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Subscapularis Muscle Activity during Selected Rehabilitation Exercises*

Michael J. Decker,† MS, John M. Tokish, MD, Henry B. Ellis, Michael R. Torry,‡ PhD, and Richard J. Hawkins, MD

From the Steadman-Hawkins Sports Medicine Foundation, Vail, Colorado

Background: The upper and lower portions of the subscapularis muscle are independently innervated and activated.
Hypothesis: Upper and lower portions of the subscapularis muscle demonstrate different activation levels and require different exercises for rehabilitation.
Study Design: Controlled laboratory study.
Methods: Fifteen healthy subjects performed seven shoulder-strengthening exercises. Electromyographic data were collected from the latissimus dorsi, teres major, pectoralis major, infraspinatus, supraspinatus, and upper and lower subscapularis muscles.
Results: Upper subscapularis muscle activity was greater than lower subscapularis muscle activity for all exercises except for internal rotation with 0° of humeral abduction. The push-up plus and diagonal exercises consistently stressed the upper and lower subscapularis muscles to the greatest extent.
Conclusions: Humeral abduction was found to have a strong influence on the selective activation of the upper versus the lower subscapularis muscle and thus supported the design of different exercise continuums. In addition, the push-up plus and diagonal exercises were found to be superior to traditional internal rotation exercises for activating both functional portions of the subscapularis muscle.
Clinical Relevance: Our results showing that the upper and lower portions of the subscapularis muscle are functionally independent may affect training or rehabilitation protocols for the rotator cuff muscles.

The activity of the subscapularis muscle is crucial for the normal performance of shoulder motion. A number of EMG evaluations have shown this muscle to be highly activated during arm elevation, overhead throwing, swimming, and golf.[9,16,17,28,29,31] Although the importance of the subscapularis muscle is rarely debated, its specific function and relative contribution to shoulder motions are unclear. Several EMG studies, for example, have demonstrated conflicting and even counterintuitive findings regarding its function.[21,32] Explanations for these conflicts may lie in the fact that the subscapularis muscle has traditionally been thought to function as a single muscle unit. However, several investigators have shown that the upper and lower portions of the subscapularis muscle are independently innervated[19,23] and activated.[18] Moreover, recent studies further suggest that the upper portion of the subscapularis muscle is more activated than the lower during throwing,[6] indicating separate functions for these two portions.

Although isolated rupture of the subscapularis muscle is uncommon,[7] its reduced activation has been found in dysfunctional shoulders that have been documented as having pathologic conditions.[9,30] In addition, partial ruptures of the upper portion of the subscapularis muscle, the so-called "hidden lesion," are becoming increasingly recognized as a source of shoulder pain and dysfunction.[33] Optimal rehabilitation of these injuries after surgery requires an understanding of the specific effects of shoulder rehabilitation on the upper and lower portions of the subscapularis muscle.

Although most rehabilitation programs for the shoulder include exercises that emphasize strengthening of the subscapularis muscle, investigations in this area have often neglected the role of this muscle. Several studies that have evaluated the EMG response of shoulder mus-

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† Address correspondence to Michael J. Decker, MS, mike.decker@mail.utexas.edu.

‡ Address reprint requests to Michael R. Torry, PhD, Biomechanics Research Laboratory, Steadman-Hawkins Sports Medicine Foundation, 181 West Meadow Drive, Suite 1000, Vail, CO 81657.

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cles to rehabilitation exercises have left out the subscapularis muscle altogether,[1,24,25] and others have not studied both functional parts of the subscapularis muscle separately.[3,12,21,30,32] The documentation of EMG activity during exercises that are intended to stimulate this muscle would lend insight into which exercises are optimal for all phases of rehabilitation for the injured subscapularis muscle and would also guide progressive strengthening in the healthy shoulder as well. Thus, the purposes of this study were to document muscle activity of the upper and lower portions of the subscapularis muscle during several different resistance exercises that target this muscle and to design exercise continuums of upper and lower subscapularis muscle activity for progressive training or rehabilitation.

