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Electromyographic analysis of selected shoulder muscles during a series of exercises commonly used in patients with symptomatic degenerative rotator cuff tears

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Background: In the nonoperative treatment of degenerative rotator cuff (RC) tears, exercise therapy is advocated. Exercises focusing on strengthening the anterior deltoid (AD) and the scapular muscles are proposed to compensate for RC dysfunction. However, the amount of electromyographic (EMG) activity in these muscles during these exercises remains unclear. Moreover, it is unknown whether muscle activity levels during these exercises alter with increasing age. Therefore, the purpose of this study was to evaluate EMG activity in the deltoid and scapular muscles during 2 series of commonly used shoulder rehabilitation exercises and assess possible age-related changes in muscle activity.

Methods: Fifty-five healthy participants (aged 18-60 years) participated in this study. Surface EMG activity was measured in 8 shoulder girdle muscles during a progression of a closed chain elevation program (bench and wall slides) and during a progression of previously published AD exercises. In addition, muscle activity was compared between 3 age categories (18-32 years, 33-46 years, and 47-60 years).

Results: The proposed progressions exhibited increasing activity from <10% of maximal voluntary isometric contraction to >20% of maximal voluntary isometric contraction for the AD for both exercise programs and for the middle deltoid, upper trapezius, and middle trapezius during the closed chain elevation exercises. Activity levels in the other muscles remained <20% throughout the progression. Age-related analysis revealed increased activity in the AD, infraspinatus, and middle trapezius and decreased lower trapezius activity during the bench and wall slides. No age-related changes were noted for the AD exercises.

Conclusion: These findings may assist the clinician in prescribing appropriate progressive exercise programs for patients with symptomatic RC tears.

This study was approved by the Ethical Committee of Ghent University Hospital on October 12, 2018 (reference 2018/1088; Belgian registration no. B670201837321).

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Keywords: Rotator cuff tear; exercise therapy; nonoperative treatment; EMG; deltoid; scapular muscles

With increasing age, shoulder pain is the most common site of musculoskeletal pain.[19] Rotator cuff (RC) disease is one of the most common musculoskeletal disorders in the adult population. RC tears are highly prevalent, ranging from a rate of 22% at the age of 65 years to more than 62% in a population older than 80 years,[20] and appear to be an age-related finding on diagnostic imaging. Age-related tendon degeneration seems to play a significant role in the development of RC disease.[16] Although degeneration with progressive mechanical failure of the RC is considered a normal age-related process and many degenerative RC tears remain asymptomatic, half of these injuries become symptomatic within 3 years of initial diagnosis.[14,17] Research data have demonstrated tear size progression in 51% and pain development in 49% of subjects with asymptomatic RC tears for a period of 5 years.[14] Moreover, it has been shown that up to 50% of the patients seeking professional help for their shoulder pain still have recurrent or persistent shoulder symptoms 1 year after first consulting with their doctor,[22] suggesting that shoulder pain may lead to chronic pain and loss of function.

Given the high prevalence, high economic burden, and disability associated with symptomatic degenerative RC tears, defining the optimal management is of high priority for health care providers and researchers. The current literature indicates a recommendation of "moderate strength" for the use of exercise therapy in the management of degenerative RC tears as a primary intervention.[13,18] Although exercises are advocated in nearly all patients with symptomatic RC tears, evidence supporting one specific program over another is scarce. In the absence of a consensus or gold-standard exercise program, clinicians often use expert opinion and clinical experience to guide exercise prescription. The current gap in the literature consists of the lack of knowledge on which exercises are best to perform in this population: either exercises to strengthen the remaining muscle fibers of the RC (loading the RC) or exercises focusing on strengthening the other shoulder muscles while decreasing the tension on the RC muscles (unloading the RC). Regarding the latter, it has been suggested to train the anterior deltoid (AD) as a compensatory muscle for glenohumeral stability and function[1,15] and to focus on scapulothoracic strength to optimize general shoulder girdle functional performance.[8] An indirect way to assess tendon load during exercise is electromyography (EMG). A recent systematic review by Edwards et al[10] summarized the literature regarding EMG activity in the RC during commonly used shoulder rehabilitation exercises in healthy subjects; however, this review did not include the activity in other shoulder muscles, in particular the deltoid, or the scapulothoracic muscles. In addition, the review did not take into account possible changes in EMG activity with increasing age.

