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original research

Electromyographic Activity of Scapular Muscle Control in Free-Motion Exercise

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Context: The appropriate resistance intensity to prescribe for shoulder rehabilitative exercise is not completely known. Excessive activation of the deltoid and upper trapezius muscles could be counterproductive for scapulohumeral rhythm during humeral elevation.

Objective: To identify the effects of different exercise intensities on the scapular muscles during a free-motion "robbery" exercise performed in different degrees of shoulder abduction in seated and standing positions.

Design: Descriptive laboratory study.

Setting: Kinesiology Adapted Physical Education Laboratory.

Patients or Other Participants: A total of 15 healthy male college students (age = 20.5 ± 2.2 years, height = 174.5 ± 5.3 cm, mass = 63.8 ± 6.0 kg).

Intervention(s): Participants performed 5 repetitions of a randomized exercise sequence of the robbery exercise in 2 body positions (seated, standing), 2 shoulder-abducted positions (W [20°], 90/90 [90°]) at 3 intensities (0%, 3%, and 7% body weight).

Main Outcome Measure(s): Electromyographic (EMG) activity of the upper trapezius, lower trapezius, serratus anterior, anterior deltoid, and infraspinatus muscles of the upper extremity was collected. All EMG activities were normalized by the maximal voluntary isometric contraction of each corresponding muscle (%).

Results: The serratus anterior, anterior deltoid, and infraspinatus EMG activities were greater at 7% body weight in the seated position compared with the standing position ($P < .05$). The EMG activities in all 5 muscles were greater in the 90/90 position than in the W position ($P < .05$).

Conclusions: Scapular muscle activity modulated relative to changes in body posture and resistance intensity. These findings will enable clinicians to prescribe the appropriate level of exercise intensity and positioning during shoulder rehabilitation.

Key Words: kinetic chain, resistance intensity, shoulder rehabilitation

Key Points

- Appropriate intensities while performing therapeutic exercises are necessary to prevent hyperactivity of the deltoid muscle.
- Anterior deltoid activity increased when intensities were greater than 3% body weight during the robbery exercise with the shoulders abducted to 90°.
- Assistance from lower body movements decreased activity of the anterior deltoid, especially at higher intensities.
- Understanding the effects of different intensities and positions will allow clinicians to individualize rehabilitation accurately and appropriately.

Undesirable positions and motions of the scapula are termed *scapular dyskinesis*. This condition is considered one factor contributing to the reduction in subacromial space. Scapular dyskinesis can be characterized by decreased upward rotation, increased anterior tilt, and increased internal rotation of the scapula during dynamic shoulder motion.[1–5] Researchers[2,5–7] have demonstrated that abnormal scapular kinematics coupled with imbalanced scapular muscle activity often cause subacromial impingement. Those muscular imbalances include reduced strength and coordination of the force couple of the lower trapezius (LT) and serratus anterior (SA) muscles and increased upper trapezius (UT) muscle activity.[2,8–10] Increased anterior deltoid (AD) muscle activity has also been observed in individuals with subacromial impingement who compensate for the lack of stability in the injured supraspinatus muscle during humeral elevation.[11,12] Hyperactivity of the deltoid muscle or increased abduction force on the shoulder can cause superior humeral head translation, which further reduces the width of the subacromial space.[13]

Incorporating scapular rehabilitation in the treatment of upper extremity injuries is important to regaining a stable base for the origins of the scapulohumeral musculature. This assists in creating optimal alignment and position of the glenohumeral joint to avoid abnormal stress to the rotator cuff.[14] Consequently, rehabilitation for patients with many shoulder conditions must initially be aimed at restoring the coordination and strength of scapular force couples to control the dynamic motion of the scapula. Practitioners should prescribe exercises that can prevent excessive activation of the UT and AD muscles to minimize superior humeral head translation and anterior tilting of the scapula, which helps to maintain adequate subacromial space for optimal rotator cuff muscle activity. On the basis of this clinical concept, numerous exercises have been examined[15–19] to identify the most beneficial exercise for recruiting the force-couple activation of the LT and SA muscles. Furthermore, some researchers[9,20,21] have suggested appropriate progressions for particular upper body exercises to strengthen the scapular muscles without hyperactivity of the UT muscle.

Whereas exercise and progression suggestions may have helped many practitioners determine which exercise to prescribe, a lack of specific knowledge persists about changes in scapular muscle activity relative to dynamic movements. Many investigators[15–20] have demonstrated scapular muscle activities in the prone, side-lying, or upright standing position with isolated single-joint movements that are not functional in daily activities or sports performance. Kibler[22] presented the role of the scapula as the important link in the proximal to distal flow of the kinetic chain for the upper extremity. When the scapula is stable, the energy the proximal segments generate is transferred efficiently to the distal segments during athletic movements, especially overhead motions.[22] Using the assistance of the hip, back, and trunk musculature, the smaller musculature, such as the rotator cuff, can be activated without excessive demand; therefore, a stable scapula is essential in the proximal-to-distal kinetic link for performance efficiency and injury prevention. Recently, the engagement of leg, hip, and trunk movement has been promoted for use in shoulder rehabilitation exercises to also improve neuromuscular control and core stability.[21,23–26] Rather than performing isolated strengthening exercises in a single joint or single plane of motion, therapeutic exercises integrating multijoint kinetic chain motions may be the key to restoring proper movement and function of the scapula.