MATERIALS AND METHODS

Subject Preparation

Nine men (average age, 28.0 ± 5.1 years; average height, 1.8 ± 0.1 meters; average weight, 87.4 ± 14.6 kg) and six women (average age, 25.0 ± 2.4 years; average height, 1.6 ± 0.1 meters; average weight, 58.0 ± 6.9 kg) with no history of shoulder injury were informed of the procedures involved in this study and gave their written informed consent to act as subjects, in accordance with the policies of the Vail Valley Medical Center's Internal Review Board. Before testing, all subjects practiced the exercise techniques and maximum voluntary muscle contraction protocols.

Pregelled and self-adhering silver/silver-chloride bipolar surface electrodes (Medicotest, A/S, Rugmaken, Denmark) were used to measure the muscle activity of the latissimus dorsi, teres major, pectoralis major (sternal portion), and infraspinatus muscles. The skin was shaved and cleansed with alcohol, and the surface electrodes were placed over the muscle bellies in line with the direction of the muscle fibers with a center-to-center interelectrode distance of 25 mm.[2] Indwelling electrodes for the supraspinatus and upper and lower subscapularis muscles were placed within the muscle substance by using the Basmajian technique.[2] The selection of surface versus indwelling electrodes was primarily based on the depth of the muscle, as both forms have been shown to demonstrate equivalent and reliable EMG amplitudes.[8,15]

Standard anatomic references for the placement of the surface and indwelling electrodes have been described by previous authors.[5,10,12,18] However, only the indwelling electrode protocols for the upper and lower portions of the subscapularis muscle are germane to this study. The needle for the upper subscapularis muscle was inserted approximately 3 cm below the spine of the scapula, anterior to the medial border and directed toward its midpoint. The needle for the lower subscapularis muscle was inserted approximately 5 cm below the spine of the scapula, anterior to the medial border and directed perpendicular to the medial border. For both muscles, the needle was inserted until it reached the costal surface of the scapula and then was carefully withdrawn, leaving the fine wire electrode within the muscle. All electrode placements were confirmed by manual muscle tests.

Experimental Protocol

The testing session began with a series of five isometric maximum voluntary contractions (MVC) for each muscle. The standardized MVC procedures and protocols have been previously reported.[12]

Applied force and EMG data were collected (1200 Hz) during seven exercises. Applied force was measured with a force plate (Bertec Corp., Columbus, Ohio) or a force transducer (Entran Devices Inc., Fairfield, New Jersey) placed in series with an elastic resistance device (Body Lines, Innovation Sports, Irvine, California). Electromyographic data were collected with the TeleMyo telemetric hardware system (Noraxon, USA, Inc., Scottsdale, Arizona) on line with the analog-to-digital board of a motion capture system (Motion Analysis, Santa Rosa, California). Each EMG signal had a bandwidth of 3 dB at 16 to 500 Hz. The lower cutoff filter was a first-order high-pass design, and the upper cutoff filter was a sixth-order Butterworth low-pass design. The differential amplifier had a fixed gain of 1700, a differential input impedance of 10 MΩ, and a common-mode rejection ratio of 130 dB. A resting trial was collected and used to remove any additional noise. In addition to the EMG data, a manual timing signal was recorded with the software of the motion capture system to assist in defining exercise phases within each trial.

Each phase of all exercises was performed at 54 beats per minute, standardized with the aid of a metronome. The exercise order was randomly selected for the first subject and subsequently balanced to eliminate any order effects. The exercises that involved use of elastic resistance were performed at a distance away from the wall where the subject could perform only 10 repetitions while maintaining consistent metronome speed. The seven exercises were performed as follows.

For the dynamic hug (Fig. 1), the subject stood with his or her back to the wall, knees slightly bent, and feet shoulder width apart. The subject grasped the elastic resistance device with his or her elbow flexed at 45°, the arm abducted 60°, and the shoulder internally rotated 45°. The subject then performed a hugging action by horizontally flexing the humerus in an imaginary arc described by his or her hands. Once the subject's hands touched together, he or she slowly returned to the starting position by following the same imaginary arc.

