lawnmower exercise ($t_{37} = 2.2$, $P = .03$). We also found a group main effect trend toward a higher UT:LT activation ratio in the GH injury group than in the healthy control group ($F_{1,\ 37} = 4.03$, $P = .052$).

Whereas we saw no group differences, we did note differences between exercises for the UT:MT ($F_{1,\ 111} = 30.17$, $P < .001$), UT:LT ($F_{1,\ 111} = 23.80$, $P < .001$), and UT:SA ($F_{1,\ 111} = 15.68$, $P < .001$) activation ratios (Table 2) and for individual muscle-activation amplitude (Table 3).

DISCUSSION

Most research on scapular rehabilitation exercises has been focused on activation of individual muscles. Few investigators have sought to establish and examine scapular muscle-activation ratios during rehabilitation exercises, making it difficult to compare our results with those of other authors. Cools et al[14] studied UT:MT, UT:LT, and UT:SA force-couple activation ratios during early-phase shoulder-girdle strengthening exercises and recommended exercises to minimize UT activity while promoting MT,

Table 3. Activation of Individual Scapular Muscles During Functional Exercises Between Groups[a]

Muscle	Functional Exercise, Mean ± Standard Error (95% Confidence Interval)				Differences Among Exercises
	Bow and Arrow	External Rotation With Scapular Squeeze	Lawnmower	Robbery	
Upper trapezius					
Glenohumeral injury (n = 20)	73.0 ± 10.5 (51.7, 94.3)	17.9 ± 4.8 (8.2, 27.6)	21.9 ± 4.1 (13.6, 31.2)	42.7 ± 5.5 (31.5, 53.8)	Bow and arrow > robbery, external rotation with scapular squeeze, and lawnmower; Robbery > external rotation with scapular squeeze and lawnmower
Healthy control (n = 19)	56.7 ± 10.8 (35.1, 78.8)	13.7 ± 4.9 (3.8, 23.7)	10.6 ± 4.2 (2.1, 19.1)	17.2 ± 5.7 (5.8, 28.7)	
Groups combined (N = 39)	64.8 ± 10.65 (49.7, 80.2)	15.8 ± 4.85 (8.9, 22.7)	16.3 ± 4.15 (10.3, 22.2)	29.9 ± 5.6 (21.9, 38.0)	
Middle trapezius					
Glenohumeral injury (n = 20)	37.5 ± 4.5 (28.3, 46.6)	27.2 ± 4.1 (18.9, 35.5)	18.8 ± 3.1 (12.6, 25.1)	22.4 ± 2.1 (18.2, 26.7)	Bow and arrow > robbery, external rotation with scapular squeeze, and lawnmower; External rotation with scapular squeeze > lawnmower and robbery
Healthy control (n = 19)	32.3 ± 4.6 (22.9, 41.7)	25.4 ± 4.2 (16.9, 33.9)	18.8 ± 3.1 (12.4, 25.2)	14.5 ± 2.2 (10.2, 18.9)	
Groups combined N = 39)	34.9 ± 4.55 (28.3, 41.4)	26.3 ± 4.15 (20.4, 32.2)	18.8 ± 3.1 (14.4, 23.3)	18.4 ± 2.15 (15.4, 21.5)	
Lower trapezius					
Glenohumeral injury (n = 20)	23.4 ± 3.1 (17.1, 29.7)	20.8 ± 2.8 (15.2, 26.4)	15.6 ± 2.1 (11.3, 19.9)	13.0 ± 1.8 (9.4, 16.6)	Bow and arrow = external rotation with scapular squeeze > lawnmower and robbery; Lawnmower > robbery
Healthy control (n = 19)	28.6 ± 3.2 (22.2, 35.1)	26.6 ± 2.8 (20.9, 32.4)	20.5 ± 2.2 (16.1, 24.9)	14.4 ± 1.8 (10.7, 18.1)	
Groups combined (N = 39)	26.0 ± 3.15 (21.5, 30.5)	23.7 ± 2.8 (19.7, 27.7)	18.0 ± 2.15 (15.0, 21.1)	13.7 ± 1.8 (11.1, 16.3)	
Serratus anterior					
Glenohumeral injury (n = 20)	19.0 ± 4.5 (9.9, 28.2)	39.3 ± 7.6 (23.8, 54.8)	24.3 ± 5.1 (14.0, 34.7)	23.1 ± 6.1 (10.7, 35.4)	External rotation with scapular squeeze > bow and arrow and robbery
Healthy control (n = 19)	25.8 ± 4.6 (16.4, 35.2)	36.5 ± 7.8 (20.6, 52.4)	31.0 ± 5.2 (20.3, 41.6)	24. 7 ± 6.2 (12.0, 37.3)	
Groups combined (N = 39)	22.4 ± 4.55 (15.9, 29.0)	37.9 ± 7.7 (26.8, 49.0)	27.6 ± 5.15 (20.2, 35.1)	23.9 ± 6.15 (15.0, 32.7)	