Another component of exercise that should be addressed is the amount of resistance to prescribe for individuals with scapular dyskinesis. Most, if not all, researchers have used a single intensity that allowed them to compare muscle activity across different types of exercises. However, such methods might cause difficulties when comparing different datasets for a certain exercise, given that different intensities were used in each study. When clinical knowledge about muscle response to various intensities in a single exercise is limited, it is difficult to prescribe an appropriate intensity for that exercise. This can be problematic if greater resistance is prescribed on the basis of one's ability, especially when a high amount of UT and AD muscle activation is considered undesirable.[9–13]

To restore scapular control in the early phases of shoulder rehabilitation, Kibler et al[27] introduced a free-motion shoulder exercise called *robbery*. The robbery exercise promotes scapular retraction and shoulder external rotation (ER) during an integrated dynamic motion. We examined the robbery exercise[27] because it can be modified to investigate the concerns and shoulder muscles addressed. In addition, we wanted to examine the gap in the literature[27,28] between methods and scapular muscle activity during this particular exercise. Therefore, the purpose of our study was 3-fold: (1) to identify the optimal resistance intensity to activate the scapular muscles without exceeding the desired amount of UT and AD muscle activity, (2) to examine the effects of engaging the lower kinetic chain, and (3) to examine the effects of different shoulder-abduction angles on scapular muscle activity.

METHODS

Participants

A total of 15 male college students (age = 20.5 ± 2.2 years, height = 174.5 ± 5.3 cm, mass = 63.8 ± 6.0 kg) volunteered to participate in this study. All volunteers completed a preparticipation physical questionnaire. Volunteers were excluded if they had experienced pain or discomfort in their joints or muscles, received any rehabilitative treatments for any injuries or physical conditions, or undergone any orthopaedic surgeries. All participants provided written informed consent, and the study was approved by the institutional review board at San José State University.

Procedures

All tests were performed in the Kinesiology Adapted Physical Education Laboratory. Participants were instructed to wear their own athletic shoes and shorts for electromyographic (EMG) data collection and were tested for approximately 1 hour. No participant had performed any physical activities or shoulder exercises before their testing procedure.

Electrode Placement. Raw EMG amplitudes of the UT, LT, SA, AD, and infraspinatus (IS) muscles on the dominant-side shoulder were collected. We defined *dominant side* as the side with which the individual threw a ball. The skin surface was prepared by shaving any hair overlying the skin and vigorously cleaning with an alcohol swab to minimize skin impedance before electrode placement. We used bipolar surface silver EMG electrodes (model Delsys Bagnoli-8; 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. The electrodes were placed at the center of the muscle belly in line with the muscle fibers for the specific manual muscle test as described by Kibler et al[27] and Tsuruike and Ellenbecker.[28] They were attached to the body using double-sided tape, secured with surgical tape, and placed as follows: UT, halfway between the C7 spinous process and the acromion process; LT, at an oblique angle from the scapular spine and just outside of the scapular medial border; SA, below the axilla between the latissimus dorsi and pectoralis major at the level of the scapular inferior angle; AD, below the lateral third of the clavicle; and IS, just below the scapular spine and at the middle of the infraspinatus fossa. The reference electrode was placed above the electrodes for the LT and medial to those for the IS. An electronic goniometer (Biometrics Ltd, Newport, UK) was placed lateral to the elbow joint on the dominant side with the upper extremity in an anatomical resting position. We examined the angles of the elbow joint to reflect the motion of the extremity and ensure consistent analysis among participants. The surface electrodes and the electrogoniometer were connected to an amplifier worn on a belt that was attached around the participant's waist.

Figure 1. Starting position of the exercise performed standing. Participants stood with their feet shoulder-width apart, a fist or dumbbell placed in front of the midthigh, and their elbows fully extended.

Maximal Voluntary Isometric Contraction. Once the electrodes were secured, participants performed 2 sets of 4-second maximal voluntary isometric contractions (MVICs) for each muscle using the manual muscle-testing procedures described by Tsuruike and Ellenbecker[28] for normalization of EMG data. Manual pressure was applied at the participant's wrist by the same examiner (Y.N.) for all testing positions. The MVICs of the UT, SA, and AD were examined during resisted scaption in a seated position. Participants abducted their upper extremities in 90° of elevation in the scapular plane with the elbows extended and resisted downward pressure. The MVIC of the IS was examined in the sitting position with the elbows flexed to 90° and the shoulders abducted to 10° and externally rotated to 0°. Participants resisted the manual pressure applied toward internal rotation. The MVIC of the LT was examined during quadruped shoulder flexion.[28] Participants flexed their shoulders to 180° with the thumbs pointed toward the ceiling and the elbows extended in the kneeling quadruped position and resisted downward pressure.

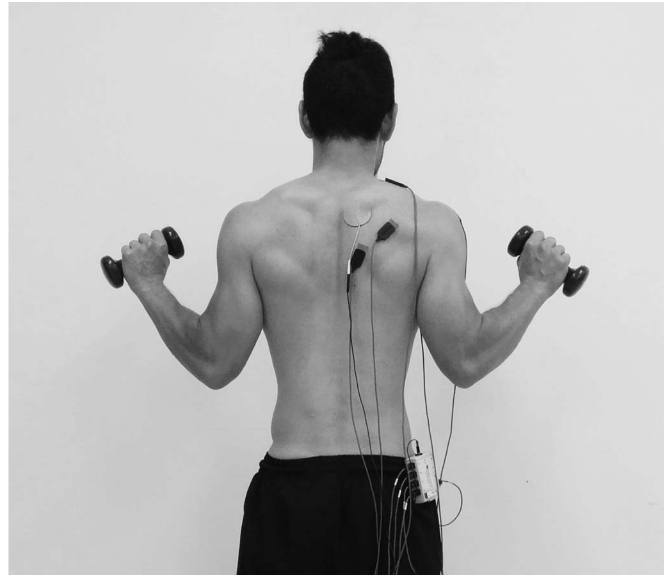

Figure 2. Ending position of the exercise performed with the shoulders in the W position. Participants retracted their scapulae toward the spine, with their elbows pulled toward the back pocket and palms facing forward.