For the forward punch (Fig. 2), the subject stood with his or her back to the wall, with knees slightly bent and feet shoulder width apart in a split stance. The subject grasped the elastic resistance device with his or her arm at the side of the body with the elbow flexed to 90°, flexed the shoulder, and extended the elbow until the hand reached the height of the xyphoid process with the elbow slightly flexed. The subject then returned to the initial position by extending the shoulder and flexing the elbow.

For the diagonal (Fig. 3), the subject stood with his or her back to the wall, knees slightly bent, and feet shoulder width apart in a split stance. The handle of the elastic

Figure 1. The start (A) and the end (B) of the dynamic hug exercise.

Figure 2. The start (A) and the end (B) of the forward punch exercise.

Figure 3. The start (A), the middle (B), and the end (C) of the diagonal exercise.

resistance device was grasped at shoulder height with the elbow slightly flexed and the humerus in the neutral position, abducted to 90°. The subject then horizontally flexed, adducted, and internally rotated the humerus until the hand reached the anterior superior iliac spine opposite to that of the resistance. The humerus was progressively internally rotated 90° throughout the entire movement, beginning from the initial position and ending at the moment of touching the anterior superior iliac spine. Once the subject's hand touched the anterior superior iliac spine, he or she slowly returned to the starting position by externally rotating, horizontally extending, and abducting the humerus.

During the push-up plus, the subject started in a prone position with one hand on the force plate and the other hand next to the force plate, with the chest near the ground. The subject then fully extended his or her elbows and continued to rise up by protracting the scapulae. The subject then returned to the starting position by retracting his or her scapula and flexing the elbows.

Internal shoulder rotation was performed at three different positions of shoulder abduction without arm support. Internal rotation at 0° of abduction (IR low) began with the elbow at 90° of flexion, the shoulder at 0° of abduction, and the humerus in 70° of external rotation. The humerus was then internally rotated against an elastic resistance device from 70° of external rotation to 70° of internal rotation. The subject then slowly returned to the starting position by externally rotating the humerus. Internal rotation at 45° (IR mid) and 90° (IR high) of shoulder abduction were performed in the same manner except that the subject maintained 45° and 90° of shoulder abduction throughout the shoulder rotation exercises, respectively.

Analysis

Each exercise was divided into phases of increasing and decreasing force (resistance). This terminology was selected rather than concentric and eccentric phases because antagonist muscles performed different muscle actions within each resistance phase of the exercises. Therefore, we chose to express the muscle activities with respect to increasing and decreasing force phases to consistently express the results.

All EMG data were processed with custom software using a 50 ms root-mean-square smoothing window algorithm.[4] Maximum EMG reference values were calculated for each muscle by using the average of the five peak EMG signals to represent 100% MVC. Muscle activity was categorized as minimal (0% to 20% MVC), moderate (21% to 50% MVC), or marked (>50% MVC).

Five trials of EMG and force data were analyzed to calculate peak and average amplitudes for all exercises during each phase. The EMG data were expressed as a percentage of MVC and provided a relative measure of muscle activity.

Statistical Analysis

Group means of peak applied force and peak and average EMG amplitudes for all muscles were calculated for each force phase. A seven-by-seven (muscle by exercise) repeated-measures analysis of variance was used to contrast peak and average EMG amplitudes (percent of MVC) within and between exercises for each force phase. A one-way repeated-measures analysis of variance was used to determine differences in the mean peak applied force for both force phases. Significant differences were scrutinized with the Bonferroni post hoc method with an adjusted alpha level for the amount of individual comparisons.

Statistical trends of peak and average EMG activity for the upper and lower subscapularis muscles, for both the increasing and decreasing force phases, were determined through simple regression analyses (linear). The level of statistical significance was set at $P = 0.05$ unless otherwise noted.

RESULTS

Group means and standard deviations for the mean peak applied force are graphically represented in Figure 4. Mean peak applied force was tightly distributed from 264 N in the forward punch to 310 N in the push-up plus and yielded no statistical differences between exercises during either phase ($P > 0.122$, mean power = 0.560).

Group means and standard deviations for average and peak EMG activity are presented in Table 1. All muscles demonstrated the greatest peak and average EMG amplitudes during the increasing force phase. Only those muscles that elicited average EMG activity greater than 20% MVC during both the increasing and decreasing force phases are presented in Table 1.