Therefore, the purpose of this study was 2-fold: (1) to analyze EMG activity in selected glenohumeral as well as scapulothoracic muscles in 2 series of commonly used shoulder rehabilitation exercises with suggested "low load" on the RC[1,10,15] in a population of healthy participants with increasing age and (2) to examine possible age-related changes in muscle activity in the targeted muscles during these exercises. We hypothesized that muscle activity would vary between exercises and between different age categories.

Materials and methods

Subjects

On the basis of an a priori analysis, the power for this study was set at 80%, based on an α level of .05, resulting in a minimal total sample size of 50 to detect a between-exercise difference in muscle activity based on the largest minimal detectable change error value. We recruited 55 healthy participants (30 men and 25 women) for this study. The mean age of the subjects was 39 years (standard deviation [SD], 13.04 years); mean weight, 76.7 kg (SD, 16.98 kg); mean height, 1.73 m (SD, 0.1 m); and mean body mass index, 25.4 kg/m^2 (SD, 4.85 kg/m^2). Participants aged between 18 and 60 years were recruited and divided into 3 groups based on age category: 18-32 years (n = 23), 33-46 years (n = 10), and 47-60 years (n = 22). Anthropometric data are summarized in Table I. Subjects with a history of shoulder or neck injury or surgery were excluded. In addition, overhead athletes (with training and/or competition for >3 hours/week) and individuals who performed intensive upper-limb strength training (>5 hours/week) were excluded. Written informed consent was acquired from all participants.

Instrumentation

The skin surface was first shaved with a disposable razor; it was then scrubbed using a cotton ball with scrubbing gel and, finally, cleansed with a cotton ball soaked in alcohol to reduce impedance. Self-adhesive circular bipolar surface electrodes (silver–silver chloride Ambu BlueSensor P [reference no. P-00-S/50], 40.8 × 34

Table I Anthropometric data of all subjects (N = 55) and by age category

Characteristic	n	Mean	SD
All age categories (18-60 yr)	55		
Male/female sex	30/25		
Age, yr		39.0	13.04
Weight, kg		76.6	16.98
Length, m		1.73	0.101
BMI, kg/m^2		25.4	4.85
Age category 1 (18-32 yr)	22		
Male/female sex	11/11		
Age, yr		25.1	5.01
Weight, kg		68.8	12.64
Length, m		1.76	0.110
BMI, kg/m^2		22.2	2.78
Age category 2 (33-46 yr)	10		
Male/female sex	5/5		
Age, yr		40.1	3.57
Weight, kg		86.2	12.31
Length, m		1.73	0.070
BMI, kg/m^2		28.9	4.72
Age category 3 (47-60 yr)	23		
Male/female sex	14/9		
Age, yr		52.8	3.84
Weight, kg		79.9	19.5
Length, m		1.72	0.109
BMI, kg/m^2		26.9	4.79

SD, standard deviation; *BMI*, body mass index.

mm; Ambu, Ballerup, Denmark) were placed on 8 muscles on the dominant side: AD, middle deltoid (MD), posterior deltoid (PD), upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), serratus anterior (SA), and infraspinatus (IS). The dominant arm was defined as the arm used to throw a ball. The SENIAM (Surface Electromyography for the Non-invasive Assessment of Muscles) recommendations for surface EMG (http://www.seniam.org/) were followed for electrode placement and inter-electrode distance.[12] All electrodes were placed over the muscle bellies, in line with the orientation of muscle fibers. A reference electrode was placed over the ipsilateral acromion. To ensure consistency, the same investigator was responsible for all electrode placements. The electrodes were connected to a 16-channel Telemyo G2 EMG receiver (Noraxon USA, Scottsdale, AZ, USA). The sampling rate was 1500 Hz, and all raw myoelectric signals were preamplified (overall gain, 1000; common rate rejection ratio, 115 dB; signal-to-noise ratio, <1 μV root-mean-square baseline noise). Prior to testing, we verified correct electrode placement and EMG signal quality through visual inspection of the signal during muscle-specific movements. In addition, an OptiTrack Flex 3 high-speed camera (100 frames/second; NaturalPoint, Corvallis, OR, USA) was used to track the direction of motion during all exercises for the purpose of automatically and more precisely marking the start and end for each exercise. Two reflective markers were applied on the lateral side of the dominant upper arm, and 2 were applied on the trunk. The humeral markers were placed on the lateral epicondyle and 10 cm more proximal; the trunk markers were located on the processus spinosus of C7 and T7. The camera was installed perpendicular to these reflective markers.