Exercise Protocol. Each participant performed 12 sets of 5 repetitions of the robbery exercise in 2 postural positions (seated, standing), in 2 shoulder positions (20° of abduction[27] [W position], 90° of abduction[28] [90/90 position]), and at 3 intensities. Given that few researchers have suggested the optimal intensity for scapular therapeutic exercises, we used 3 intensities (0%, 3%, and 7% of the individual's body weight [BW]), on the basis of previous studies.[28–31]

For the starting position of the exercise, participants were instructed to fully extend their elbows to clarify the start of the movement and place their fists or dumbbells in front of the midthighs in the standing position (Figure 1) and by the sides of their torsos in the seated position.

To perform the W position, we instructed participants to pull their fists or dumbbells up toward their shoulders, keeping their elbows by their torsos and palms facing forward. At the end of the repetition, they were instructed to "squeeze the shoulder blades together toward the spine and pull the elbows down toward the back pocket." This ensured scapular retraction and depression at the end of shoulder ER motion while maintaining the W position with minimal shoulder abduction (Figure 2).

For the 90/90 position, participants were instructed to pull the dumbbells toward the ceiling with palms facing forward and to bring the shoulders to 90° of shoulder abduction in the frontal plane by externally rotating their shoulders with the elbows flexed to 90°. At the end of the repetition, we instructed participants to "squeeze the shoulder blades together toward the spine" to ensure scapular retraction (Figure 3). This position was used to simulate the shoulder motion seen in athletes performing overhead activities.

To examine the effects of engaging the lower kinetic chain, we used robbery exercises performed while standing. Participants were instructed to flex their knees and hips

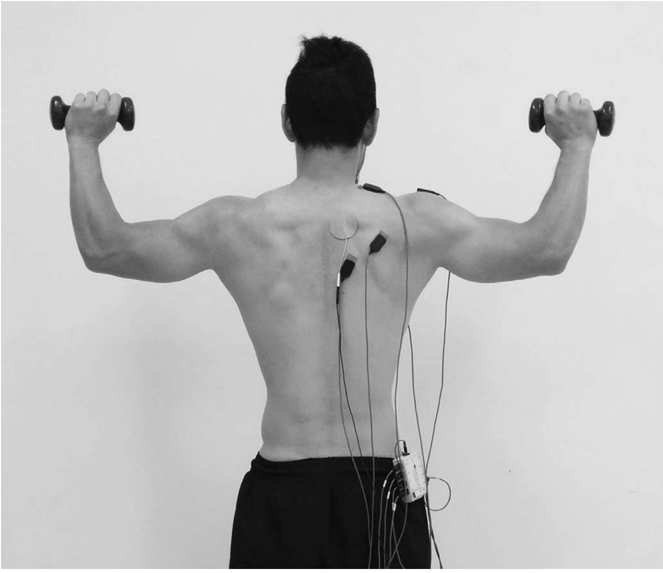

Figure 3. Ending position of the exercise performed with the shoulders in the 90/90 position. Participants brought their elbows to shoulder height, retracted their scapulae toward the spine, and kept their palms facing forward.

slightly to create momentum at the starting position and raise the dumbbells to the required position by extending their knees and thrusting their hips as if they were performing a deadlift. Robbery exercises performed in the seated position were aimed at minimizing the effects of sequenced kinetic chain movement of the lower extremity.

To standardize the exercise among all participants, they were instructed to follow the sound of a metronome (https://www.metronomeonline.com; eMusicInstitute, Inc, Los Angeles, CA) set to 45 beats per minute. The count for the movement was 1 beat at the starting position and 1 beat at the desired shoulder position. The investigators (Y.N., M.T.) instructed participants on how to properly perform the exercises for each position before data collection and allowed them to practice to confirm that they understood the required movement. Oral and visual feedback were not given during data collection. The investigators randomized the order of exercises to minimize the effect of motor learning and fatigue.

Data Analysis

The EMG activities and joint angles were measured using a data-collection program (MP 150 Data Acquisition System; Biopac System, Inc, Goleta, CA) with a sample rate of 1000 Hz. All data were recorded and stored in a computer for off-line analysis. For each participant, we calculated the mean EMG activity of the middle 2 seconds of each 4-second isometric contraction and selected the greater value of the 2 sets to determine his MVIC. The second, third, and fourth trials of 5 repetitions of each exercise were selected and averaged for analysis to eliminate the effects of fatigue and error in performance. We selected 1 second from the initiation of the motion reflected by the 0° of elbow flexion of each repetition for data analysis (Figure 4). All data were calculated in root