All seven-by-seven repeated-measures analysis of variance for peak and average EMG amplitudes within the increasing and decreasing force phases yielded significant main effects (muscle, exercise) and interactions (muscle by exercise) ($P < 0.001$, mean power = 1.00). These results were interpreted to indicate that a difference between the seven muscles within an exercise and a difference between the seven exercises within a muscle were statistically different in one or more of the individual comparisons. In addition, the significant interaction terms for both EMG variables and force phases indicated that the exercises stimulated a different response from each muscle, further justifying the need for post hoc comparisons.

Upper subscapularis muscle activity ranged from 29% MVC in the decreasing force phase to 136% MVC in the increasing force phase. The push-up plus exercise demonstrated significantly higher peak and average upper subscapularis muscle activity compared with all exercises (all $P < 0.001$) except the diagonal (both $P > 0.0024$). The IR high, dynamic hug, and the diagonal exercises elicited greater peak upper subscapularis muscle activity than the forward punch (all $P < 0.001$).

Lower subscapularis muscle activity ranged from 7% MVC in the decreasing force phase to 79% MVC in the increasing force phase. The dynamic hug, IR low, diagonal, and push-up plus exercises demonstrated greater average lower subscapularis muscle activity compared with the forward punch and IR high (all $P < 0.001$). The IR low, diagonal, and push-up plus exercises demonstrated greater peak lower subscapularis muscle activity than did the forward punch and IR high exercises (all $P < 0.001$).

Supraspinatus muscle activity ranged from 17% MVC in the decreasing force phase to 125% MVC in the increasing force phase. The push-up plus elicited greater peak and average supraspinatus muscle activity compared with all other exercises (all $P < 0.001$). The dynamic hug, diagonal, and forward punch had greater average supraspinatus activity compared with the IR low, and the dynamic hug had greater activity than the IR mid. All exercises except the IR mid demonstrated greater peak supraspinatus activity than did the IR low.

Infraspinatus muscle activity ranged from 8% MVC in the decreasing force phase to 115% MVC in the increasing force phase. The push-up plus induced the greatest average and peak infraspinatus muscle activity compared with all other exercises (all $P < 0.001$). The forward punch exercise had greater peak supraspinatus muscle activity compared with the IR low, mid, and high (all $P < 0.001$).