Exercise selection

On the basis of the current literature[1,10,13,15] and expert opinion,[9,21] 2 series of exercises were selected. These exercises are suggested to have low (<20% of maximal voluntary isometric contraction [MVIC]) RC activity[10] or are recommended for patients with massive RC tears.[1,15] Eight variations of closed chain exercises, namely bench and wall slides (exercises 1-8), were performed, in addition to 1 open chain elevation exercise as a reference exercise (exercise 9) with which to compare the closed chain exercises. In addition, 4 progressions from the AD exercise program from Levy et al[15] were used, referred to hereafter as the "Levy exercises" (exercises 10-13). All exercises are described in Table II, and examples are illustrated in Figures 1-9. To eliminate the influence of fatigue, the cluster sequence was randomized and all exercises within each cluster were mutually randomized. Putting this information together, 10 unique exercise series were used to test the subjects. Each series had its own number. The subject took a card containing one of the numbers, which determined the series of exercises he or she needed to perform.

Procedures

Prior to the exercises, an MVIC for each muscle was performed against manual resistance by the same examiner. Table III describes the configuration method for each assessed muscle. The EMG activity was measured for 5 seconds, and the contraction was repeated 3 times, with 15 seconds of rest between efforts. A 2-minute rest was taken between assessments of each muscle. Time was controlled with a metronome (60 beats/min) to ensure an equal performing speed among the participants. The subjects were encouraged in a standardized manner to execute the tasks. Signal markers were placed on the EMG signal at the second count of the isometric contraction.[6] For each muscle, the highest activity level generated across the standard set of 8 positions was used for normalization.[6] The same investigator was responsible for all MVIC measurements to ensure test consistency.

After the MVIC procedure, each exercise was thoroughly explained and demonstrated to the participants. The tasks had a specific phasing, which was controlled by a metronome. All the bench and wall slides, as well as the open chain exercise, started with 5 seconds of rest, followed by 3 seconds up and 3 seconds down 5 times, and finally, 5 seconds of rest again. The phasing for the Levy exercises was as follows: 5 seconds of rest, 3 seconds up, 3-second hold, 3 seconds forward and 3 seconds backward 6 times, 3-second hold, 3 seconds down, and finally, 5 seconds of rest. In total, 5 repetitions of the bench slides, wall slides, and elevation exercises were conducted, and data for the first and last attempts were excluded from further analysis. The Levy exercises were repeated 3 times. There was a break of 2 minutes between exercises. For the bench and wall slides, a handball-sized ball and a 1.5-m green elastic band (TheraBand, Akron, OH) were used. For the Levy exercises, 1-kg TheraBand weight balls were used.

Signal processing and data analysis

The Noraxon Myovideo module MR3.6 software program was used for signal processing. Raw EMG signals underwent electrocardiographic reduction, rectification, and smoothing (root