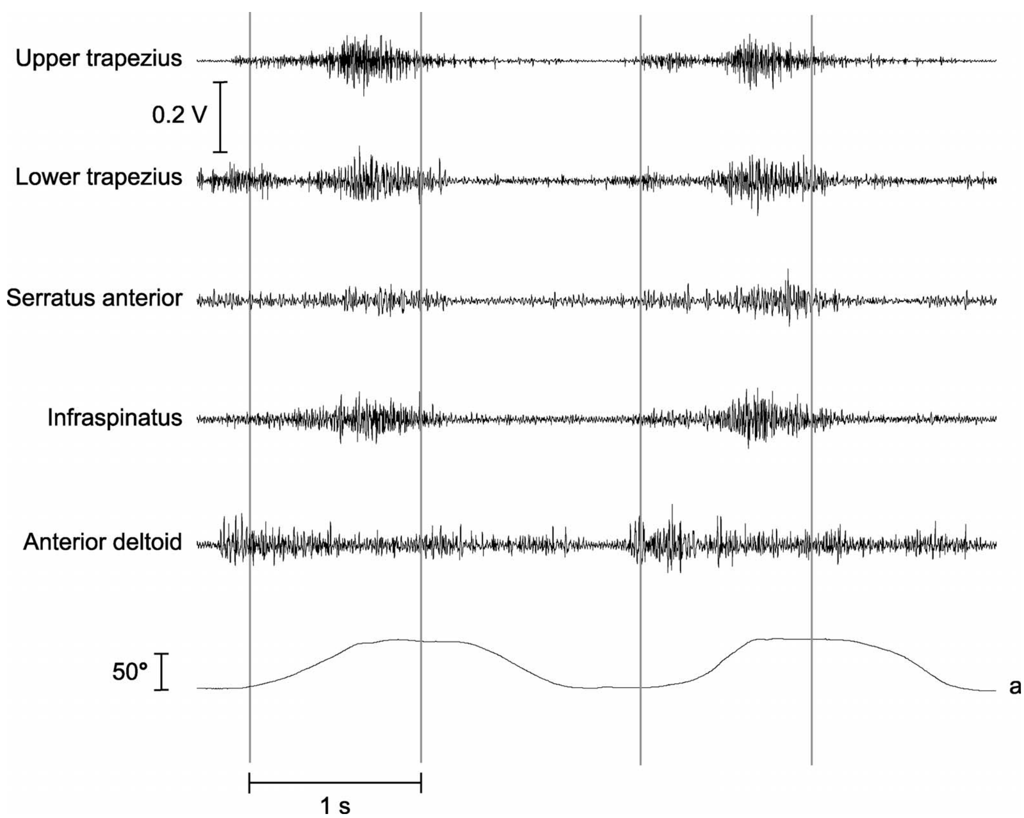

Figure 4. Sample of a typical raw electromyography trace of the upper trapezius, lower trapezius, serratus anterior, infraspinatus, and anterior deltoid muscles during the robbery exercise in the standing 90/90 position using a dumbbell load of 3% body weight. [a] The elbow-joint angle trace measured by an electronic goniometer.

Table. Electromyographic Activity of 5 Muscles[a]

Position	Intensity, % Body Weight	Muscle, Mean ± SD				
		Upper Trapezius	Lower Trapezius	Serratus Anterior	Anterior Deltoid	Infraspinatus
Seated						
W	0	47.8 ± 19.6	44.4 ± 24.0	44.1 ± 21.3	25.2 ± 15.0	61.3 ± 17.1
	3	52.6 ± 21.7	45.8 ± 22.0	44.6 ± 21.4	27.1 ± 15.0	64.8 ± 16.9
	7	63.3 ± 23.8	50.8 ± 17.4	46.6 ± 21.4	31.3 ± 13.9	70.1 ± 19.5
90/90	0	68.5 ± 36.1	55.3 ± 19.5	52.3 ± 19.1	32.9 ± 14.9	64.1 ± 16.5
	3	75.9 ± 28.9	58.1 ± 20.0	57.8 ± 21.3	39.4 ± 18.1	66.8 ± 16.7
	7	85.4 ± 26.7	66.1 ± 17.9	71.1 ± 25.9	55.3 ± 27.5	82.3 ± 15.0
Standing						
W	0	52.2 ± 25.0	41.8 ± 24.5	45.2 ± 21.4	25.4 ± 15.3	61.9 ± 18.9
	3	56.7 ± 24.9	45.2 ± 23.2	45.8 ± 22.4	27.0 ± 15.0	65.4 ± 18.1
	7	64.4 ± 25.7	49.3 ± 22.7	47.4 ± 21.9	32.0 ± 15.2	67.4 ± 18.3
90/90	0	60.9 ± 29.0	49.6 ± 21.7	49.1 ± 19.1	29.6 ± 14.2	61.2 ± 18.7
	3	73.2 ± 29.5	55.5 ± 20.6	55.0 ± 27.7	36.1 ± 16.6	63.9 ± 18.3
	7	81.8 ± 27.2	59.2 ± 18.7	63.8 ± 27.1	44.7 ± 21.3	69.5 ± 19.0

[a] Normalized by percentage of maximal isometric voluntary contraction in each exercise.

mean square values, normalized to MVIC of the corresponding muscles, and presented as a percentage of MVIC.

The dependent variable was percentage of MVIC amplitude for each muscle studied. We used a 3-way (postural position × shoulder position × intensity) repeated-measures analysis-of-variance design within participants crossed with postural position, shoulder position, and intensity to determine differences for each dependent variable. Where appropriate, we calculated the simple main effect and a post hoc test with the Tukey honestly significant difference to measure any difference and present the main outcome. The α level was set at .05. We used SPSS (version 20; IBM Corporation, Armonk, NY) to analyze the statistics.

RESULTS

The percentage of MVIC for each muscle is described in the Table.

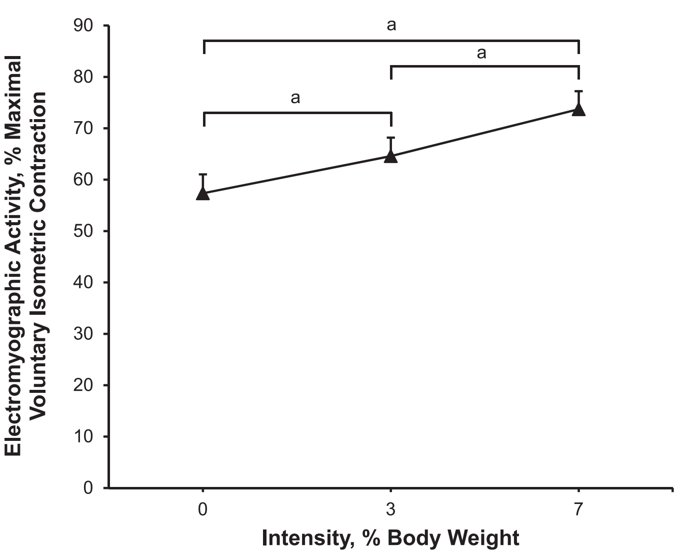

Figure 5. Normalized upper trapezius electromyographic activity during the robbery exercise (Mean ± SE). [a] Difference between intensities regardless of the postural and shoulder positions.