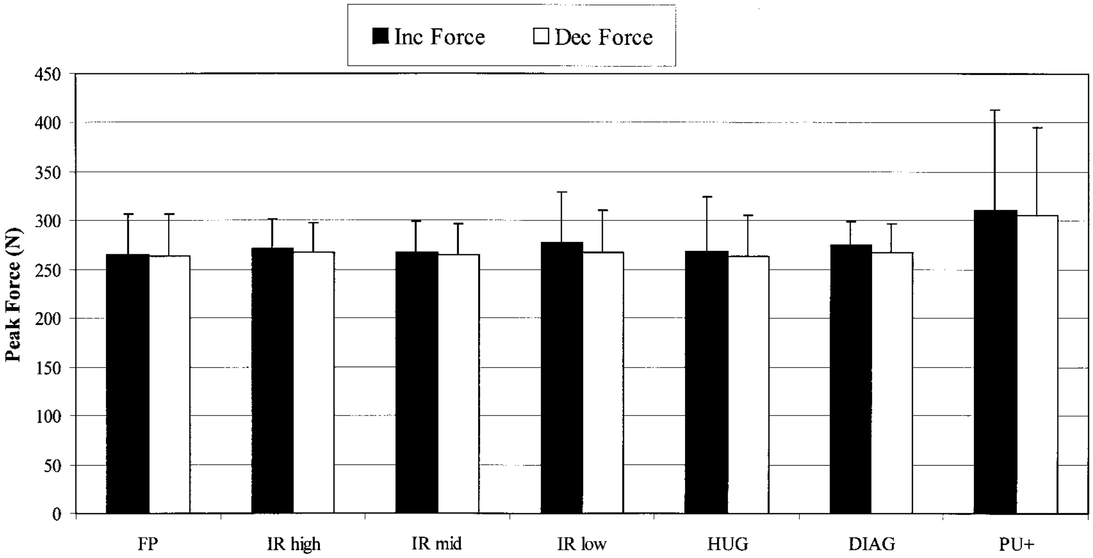

Figure 4. Mean peak force (in newtons) and standard deviations for the increasing force (Inc Force) and decreasing force (Dec Force) phases for seven shoulder rehabilitation exercises: forward punch (FP); internal rotation at 90° (IR high), 45° (IR mid), and 0° (IR low) of shoulder abduction; dynamic hug (HUG); diagonal (DIAG); and push-up plus (PU+).

TABLE 1
Means (Standard Deviations) Expressed as a Percentage of Maximum Voluntary Contraction for Average and Peak Amplitudes in Muscles with Average Amplitudes Greater than 20%

Exercise	Muscle	Average amplitude		Peak amplitude	
		Increasing	Decreasing	Increasing	Decreasing
Forward punch	Upper subscapularis	33.0 (27.6)	29.4 (27.9)	49.8 (32.6)	43.2 (32.3)
	Supraspinatus	45.6 (23.6)	41.7 (23.7)	73.4 (39.5)	69.9 (47.1)
	Infraspinatus	27.6 (12.1)	24.7 (11.3)	54.1 (21.4)	49.7 (22.3)
	Pectoralis major	25.0 (12.4)	24.3 (18.5)	47.1 (21.1)	41.5 (20.0)
IR high	Upper subscapularis	57.9 (38.4)	52.0 (34.4)	91.3 (50.6)	79.2 (45.9)
	Supraspinatus	39.6 (22.8)	38.7 (20.9)	74.4 (35.6)	73.6 (32.1)
IR mid	Upper subscapularis	52.8 (39.7)	45.8 (39.3)	87.1 (55.6)	74.8 (55.1)
	Lower subscapularis	26.2 (18.7)	25.0 (15.5)	51.1 (30.0)	42.5 (27.8)
	Supraspinatus	33.1 (25.4)	31.6 (25.6)	37.8 (23.1)	33.1 (19.7)
	Pectoralis major	39.0 (22.0)	36.1 (21.2)	67.8 (32.2)	60.2 (27.9)
IR low	Upper subscapularis	50.1 (23.0)	41.3 (22.2)	84.6 (35.3)	72.0 (30.7)
	Lower subscapularis	39.9 (26.6)	33.2 (19.8)	67.9 (39.2)	55.4 (33.6)
	Pectoralis major	50.8 (23.7)	49.0 (25.6)	78.4 (29.6)	68.4 (29.2)
Dynamic hug	Upper subscapularis	58.3 (31.9)	47.5 (34.1)	94.1 (46.1)	70.7 (44.5)
	Lower subscapularis	37.6 (20.3)	34.8 (27.3)	52.7 (29.1)	43.2 (24.9)
	Supraspinatus	61.9 (30.6)	61.3 (29.3)	82.0 (36.6)	79.2 (38.7)
	Pectoralis major	46.4 (23.7)	36.3 (26.8)	87.3 (43.1)	63.3 (40.0)
Diagonal	Upper subscapularis	60.2 (34.4)	55.9 (37.1)	99.7 (44.9)	85.0 (41.3)
	Lower subscapularis	38.6 (26.1)	37.7 (23.8)	56.9 (29.4)	55.8 (23.6)
	Supraspinatus	53.5 (34.8)	46.6 (29.5)	76.4 (41.2)	71.4 (37.3)
	Pectoralis major	75.8 (31.6)	63.3 (22.2)	104.0 (36.0)	100.4 (30.4)
	Latissimus dorsi	20.7 (12.1)	20.0 (8.4)	48.5 (27.1)	43.8 (25.7)
Push-up plus	Upper subscapularis	121.8 (22.2)	111.2 (19.0)	135.5 (41.0)	130.2 (38.4)
	Lower subscapularis	46.1 (29.2)	42.9 (30.0)	78.9 (46.9)	66.9 (38.7)
	Supraspinatus	98.6 (35.8)	96.3 (30.8)	124.7 (37.0)	114.1 (36.3)
	Infraspinatus	104.1 (54.1)	98.9 (51.8)	114.6 (34.6)	97.6 (38.7)
	Pectoralis major	94.3 (27.2)	92.1 (26.0)	132.0 (36.6)	126.7 (32.7)
	Teres major	47.0 (26.3)	46.6 (24.1)	59.5 (36.5)	57.9 (27.8)
	Latissimus dorsi	48.8 (24.8)	47.4 (24.5)	65.0 (32.1)	62.8 (35.2)