Table II Description of 13 exercises with reference to figures

Name	Description
Bench slides	
1. Bilateral bench slide (Fig. 1)	The subject sits in front of a bench, slides a ball with both hands forward to 60° of forward flexion, and returns to the starting position.
2. Unilateral bench slide < 90° (Fig. 2)	The subject sits beside a bench, slides a ball with 1 hand forward to 60° of forward flexion, and returns to the starting position.
3. Unilateral bench slide > 90° (Fig. 3)	The subject sits beside a bench, slides a ball with 1 hand forward to 150° of forward flexion, and returns to the starting position.
4. Unilateral bench slide > 90° with resistance from elastic band (Fig. 4)	The subject sits beside a bench, slides a ball with 1 hand forward to 150° of forward flexion with resistance from an elastic band in the direction of this movement, and returns to the starting position.
5. 45° inclined bench slide with resistance from elastic band	The subject slides a ball with 1 hand forward on a 45° inclined table to 150° of forward flexion and returns to the starting position.
Wall slides	
6. Wall slide with ball (Fig. 5)	The subject rolls a ball with 1 hand on the wall in the scapular plane to 150° of forward flexion and returns to the starting point.
7. Wall slide with towel	The subject slides a towel with 1 hand on the wall in the scapular plane to 150° of forward flexion and returns to the starting position.
8. Wall slide with towel and resistance from elastic band	The subject slides a towel with 1 hand on the wall in the scapular plane to 150° of forward flexion with resistance of an elastic band in the direction of this movement and returns to the starting position.
Elevation open chain	
9. Elevation in open chain without resistance	The subject performs elevation in the scapular plane in an open chain to 150° of elevation and returns to the starting position.
Levy exercises	
10. Passive (Fig. 6)	The subject brings the arm passively to 90° of forward flexion, moves the arm passively upward to 120° of forward flexion and downward to 60° of forward flexion for 6 repetitions, and returns to the starting position.
11. Active without resistance (Fig. 7)	The subject brings the arm passively to 90° of forward flexion, moves the arm actively upward to 120° of forward flexion and downward to 60° of forward flexion for 6 repetitions, and returns to the starting position.
12. Active with resistance from plyometric ball (Fig. 8)	The subject brings the arm, passively holding a 1-kg plyometric ball, to 90° of forward flexion; moves the arm actively upward to 120° of forward flexion and downward to 60° of GH forward flexion for 6 repetitions; and returns to the starting position.
13. Active with resistance from plyometric ball with 45° inclination of the trunk (Fig. 9)	While lying in a 45° inclined supine position, the subject brings the arm, passively holding a 1-kg plyometric ball, to 90° of forward flexion; moves the arm actively upward to 120° of forward flexion and downward to 60° of GH forward flexion for 6 repetitions; and returns to the starting position.

GH, glenohumeral.

mean square window, 100 milliseconds). Resting EMG activity was considered baseline activity. For the MVICs, we used the mean amplitude of EMG activity in the 3-second interval after the marker for further analysis. The marker was set at the time point at which maximal effort was achieved. All data were visually inspected, and the marker was manually reset when the interval did not contain the highest EMG activity. The normalization reference level for each of the muscles of interest was taken as the maximal activity level generated across the 8 MVIC tests.[4,6]

EMG processing was performed for all 8 muscles during the progression of bench and wall slides; however, for the Levy exercises, only 5 muscles were analyzed (AD, MD, PD, UT, and SA) because data collection for the remaining muscles (MT, LT, and IS) was not possible in view of the nature of the exercises. During the supine exercises, the subject would lie on the electrodes, giving unreliable signals. The EMG data for each muscle during the exercises were averaged across the 3 intermediate repetitions of the 5 repetitions of the bench and wall slides completed and across all 3 repetitions of the Levy exercises. For the bench and wall slides, the whole movement was used for analysis. For the Levy exercises, only the 6 seconds alternating between 60° and 120° were taken into account for further analysis; passive elevation and the return to the starting position were disregarded. Periods were defined by markers based on video analysis with visual markers. The markers were set by synchronizing the video analysis with the EMG registration. The mean EMG signal amplitude, expressed as a percentage of MVIC, was used to assess the activity in the 8 muscles of interest.

Figure 1 Bilateral bench slide.

Figure 3 Unilateral bench slide > 90°.

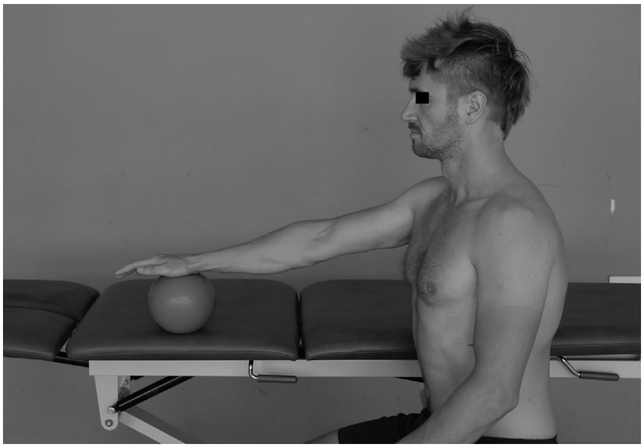

Figure 2 Unilateral bench slide < 90°.