Upper Trapezius

We did not observe 3-way or 2-way interactions in UT EMG activity. The mean value of the EMG activity was greater in the 90/90 position than in the W position, regardless of intensity or body position (74.3% and 56.2% of MVIC, respectively; $F_{1,14} = 25.3$, $P < .001$). We also noted differences in the mean values between 0% and 3% of BW (57.4% and 64.6% of MVIC, respectively), 3% and 7% of BW (64.6% and 73.7% of MVIC, respectively), and 0% and 7% of BW (57.4% and 73.7% of MVIC, respectively), regardless of the postural or shoulder positions ($D_{Tukey} = 4.0\%$, $P < .05$; Figure 5).

Lower Trapezius

Three-way and 2-way interactions were not demonstrated in LT EMG activity. The mean value of the EMG activity was greater in the 90/90 position than in the W position (57.3% and 46.2% of MVIC, respectively; $F_{1,14} = 45.9$, $P < .001$). We also identified differences between 0% and 7% of BW (47.8% and 56.4% of MVIC, respectively) and 3% and 7% of BW (51.2% and 56.4% of MVIC, respectively), regardless of the postural and shoulder positions ($D_{Tukey} = 3.4\%$, $P < .05$), but no difference between 0% and 3% of BW (Figure 6).

Serratus Anterior

We did not observe 3-way interactions in SA EMG activity. However, a 2-way interaction occurred between postural position and shoulder position ($F_{1,14} = 8.58$, $P = .01$). Specifically, the mean value of the EMG activity was greater in the 90/90 position than in the W position in both the seated (60.4% and 45.1% of MVIC, respectively; $F_{1,56} = 86.25$, $P < .001$) and standing (55.9% and 46.1% of MVIC, respectively; $F_{1,56} = 35.67$, $P < .001$) positions. When participants performed the exercise in the 90/90 position, the mean value of the EMG activity was greater in the seated position than in the standing position (60.4% and 56.0% of MVIC, respectively; $F_{1,56} = 20.33$, $P < .001$), whereas no difference was found in the W position.

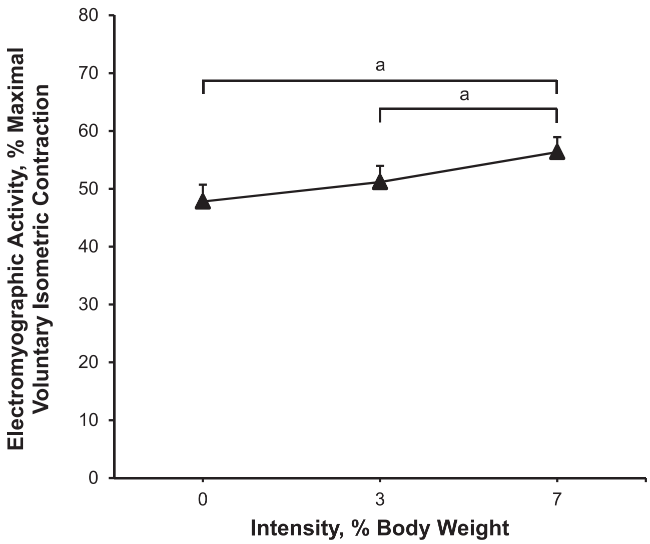

Figure 6. Normalized lower trapezius electromyographic activity during the robbery exercise (Mean ± SE). [a] Difference between intensities regardless of the postural and shoulder positions.

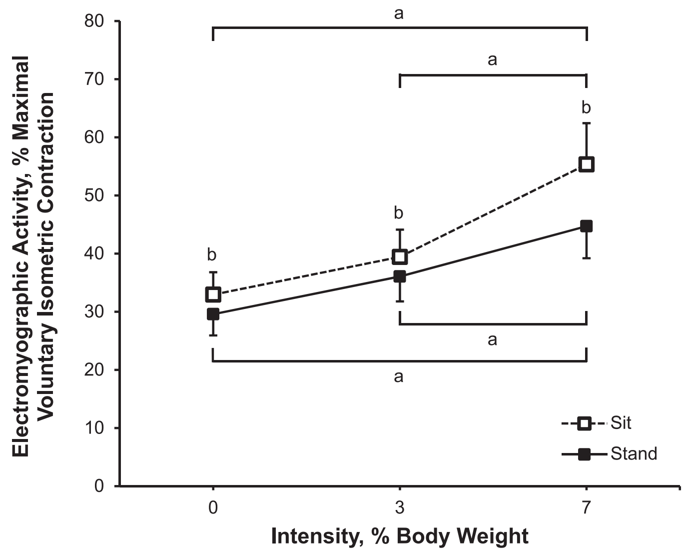

Figure 8. Normalized anterior deltoid electromyographic activity during the 90/90 position in the seated and standing positions (Mean ± SE). [a] Difference between intensities. [b] Different from the standing position.

Another 2-way interaction was revealed between shoulder position and intensity ($F_{2,28} = 14.3$, $P = .001$). We demonstrated differences in the 90/90 position between 0% and 3% of BW (50.7% and 56.4% of MVIC, respectively), 3% and 7% of BW (56.4% and 67.4% of MVIC, respectively), and 0% and 7% of BW (50.7% and 67.4% of MVIC, respectively; $D_{Tukey} = 4.5\%$, $P < .05$) but no differences in the W position (Figure 7).