Teres major muscle activity ranged from 12% MVC in the decreasing force phase to 60% MVC in the increasing force phase. The push-up plus induced the greatest average and peak teres major muscle activity compared with all exercises (all $P < 0.001$) except the IR low ($P > 0.0024$).

Pectoralis major muscle activity ranged from 18% MVC in the decreasing force phase to 132% MVC in the increasing force phase. The push-up plus and diagonal exercises elicited greater average and peak pectoralis major muscle activity than all other exercises (all $P < 0.002$). The IR low and the dynamic hug both induced greater peak and average pectoralis major muscle activity than the forward punch and the IR high exercises (all $P < 0.002$).

Latissimus dorsi muscle activity ranged from 10% MVC in the decreasing force phase to 65% MVC in the increasing force phase. The push-up plus and diagonal exercises elicited greater average and peak latissimus dorsi major muscle activity than all of the other exercises (all $P < 0.002$). The push-up plus demonstrated greater average latissimus dorsi muscle activity compared with the diagonal ($P < 0.001$).

Post hoc results for the EMG amplitude comparisons between muscles within an exercise were limited to the contrasts between the upper and lower portions of the subscapularis muscle. During the increasing and decreasing force phases, average amplitude EMG activity was greater for the upper subscapularis muscle compared with the lower subscapularis muscle for the forward punch, IR high, IR mid, and push-up plus exercises (all $P < 0.002$). In addition, peak amplitude EMG activity was greater for the upper subscapularis muscle during the IR high, dynamic hug, diagonal, and push-up plus exercises compared with the lower subscapularis muscle during both force phases (all $P < 0.001$). Upper and lower subscapularis muscle peak and average EMG amplitudes were not different for the IR low exercise for either force phase (all $P > 0.0024$).

Continuum Design

The final rank order and the results for the four regression analyses of upper and lower subscapularis muscle activity are presented in Tables 2 and 3. All regression analyses demonstrated a significant linear trend ($P < 0.001$) and explained 17% to 25% of the variance in EMG activity.

Overall continuums of upper and lower subscapularis muscle activity were designed from the respective four regression analyses. For each continuum, muscle activity was rank-ordered by exercise, with equal weighting given to average and peak EMG amplitudes and to increasing and decreasing force phases.[4] The exercise that consistently elicited the greatest EMG activity for either the upper or lower subscapularis muscle represented the top-ranking exercise.

TABLE 2
Final Rank Order and Linear Regression Results of Exercises for Activating the Upper Subscapularis Muscle

Final order	Exercise	Increasing force phase[a]		Decreasing force phase[a]	
		AA	PA	AA	PA
1	Push-up plus	1	1	1	1
2	Diagonal	2	2	2	2
3	IR high	4	4	3	3
4	Dynamic hug	3	3	4	6
5	IR mid	5	5	5	4
6	IR low	6	6	6	5
7	Forward punch	7	7	7	7
	P	<0.001	<0.001	<0.001	<0.001
	Adjusted R^2	0.253	0.168	0.247	0.184
	Standard error	35.2	46.0	34.5	43.9

[a] AA, average amplitude; PA, peak amplitude.

TABLE 3
Final Rank Order and Linear Regression Results of Exercises for Activating the Lower Subscapularis Muscle

Final order	Exercise	Increasing force phase[a]		Decreasing force phase[a]	
		AA	PA	AA	PA
1	Push-up plus	1	1	1	1
2	Diagonal	3	3	2	2
3	IR low	2	2	4	3
4	Dynamic hug	4	4	3	4
5	IR mid	5	5	5	5
6	IR high	6	6	6	6
7	Forward punch	7	7	7	7
	P	<0.001	<0.001	<0.001	<0.001
	Adjusted R^2	0.244	0.223	0.251	0.203
	Standard error	21.8	32.1	20.9	27.9

[a] AA, average amplitude; PA, peak amplitude.