Figure 4 Unilateral bench slide > 90° with resistance from elastic band.

Statistical analysis

Means and SDs were calculated for normalized EMG activity for 8 muscles (AD, MD, PD, IS, UT, MT, LT, and SA) during 8 progressions of the bench and wall slide exercises (exercises 1-8), for the open chain elevation (exercise 9), and for 5 muscles (AD, MD, PD, UT, and SA) during 4 progressions of the Levy exercises (exercises 10-13). Because all data were normally distributed (Kolmogorov-Smirnov test) with equal variances (Levene test), parametric statistics were performed. For all statistical analysis, IBM SPSS Statistics (version 25; IBM, Armonk, NY, USA) was used and α was set at .05.

Analysis of bench and wall slide exercise set

First, the whole data set (N = 55) was used to analyze differences in EMG activity between the exercises, using a general linear model analysis of variance (ANOVA) for repeated measures with 1 within-subject factor (9 levels) for each muscle separately. Post hoc Bonferroni tests were used for pair-wise comparisons. To analyze age-based differences, a 2-way ANOVA for repeated measures was performed with 1 within-subject factor (exercise) and 1 between-group factor (age category). Interaction effects of Exercise × Age were of primary interest. In case of the absence of interaction effects, main group effects were explored. Post hoc analysis was performed using Bonferroni correction. Analysis of main exercise effects was not necessary because this was already performed in the first part of the analysis on the whole group.

Analysis of Levy exercise set

First, the whole data set (N = 55) was used to analyze differences in EMG activity in the 5 muscles of interest (AD, MD, PD, UT, and SA) between the 4 exercises using a general linear model ANOVA for repeated measures with 1 within-subject factor (exercise, 4 levels) for each muscle separately. To analyze age-based differences, a 2-way ANOVA for repeated measures was performed with 1 within-subject factor (exercise, 4 levels) and 1 between-group factor (age category, 3 levels). Interaction effects of Exercise × Age were of primary interest. In case of the absence of interaction effects, main group effects were explored. Post hoc analysis was performed using Bonferroni correction. Analysis of

Figure 5 Wall slide with ball.

main exercise effects was not necessary because this was already performed in the first part of the analysis on the whole group.

Results

Bench and wall slide exercise set

First, the total data set (N = 55) was considered for analysis of the bench and wall slide exercise set. Descriptive analysis of normalized EMG activity in the 8 muscles of interest during the 8 variations of the bench and wall slides and the open chain elevation exercise is displayed in Table IV and Figure 10. For all muscles involved, ANOVA for repeated measures revealed significant main effects of

Figure 6 Levy exercise passive.

Figure 7 Levy exercise active without resistance.

Figure 8 Levy exercise active with resistance from plyometric ball.

Figure 9 Levy exercise active with resistance from plyometric ball and inclination of trunk.

exercise. Subsequently, post hoc analysis using a Bonferroni procedure was performed. To avoid redundancy of data, only the pair-wise comparisons between 2 consecutive progressions were of interest. For the AD, the primary muscle of interest in view of clinical applicability, all progressions revealed a significant increase in muscle activity ($P < .05$) except the progressions from exercise 1 to exercise 2, and from exercise 6 to exercise 7. Post hoc tests for the 7 remaining muscles showed that the progression from exercise 5 to exercise 6 (from inclined bench to wall slide) resulted in significantly increased SA activity, the progression from exercise 6 to exercise 7 (wall slide with ball or towel) increased activity in the UT and MT, and the progression from exercise 7 to exercise 8 (from wall slide to resisted wall slide) resulted in significantly increased activity in the UT, MT, LT, and SA ($P < .05$).

In a second stage, to examine the age-related changes in muscle activity during the exercises, statistical analysis was performed on the 3 different age groups for each muscle during all exercises. A detailed overview with descriptive data is presented in Table V. For the AD ($P = .006$), MT ($P = .009$), LT ($P < .001$), SA ($P < .001$), and IS ($P = .01$), a significant interaction effect of Exercise × Age was found. Subsequently, post hoc tests were performed. In view of this secondary research question, only age differences were explored. For the UT, MD, and PD, no significant interaction effect or main effect of age was found. Therefore, no post hoc tests were performed. All results are summarized in Table VI.