Anterior Deltoid

A 3-way interaction occurred between postural position and shoulder position across intensities ($F_{2,28} = 7.23$, $P = .003$). Specifically, the mean value of the AD EMG

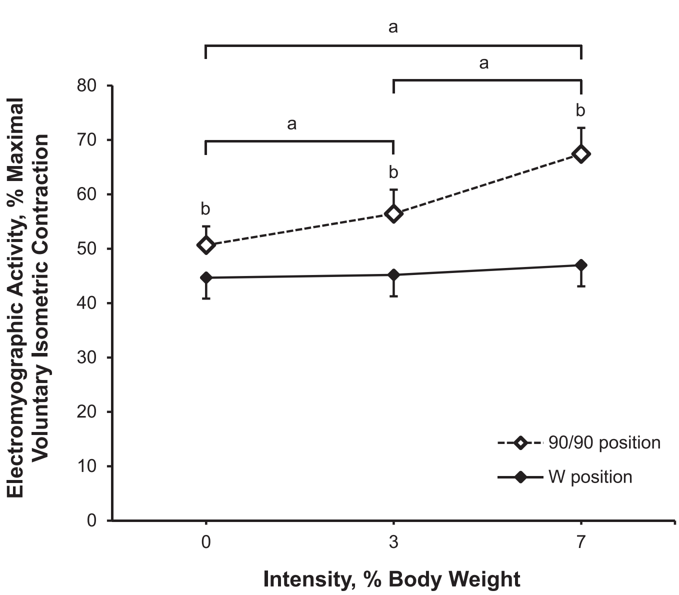

Figure 7. Normalized serratus anterior electromyographic activity during the W and 90/90 shoulder positions, regardless of postural position (Mean ± SE). As intensity increased, serratus anterior activity in the 90/90 position increased. Serratus anterior activity did not differ in the W position. [a] Difference between intensities for the 90/90 position. [b] Difference between the W and 90/90 positions.

activity was greater in the seated than in the standing position when the exercises were performed in the 90/90 position at 0% of BW (32.9% and 29.6% of MVIC, respectively; $F_{1,70} = 5.0$, $P = .03$), 3% of BW (39.4% and 36.1% of MVIC, respectively; $F_{1,70} = 5.02$, $P = .001$), and 7% of BW (55.3% and 44.7% of MVIC, respectively; $F_{1,70} = 50.03$, $P < .001$), whereas no differences were noted in the W position (Figure 8). Furthermore, the mean value of the EMG activity in the seated position was greater in the 90/90 position than in the W position at 0% of BW (32.9% and 25.2% of MVIC, respectively; $F_{1,70} = 5.25$, $P = .03$), 3% of BW (39.4% and 27.1% of MVIC, respectively; $F_{1,70} = 13.3$, $P = .001$), and 7% of BW (55.3% and 31.3% of MVIC, respectively; $F_{1,70} = 50.58$, $P < .001$; $D_{Tukey} = 6.2\%$, $P < .05$; Figure 9). However, the mean value of the EMG activity in the standing position was greater in the 90/90 position than in the W position at 3% of BW (36.1% and 27.0% of MVIC, respectively; $F_{1,70} = 7.26$, $P = .009$) and 7% of BW (44.7% and 32.0% of MVIC, respectively; $F_{1,70} = 14.26$, $P < .001$), whereas no difference was evident at 0% of BW. Last, the 90/90 position demonstrated differences between 0% and 7% of BW for the seated (32.9% and 55.3% of MVIC, respectively) and standing (29.6% and 44.7% of MVIC, respectively) positions ($D_{Tukey} = 6.7\%$, $P < .05$) and between 3% and 7% of BW for the seated (39.4% and 55.3% of MVIC, respectively) and standing (36.1% and 44.7% of MVIC, respectively) positions ($D_{Tukey} = 6.7\%$, $P < .05$) but no differences between 0% and 3% of BW. In contrast, we did not identify differences for the W position across intensities in either the seated or standing position.

Infraspinatus

No 3-way interaction was observed in IS EMG activity. However, we found a 2-way interaction between the postural and shoulder positions with participants seated ($F_{1,14} = 5.12$, $P = .04$). The mean value of the EMG activity was greater in the 90/90 position than in the W position

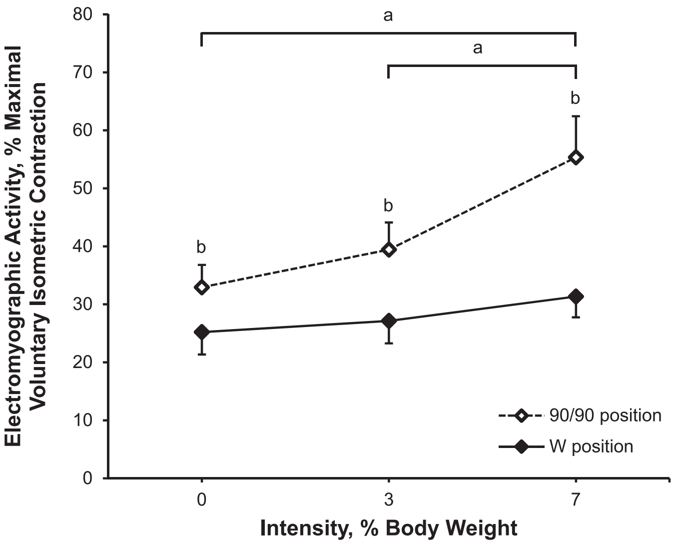

Figure 9. Normalized anterior deltoid electromyographic activity during the W and 90/90 shoulder positions in the seated position (Mean ± SE). [a] Difference between intensities for the 90/90 position. [b] Different from the W position.