DISCUSSION

The subscapularis muscle is important for optimal shoulder function. Although most authors agree that the subscapularis muscle functions as an internal rotator of the humerus,[26] others have shown the muscle to function as a shoulder abductor,[13,22] anterior stabilizer,[27] and humeral head depressor.[14] These functions are reflected in the EMG evaluations of several sport-specific activities in which marked subscapularis muscle activity is typically found throughout the motion.[9,16,17,28,29,31]

Other authors have found the upper and lower portions of the subscapularis muscles to have separate functions[6] and reduced muscular activation of either may lead to shoulder dysfunction.[9,30] We recommend that training or rehabilitation programs approach this muscle as two independent muscle units. The results of this study provide the clinician with several exercises that target the upper and lower portions of the subscapularis muscle for progressive training or rehabilitation.

All seven of the exercises elicited EMG amplitudes above 20% MVC from the upper subscapularis muscle, whereas all but the IR high and forward punch exercises stimulated the lower subscapularis muscle above 20% MVC. The push-up plus and the diagonal exercises consistently activated both the upper and lower subscapularis muscle more than did the other exercises. Although Belle and Hawkins[3] did not report which part of the subscapularis muscle was investigated, they noted marked EMG activity from this muscle during the push-up and are in agreement with our results from the upper subscapularis muscle. In contrast, Townsend et al.[32] reported that the push-up did not produce subscapularis muscle activity greater than 50% MVC through three consecutive arcs of motion. No report was made on whether the upper or lower subscapularis was studied, but their results would be consistent with the moderate output of the lower subscapularis muscle found in the current study. Our study provided support for the newly designed diagonal exercise, as it resulted in marked upper and lower subscapularis muscle activity.

We observed that upper subscapularis muscle activity increased and lower subscapularis muscle activity decreased during the internal rotation exercises with progressively greater shoulder abduction positions without arm support (Tables 2 and 3). This finding is in direct disagreement with that of Kadaba et al.,[18] who found the opposite to occur during the performance of internal rotation at 0° and 90° of abduction with the arm supported. The upper subscapularis muscle has been shown to contribute to both shoulder abduction and internal rotation[26]; thus, larger EMG amplitudes from this muscle would be expected during an internal rotation exercise that is performed with progressively greater degrees of abduction. The performance of the internal rotation exercises without the arm supported may account for the differences between our findings and those of Kadaba et al.,[18] because we replicated their EMG methods. In a similar study of internal rotation exercises at 0°, 45°, and 90° of abduction,[21] subscapularis muscle activity was found to decrease with abduction, but the electrode location was not clearly specified. Because the arm of each of the subjects in this study was reported to be unsupported during the exercises, we think that their electrodes were monitoring the lower subscapularis muscle; thus, the findings of Kronberg et al.[21] support the results of the current study. In addition, upper and lower subscapularis muscle activity during internal rotation was similar in magnitude to the results of other studies.[10,12]

The dynamic hug induced moderate-to-marked upper and lower subscapularis muscle activity. In a previous study, the dynamic hug, along with the push-up plus, were both found to substantially activate the serratus anterior muscle.[4] The scapular rotator muscles are important for providing a stable platform for humeral elevation.[20] Scapulohumeral stability is enhanced when the rotator cuff muscles are activated to maintain the humerus on the stable platform.[11] Studies of the muscles used during throwing activities have found that patients with shoulder instability demonstrate reduced activation of the serratus anterior and subscapularis muscles.[9] Thus, the dynamic hug and the push-up plus are efficient exercises for promoting both serratus anterior and subscapularis muscle activity, and these exercises may be efficient for the training programs of overhead sporting activities.