Levy exercise set

First, the total data set (N = 55) was considered for analysis of the Levy exercise set. Descriptive analysis of normalized EMG activity in the 5 muscles of interest during the 4 variations of the Levy exercises is displayed in Table VII. For all muscles involved, ANOVA for repeated measures revealed significant main effects of exercise. Subsequently, post hoc analysis using a Bonferroni procedure was performed. For the primary muscle of interest, the AD, post hoc analysis revealed significant differences ($P < .05$)

Table III Description of MVIC procedures for 8 muscles of interest

Muscle	Description
AD	With the subject in the seated position, both feet supported, the elbow in 90° of flexion, and the shoulder in a neutral position, resistance is applied proximal to the elbow in the backward direction (to resist forward flexion).
MD	With the subject in the seated position, both feet supported, the elbow in 90° of flexion, and the shoulder in 70° of abduction, resistance is applied proximal to the elbow in the medial-downward direction (to resist further abduction).
PD	With the subject in the seated position, both feet supported, the elbow in 90° of flexion, and the shoulder in the neutral position, resistance is applied proximal to the elbow in the forward direction (to resist extension).
IS	With the subject in the seated position, both feet supported, the elbow in 90° of flexion, and the shoulder in the neutral position, resistance is applied proximal to the wrist in the medial direction (to resist external rotation).
SA	With the subject in the seated position, both feet supported, the elbow extended, and the shoulder in 135° of forward flexion, resistance is applied proximal to the elbow in the forward-downward direction (to resist further forward flexion).
UT	With the subject in the seated position, both feet supported, the elbow extended, and the shoulder in 90° of abduction, resistance is applied proximal to the elbow in the downward direction (to resist further abduction).
MT	With the subject in the prone position, the elbow extended, and the shoulder in 90° of abduction and external rotation (thumb up), resistance is applied proximal to the elbow in the downward direction (to resist horizontal abduction).
LT	With the subject in the prone position, the elbow extended, and the shoulder in 145° of abduction in the frontal plane and external rotation (thumb up), resistance is applied proximal to the elbow in the downward direction (to resist further elevation).

MVIC, maximal voluntary isometric contraction; *AD*, anterior deltoid; *MD*, middle deltoid; *PD*, posterior deltoid; *IS*, infraspinatus; *SA*, serratus anterior; *UT*, upper trapezius; *MT*, middle trapezius; *LT*, lower trapezius.
The highest value for each muscle across the standard set was used for further analysis.

Table IV Mean EMG activity for 8 muscles during bench and wall slides (exercises 1-8) and open chain elevation (exercise 9)

Exercise	% of MVIC															
	AD		MD		PD		IS		UT		MT		LT		SA	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	7.66	7.10	2.86	7.79	1.62	3.01	3.80	2.95	11.04	11.79	8.70	11.32	4.79	3.05	2.02	2.44
2	6.08	3.88	4.84	3.93	3.59	4.56	4.55	3.52	13.64	15.49	13.44	12.53	6.58	5.82	1.93	3.21
3	11.00	8.02	11.90	12.29	4.61	4.01	6.96	6.49	14.87	16.16	19.00	22.34	6.85	4.57	5.31	3.45
4	14.64	8.66	11.64	9.92	4.75	4.87	9.28	8.08	15.94	17.65	17.93	18.44	7.20	4.39	7.22	4.45
5	18.29	8.10	13.43	11.11	3.37	3.26	8.26	6.01	24.39	21.14	22.03	27.80	7.56	4.62	7.74	4.07
6	28.49	9.71	15.02	13.25	3.92	4.37	12.06	7.33	26.81	21.11	18.61	17.04	8.36	4.39	12.77	8.30
7	28.65	9.53	16.88	13.86	3.13	1.32	10.80	5.63	33.70	26.10	24.36	23.52	10.18	4.89	9.52	5.56
8	39.63	10.10	22.95	17.38	4.34	1.82	15.86	7.75	43.63	28.77	31.36	25.35	17.20	7.96	13.93	7.92
9	27.32	8.21	17.96	13.33	3.88	1.70	13.65	6.63	36.97	25.03	31.02	26.63	18.29	9.42	9.84	6.14