[a] Values reflect percentage of maximal voluntary isometric contraction. Differences among exercises occurred at $P \leq .05$.

LT, and SA activation. We were interested in examining the activation ratios of the scapular upward-rotation force-couple muscles during more functional exercises that are more dynamic and incorporate multiple planes and joints. Theoretically, proper balance among these muscles should be reestablished during the early rehabilitation phase; however, clinicians must monitor and maintain this balance by selecting appropriate exercises for protocols that incorporate more functional, multijoint movements. Balance is important, and clinicians should evaluate it in all patients, especially those with shoulder injuries. In a laboratory, balance can be measured with EMG, but EMG is not practical in all clinical settings. As an alternative, balance can be evaluated through clinician judgment using manual muscle testing and scapular function testing, which are typical skills of athletic trainers. Clinically, investigating imbalances among muscles is important because these imbalances reflect how muscles work with and against one another during functional activities.

The purpose of our study was to examine how scapular-activation ratios and individual muscle activation differed between individuals with GH injuries and healthy control participants during 4 multiplanar, multijoint functional rehabilitation exercises. Based on previous research demonstrating alterations in UT, LT, and SA activation in patients with GH injuries, we hypothesized that participants with GH injuries would have imbalances in scapular-activation ratios of muscles that compose the upward-rotation force couple such that UT activity would increase with concomitant decreases in MT, LT, and SA activity compared with healthy control participants.[4,5,14,16–22] Our results did not support our hypothesis; no group differences were found among any of the activation ratios studied. However, trends toward higher UT:MT and UT:LT activation ratios in the GH injury group were suggested. Both activation ratios and individual muscle-activation amplitudes were different among the exercises tested. Whereas unexpected, the lack of group differences in our study in relation to activation ratios and individual muscle amplitude is consistent with the findings of others[23,34] and can be explained by examining the profile of our GH injury group, as well as how the exercises in our study were executed.

Our GH injury group self-reported shoulder pain and limitations, and injuries were confirmed through clinical examination. At the same time, the GH injuries were not severe, as indicated by the ability of participants to maintain relatively active lifestyles. The DASH score for the GH injury group was 13.4 ± 10.0 (Table 1). Although this score was higher than the score for the healthy control group, indicating that the GH injury group had less disability and more symptoms than the control group, it arguably does not represent the diminished health status of patients with moderate to severe GH injuries that coincide with notable impairments and functional limitations represented in higher DASH scores (average range: 30–60 points).[35,36] This profile of disability and symptoms suggests our GH injury group may be more representative of physically active individuals with shoulder injuries who can maintain levels of physical activity and regularly participate in sport with pain or mild or chronic shoulder injury (ie, the population with whom athletic trainers work). Given this, the role of the scapular muscles to provide dynamic stabilization and contribute to maintaining GH joint function during motions, such as upper extremity elevation, was fulfilled by both the GH injury and healthy control groups. The scapular muscle-activation ratios indicate balance between muscles to promote upward rotation during the exercises we tested.

The tested exercises were selected because they are multiplanar and multijoint, representing more functional movements compared with others.[14] Cools et al[14] also studied activation ratios between scapular muscles and recommended sidelying and prone exercises that are uniplanar and single joint to minimize UT and promote MT, LT, and SA activation to achieve a more balanced force couple. Kibler et al[23] studied 2 of the exercises (lawnmower and robbery) included in our study. The exercises in our study and the study by Kibler et al[23] are considered more functional and typically are used as a progression after uniplanar and single-joint movements. In both studies, the multiplanar, multijoint exercises were performed in a controlled manner without load, which also may explain the lack of group differences in muscle-activation ratios and individual muscle amplitudes. Other researchers[23,34,37] have suggested that if activation amplitudes are affected by injuries, differences are more apparent when the shoulder complex is challenged, which occurs when movements are performed with more dynamic speed or load. The trend toward higher UT:MT activation ratios during the lawnmower and a main effect for higher UT:LT in the GH injury group, supported by moderate to strong effect sizes (0.74 and 2.2, respectively; Table 2), suggest that compensations of UT hyperactivity and decreased MT and LT activity as reported by Cools et al[14] may occur. The addition of a load might have shifted the trend to produce a difference. However, further study is necessary to fully explore this idea. Clinically, the effect of exercise speed or load on muscle activation is important to consider in developing a rehabilitation exercise progression and warrants further study.