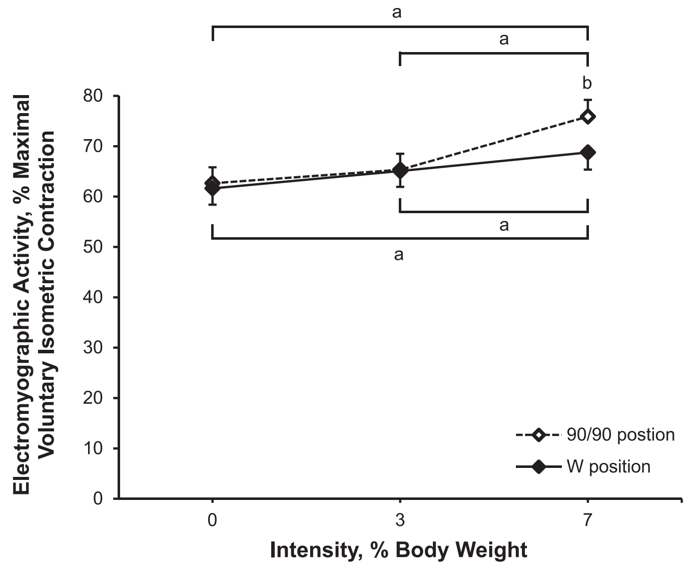

Figure 10. Normalized infraspinatus electromyographic activity during the W and 90/90 shoulder positions in the seated position (Mean ± SE). [a] Difference between intensities. [b] Different from the W position.

with participants seated (71.1% and 65.4% of MVIC, respectively; $F_{1,56} = 13.0$, $P = .001$), whereas we noted no differences with participants standing.

We demonstrated another 2-way interaction between postural position and intensity ($F_{2,28} = 17.70$, $P = .001$). The mean value of the EMG activity was greater in the seated than in the standing position at 7% of BW (76.2% and 68.4% of MVIC, respectively; $F_{1,70} = 27.5$, $P < .001$), whereas no differences were evident at 0% or 3% of BW. Furthermore, we observed differences in EMG activity between the intensities of 0% and 7% of BW (62.6% and 75.9% of MVIC, respectively) and 3% and 7% of BW (65.3% and 75.9% of MVIC, respectively) for both the seated and standing positions ($D_{Tukey} = 3.3\%$, $P < .05$) but no differences between 0% and 3% of BW.

The other 2-way interaction was between shoulder position and intensity ($F_{2,28} = 9.22$, $P = .001$). The mean value of the EMG activity was greater in the 90/90 position than in the W position at 7% of BW (75.9% and 68.8% of MVIC, respectively; $F_{1,56} = 37.6$, $P < .001$), whereas no differences were noted at 0% or 3% of BW. We identified differences for both shoulder positions between 0% and 7% of BW for the W position (61.6% and 68.8% of MVIC, respectively) and the 90/90 position (62.6% and 75.9% of MVIC, respectively) and between 3% and 7% of BW for the W position (65.1% and 68.8% of MVIC, respectively) and the 90/90 position (65.3% and 75.9% of MVIC, respectively; $D_{Tukey} = 3.5\%$, $P < .05$) but no differences between 0% and 3% of BW (Figure 10).

DISCUSSION

The free-motion shoulder ER and scapular-retraction exercise that we examined is recommended for individuals with pathologic shoulder conditions to restore an appropriate balance between scapular muscle strength and function.[27] Whereas many shoulder exercises have been suggested for improving scapular-muscle imbalances, little is known about how different resistance intensities during an exercise influence the muscle-recruitment pattern. To determine the amount of resistance intensity that can recruit scapular muscles without inducing hyperactivity of the UT and AD muscles, we explored the effects of 3 resistance intensities during a free-motion shoulder exercise. In addition, we compared 2 shoulder-abduction angles and the engagement of the lower kinetic chain to identify their effects on scapular muscle activity.[27,28] We followed the guideline from DiGiovine et al[32] that EMG activities between 21% and 40% of MVIC should be considered a moderate level to retrain neuromuscular control in scapular muscles during the initial phase of rehabilitation. Accordingly, the UT and AD muscles were considered highly active when EMG activity was greater than 40% of MVIC.

Our participants demonstrated increased scapular muscle activity with increased resistance intensities during all variations of the robbery exercise. However, the most important finding was that differences in both the postural and shoulder positions altered the amount of increase in SA, AD, and IS muscle activity, even when the same intensity was used. The results of our study may provide insight into how practitioners select appropriate intensity and positional variations of the robbery exercise for patients undergoing shoulder rehabilitation. On the basis of the patient's available range of motion, scapular kinematics, and underlying purpose of rehabilitation, we advocate a progression sequence for the robbery exercise.

Kibler et al[27] recommended the robbery exercise for scapular-muscle recruitment because it can be performed even before full shoulder range of motion is regained after an injury or surgery. Our findings suggested that the robbery exercise should be introduced first with the shoulders in the W position and using an intensity of less than 3% of BW. The body position for this exercise pattern can be either seated or standing. The goal is to regain scapular retraction and initiate active shoulder ER motion during rehabilitation.

We did not observe differences for SA EMG activity with the shoulders in the W position, even with an increase in resistance, but we did see an increase in SA EMG activity in the 90/90 position with all 3 intensities, regardless of the postural position (seated versus standing). This finding is consistent with Hardwick et al,[17] who stated that the SA muscle is activated most effectively with shoulder positions at and above 90° of abduction. Nonetheless, the robbery exercise in the W position consistently resulted in SA EMG activities of greater than 40% MVIC, which is sufficient for the initial stage of rehabilitation (Table).

Oyama et al[18] suggested that shoulder exercises in the W position are appropriate for promoting scapular ER and retraction. Their W-position exercise was performed in the prone position and demonstrated greater activity of the LT and middle trapezius than the UT muscle, whereas we observed greater UT than LT activity for the exercise performed in the upright position. The gravitational effects on the UT and LT muscles may be attributed to these differences in muscle-activity patterns during scapular retraction.