EMG, electromyographic; *MVIC*, maximal voluntary isometric contraction; *AD*, anterior deltoid; *MD*, middle deltoid; *PD*, posterior deltoid; *IS*, infraspinatus; *UT*, upper trapezius; *MT*, middle trapezius; *LT*, lower trapezius; *SA*, serratus anterior; *SD*, standard deviation.
Activity levels are visually categorized into <10% of MVIC (*white*), 10%-20% of MVIC (*grey*), and >20% of MVIC (*dark*).

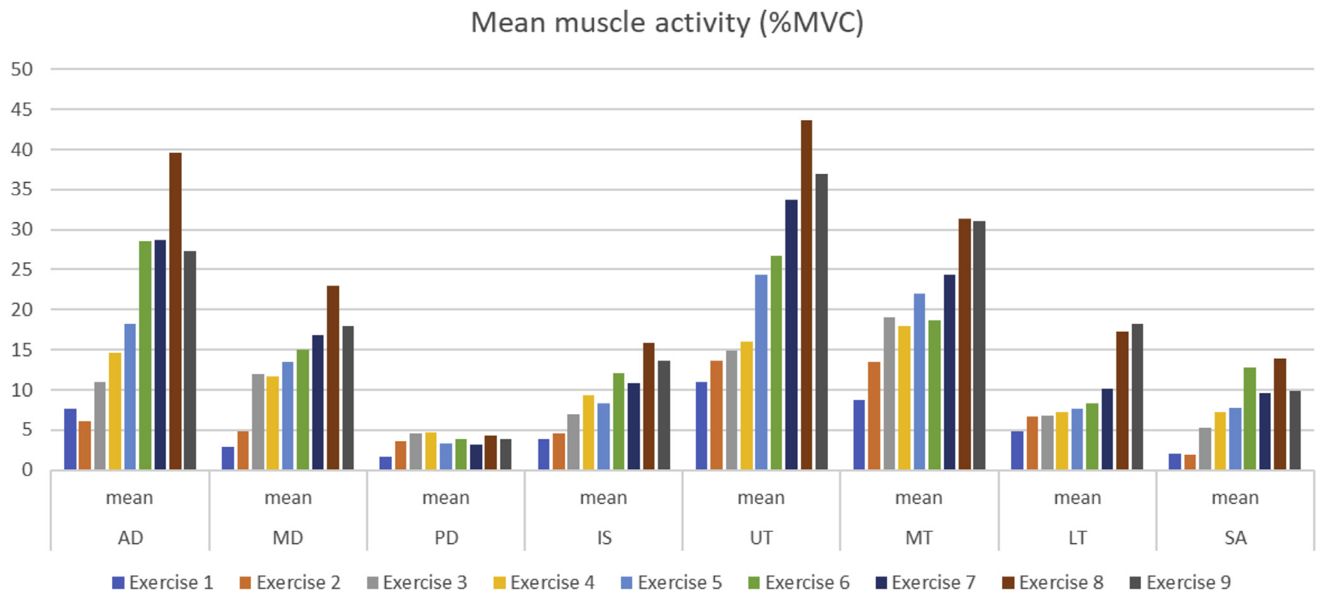

Figure 10 Visual overview of muscle activity levels (mean percentage of maximal voluntary contraction *[MVC]*) for 8 muscles during 8 exercises (exercises 1-8) and a reference open chain exercise (exercise 9). *AD*, anterior deltoid; *MD*, middle deltoid; *PD*, posterior deltoid; *IS*, infraspinatus; *UT*, upper trapezius; *MT*, middle trapezius; *LT*, lower trapezius; *SA*, serratus anterior.

among all 4 exercises, indicating an increase in AD activity from exercise 10 to exercise 13. Analysis of the post hoc tests for the remaining 4 muscles showed that only the progression from exercise 12 to exercise 13 resulted in a significant ($P < .05$) increase in muscle activity in all muscles examined.