Whereas we found no differences between groups, our findings for activation ratios and individual muscle-activation amplitudes between the exercises tested in our study are notable. Overall, the BA exercise produced the highest UT:MT, UT:LT, and UT:SA activation ratios (>2), indicating more reliance on UT activation than the MT, LT, and SA counterparts in the ratio to perform the exercise. If clinicians note scapular imbalances in patients due to deficits in MT, LT, or SA found during clinical manual muscle tests or scapular function tests, our results do not support using the BA exercise. In addition, the BA exercise requires the most upper extremity elevation to perform, and that could exacerbate impingement if imbalances do exist. Instead, the ERSS and lawnmower exercises may be considered more effective at targeting the MT, LT, and SA while simultaneously minimizing UT activation, as indicated by a ratio value of close to or less than 1 (ie, more MT or LT activity than UT activity).

Overall, the lowest UT activation was found in the ERSS, followed by the lawnmower, robbery, and BA (low to high, respectively). Theoretically, a rehabilitation goal is often to "quiet" the UT, especially in patients with GH injuries; therefore, the ERSS and lawnmower are recommended for this purpose, whereas use of the BA and robbery may be reserved for cases when UT activity is desired, such as in patients who have sustained substantial injury. Conversely, if the goal is to maximize MT and LT activity independent of the UT, the BA may be used because it also elicited the highest MT and LT activation. Finally, the ERSS produced the highest SA activation, followed by the lawnmower, robbery, and BA (high to low, respectively). Depending on the rehabilitation goals, clinicians may use these results to select appropriate multiplanar, multijoint functional exercises.

In comparing our results with those of Kibler et al,[23] the activation amplitude of the UT during the lawnmower and robbery exercises was similar. In both studies, the robbery produced more UT activation than the lawnmower. Conflicting results were found for LT activation. In our study, the LT was activated less than reported by Kibler et al,[23] and the lawnmower produced more activity than the robbery, which is the opposite of the findings of Kibler et al.[23] These differences may indicate variability in LT activation properties that often are speculated. In addition to evaluating muscle activation, Kibler et al[23] assessed the muscle-activation amplitudes for use in moderate strengthening and found that activations ranging from 20% to 30% MVIC were needed. The activation amplitude ranges for the muscles in our study were 15.8% to 64.8% for the UT, 18.4% to 34.9% for the MT, 13.7% to 26.0% for the LT, and 22.4% to 37.9% for the SA. These activation ranges suggest that, for all of the unloaded muscles tested in our study, the level of contraction elicited was sufficient to promote moderate strengthening.

Our study had limitations. The use of surface EMG, while reliable, produces inherently wide variability in measures that ultimately affect the power of the study results. However, a priori power analyses indicated our group sizes were adequate to establish acceptable power, which was achieved given that our findings were different. Our GH injury group self-reported relatively few limitations in disability and symptoms, as evidenced by an average DASH score of 13.4 ± 10.0 points, and this may be perceived as a limitation in our ability to generalize results to patients with more severe injuries. The maximal score for the DASH is 100, which indicates the presence of symptoms and disability (eg, worse health), so scores in the range we found indicated relatively good health. However, our participants had external validity to athletes because they tended to present as high-functioning injured athletes who can perform most daily tasks without substantial limitation.

CONCLUSIONS

Scapular muscle-activation ratios and individual muscle activation were similar between participants with GH injuries and healthy control participants when performing the unloaded multiplanar, multijoint functional exercises tested. High activation ratios during the BA exercise indicated UT hyperactivity or decreased MT, LT, and SA activity. Our GH injury group may be comparable with injured but participating athletes. These study results may help clinicians to select appropriate exercises for specific scapular muscle activation in the care of injured athletes.

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