The subscapularis and infraspinatus muscles provide anterior and posterior stability, respectively, and both counter the superior pull on the humerus from the deltoid and supraspinatus muscles.[14] This coordinated muscular strategy is thought to center the humerus in the glenoid for the performance of safe overhead movements. Only the push-up plus and forward punch exercises coincidentally induced subscapularis, infraspinatus, and supraspinatus muscle activity above 20% MVC. These two exercises may be beneficial for training shoulder stability via muscular coordination. However, the supraspinatus muscle is often injured from repetitive overhead movements. The IR low exercise elicited minimal supraspinatus muscle activity with moderate-to-marked upper and lower subscapularis muscle activity. This exercise may be optimal for protecting the supraspinatus muscle during the early phases of shoulder rehabilitation while still training the upper and lower subscapularis muscle.

The greatest EMG activity from the latissimus dorsi, pectoralis major, and teres major muscles was found when shoulder adduction and horizontal shoulder adduction were required by the performances of the push-up plus and diagonal exercises. Marked subscapularis muscle activity was also evident in these exercises and may indicate that the rotator cuff muscles were acting to stabilize the humerus in the glenoid and supplementing internal rotation. This action may be similar to powerful overhead motions in which the pectoralis major and latissimus dorsi muscles are the primary movers that require marked activation from the rotator cuff muscles to prevent the humerus from abnormal translation on the glenoid.

Exercise continuums for the upper and lower subscapularis muscle were designed from the peak and average EMG amplitudes during both force phases. The increasing and decreasing force phases, specific to the exercises studied, are consistent with concentric and eccentric activation of the subscapularis muscle. Different clinical approaches are required for applying the exercise continuums for either training or rehabilitation. The selection of the most effective exercise for training the rotator cuff is the one that stimulates the largest EMG amplitudes from the most muscles, such as the push-up plus exercise. However, the subscapularis muscle is selectively stressed during particular sporting activities and may require focused exercises to be included in a training program. For example, athletes involved in overhead throwing activities require substantial eccentric activation from the upper subscapularis muscle. Tables 1 through 3 reveal the diagonal and IR high exercises to be effective in activating this muscle during the decreasing force phase; thus, including these exercises in the training program would satisfy the eccentric conditioning of the subscapularis muscle.

When applying either exercise continuum for rehabilitation, it is important to begin by matching the patient's needs with his or her movement limitations and goals. The selection of an appropriate exercise, therefore, would safely activate all injured muscles via light resistance and low muscle activation levels. It is common to have concurrent subscapularis and supraspinatus muscle tears. Thus, a strengthening program for both rotator cuff muscles could potentially be designed from the documented muscle activities and exercise continuums shown in Tables 1 through 3. The data reveal that the IR low exercise induces low-to-moderate muscle activity in the subscapularis and supraspinatus muscles. Rehabilitation would begin with light resistance for this exercise and then progress to greater resistances, eventually leading to exercises with increased arm elevations, such as the dynamic hug or diagonal.

The primary limitation of this study may be the placement of the indwelling electrodes into the upper and lower portions of the subscapularis muscle. Although we used established techniques,[2,18] we did not obtain MRI or CT confirmation of exact anatomic placement. This weakness is somewhat defended by the fact that the medial subscapular insertion of the needles could realistically only have been misplaced into the serratus anterior muscle. We did not think this was the case, as a previous study from this institution showed a vastly different EMG pattern for the serratus anterior muscle during MVC testing.[4] In addition, six of the seven exercises demonstrated the average or peak EMG amplitude to be different between the upper and lower subscapularis muscle, indicating that we monitored separate muscle units and that these muscle units were functionally independent.

Average and peak EMG activity were documented from the upper and lower subscapularis muscle, and exercise continuums were designed accordingly. Although resisted internal rotation has long been the standard method for optimal rehabilitation or training of the subscapularis muscle, the push-up plus and diagonal exercises appear to be superior in activating both portions of the subscapularis muscle. Proper application of either exercise continuum depends on the athlete's or the patient's needs and limitations. Rotator cuff muscle activity was influenced by humeral abduction, which has important clinical ramifications when designing an appropriate rehabilitation or training program. Further investigations of the functions of the upper and lower portions of the subscapularis muscle are warranted, as the results of the current study are in disagreement with those of some other studies.

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