When sufficient control of scapular motion is regained gradually, the robbery exercise in the W position can be progressed with an increase in resistance intensity up to 7% of BW in the standing position, followed by the seated position. We identified a 10% of MVIC increase in IS muscle activity in the seated position compared with the standing position using 7% of BW intensity. Thus, we recommend using the standing position and increasing intensity by engaging the lower kinematic chain to assist the IS muscle in externally rotating the shoulder.

Furthermore, when pain-free shoulder abduction is restored, the robbery exercise with the shoulders in the 90/90 position and no-resistance intensity can be introduced safely into the rehabilitation program. When the goal of the exercise is to gain functional shoulder motion, such as in the cocking phase of pitching or volleyball spiking, the nonresistant robbery exercise in the 90/90 position can be performed in either the seated or standing position. When resistance in the 90/90 position is desired, exercises in the standing position should be prescribed with an intensity of no greater than 3% of BW. When the lower kinetic chain was engaged during the robbery exercise with the shoulders in the 90/90 position, we found that the amount of AD muscle activity was less than in the seated position. The energy created by the lower body transferred to the upper body and assisted the AD muscles in shoulder ER. Furthermore, an intensity of 7% of BW during the robbery exercise with the shoulders in the 90/90 position resulted in hyperactivity of the AD muscle, regardless of body position. Specifically, the AD activity increased by 15.9% of MVIC from 3% to 7% of BW intensity in the seated position, whereas it increased by 8.6% of MVIC in the standing position (Table; Figures 8 and 9).

As the strength of the scapular muscles becomes sufficient for scapular and glenohumeral stability, the goal of rehabilitation is to strengthen the scapular and rotator cuff muscles in the sport-specific motion with greater resistance intensity. The 7% of BW intensity can be prescribed for the robbery exercise in the 90/90 position if appropriate for the individual's needs, possibly before upper body plyometric exercises. We suggest that the patient perform the exercise in the standing position before progressing to the seated position.

Our study confirmed similar EMG activation patterns between the UT and LT muscles. First, the EMG activities of those muscles were greater when the robbery exercise was performed in the 90/90 position than in the W position. Second, UT and LT muscle activities increased with each increase in resistance intensity (0%, 3%, 7% of BW). Third, the postural position did not influence the EMG activity of the UT and LT muscles during the robbery exercise. Fourth, the UT muscle consistently showed greater EMG activity than the LT muscle during every variation of the robbery exercise performed in this study. Our findings are in agreement with those of Cools et al[9] and suggest that the coordinated force-couple relationship of the UT and LT muscles enables normal scapular kinematics during humeral abduction in healthy individuals. The robbery-exercise variations that we investigated may not result in LT strengthening with inhibition of UT activation. This may be due to the amount of shoulder abduction, which was up to 90° in this study. Ekstrom et al[15] examined 10 shoulder exercises and demonstrated that LT activation was greatest when the upper extremity was raised overhead in line with the muscle fibers of the LT, which was from roughly 120° to 150° of shoulder abduction. However, in that study, participants not only performed the exercise in the prone position with the effects of gravity, but they also used a higher resistance intensity as determined by the 5-repetition maximum.

We examined 3 intensities that were based on the findings of Tsuruike and Ellenbecker,[28] who did not report any differences between intensities of 3% and 5% of BW and 5% and 7% of BW. The dumbbell of 3% to 7% of BW was equivalent to 2 to 5 kg because the mean BW of the participants was 63.8 kg in our study and similar in their study.[28] However, the EMG activation level of the muscles that we investigated during the robbery exercise in the 90/90 position was relatively higher than their results. This difference may be attributed to the difference in postural positions. Our participants performed the exercises in the seated position with no hip or knee extension, and their participants used hip extension but no knee extension. Similarly, the amount of EMG activity in our study was relatively higher than that reported by Kibler et al[27] during the nonresistance robbery exercise in the W position. This difference might have been due to the different speeds at which the exercise was performed and the duration of scapular contraction in retraction at the end of the motion. Thus, the speed of motion may be another variable that can influence the modulation of scapular-muscle activity.

All participants in our study were young, healthy men with no abnormal shoulder or scapular conditions. Therefore, caution must be taken when applying our findings to individuals with pathologic shoulder conditions because scapular kinematics and scapular muscle activation may differ in those populations. Examination of bilateral shoulders and further investigation of individuals with pathologic shoulder or scapular conditions are warranted to fully reveal and identify the effects of different exercise intensities on scapular-muscle recruitment during a dynamic free-motion shoulder ER and retraction exercise.

CONCLUSIONS

We demonstrated the modulation of scapular muscles relative to changes in resistance intensity and exercise movement patterns during a free-motion shoulder ER and retraction exercise using dumbbells. Hyperactivity of the AD muscle can lead to superior translation of the humeral head, which has been found to decrease the subacromial space.[13] For this reason, it is critical to understand the appropriate resistance intensity for a therapeutic exercise, particularly for individuals with shoulder impingement syndrome. On the basis of our results, we suggest that the intensity of the robbery exercise should be no greater than 3% of BW, especially when the shoulders are abducted to 90°, regardless of whether the position is seated or standing. The robbery exercise performed with less shoulder abduction and with the contribution of energy transferred from the lower body was beneficial in activating the scapular muscles and preventing excessive AD muscle activity and, thus, is recommended for the initial phase of the exercise progression. Understanding the effects of different intensities, along with the effects of the postural and shoulder positions, will allow clinicians to prescribe an appropriate level of intensity for each individual depending on the purpose and phase of shoulder rehabilitation.

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