The analysis of age-related changes in EMG activity during the Levy exercises revealed no significant interaction effect of Exercise × Age or significant main effect of age. Therefore, they were not further explored.

Discussion

The purpose of this study was to analyze the EMG activity in the scapulothoracic and glenohumeral muscles during commonly used exercises in a healthy population as a reference base for the use in patients with RC tears. To our knowledge, this is the first study that included deltoid, IS, and scapular muscle activity during these sets of exercises. A second goal was to evaluate age-related differences in EMG activity during these exercises.

Table V Mean EMG activity during bench and wall slides according to age category

Exercise	% of MVIC					
	Group 1 (18-32 yr)		Group 2 (33-46 yr)		Group 3 (47-60 yr)	
	Mean	SD	Mean	SD	Mean	SD
AD						
1	5.82	3.85	6.32	2.74	10.00	9.84
2	4.89	3.91	6.45	2.33	7.05	4.20
3	7.45	5.67	9.61	4.37	14.99	9.45
4	10.39	5.80	13.33	5.31	19.26	9.96
5	14.30	6.05	16.66	4.43	22.82	8.92
6	28.48	9.08	27.76	7.83	28.83	11.29
7	27.57	8.39	26.68	8.52	30.53	10.92
8	40.16	10.12	35.94	10.01	40.73	10.18
9	26.66	8.26	25.81	8.24	28.60	8.32
MD						
1	1.61	1.84	1.90	1.83	4.48	11.82
2	4.79	5.02	4.45	3.45	5.05	2.97
3	10.03	15.03	9.34	4.82	14.81	11.40
4	8.96	11.44	11.09	7.08	14.44	8.98
5	9.85	9.25	10.45	5.24	18.15	13.03
6	15.27	16.33	10.61	3.32	16.70	12.65
7	15.53	15.74	13.21	4.00	19.77	14.54
8	21.59	20.34	18.55	8.22	26.17	17.26
9	16.18	14.23	14.93	5.44	20.98	14.61
PD						
1	1.20	0.59	1.32	0.46	2.16	4.61
2	3.30	2.03	2.66	1.18	4.27	6.75
3	4.70	3.53	3.27	1.00	5.12	5.11
4	4.61	3.93	3.57	1.15	5.39	6.48
5	2.74	1.43	2.52	1.00	4.34	4.70
6	3.38	1.66	2.84	1.22	4.90	6.46
7	3.03	1.27	2.89	1.41	3.34	1.35
8	4.33	2.13	3.94	1.94	4.51	1.48
9	3.81	1.84	3.47	1.71	4.12	1.60
UT						
1	8.25	5.79	9.01	5.82	14.59	16.50
2	9.58	5.43	10.28	9.62	18.99	21.72
3	9.66	6.16	9.68	5.06	22.10	22.37
4	9.23	5.26	13.28	4.53	23.51	24.93
5	16.02	9.02	21.68	14.48	33.57	27.79
6	23.11	13.11	24.86	16.38	31.20	28.02
7	25.87	14.71	32.28	21.23	41.80	33.91
8	34.70	18.88	42.74	27.49	52.55	34.91
9	29.55	15.86	37.30	28.55	43.93	29.30
MT						
1	5.49	3.22	7.81	9.07	12.15	15.75
2	10.24	7.10	10.89	8.02	17.61	16.72
3	10.98	6.17	13.38	8.76	29.13	31.16
4	11.72	8.12	14.86	9.79	25.22	25.17
5	11.83	8.03	14.24	6.19	35.18	38.82
6	13.88	7.56	13.19	6.68	25.50	23.55
7	16.69	9.40	19.58	8.48	33.76	32.90
8	22.70	16.18	26.21	12.42	41.88	32.58
9	23.27	12.43	25.81	14.36	40.70	36.58
LT						
1	5.67	3.58	4.18	2.55	4.22	2.57
2	8.05	6.74	4.90	3.24	5.91	5.62

(*continued on next page*)

Table V Mean EMG activity during bench and wall slides according to age category (*continued*)

Exercise	% of MVIC					
	Group 1 (18-32 yr)		Group 2 (33-46 yr)		Group 3 (47-60 yr)	
	Mean	SD	Mean	SD	Mean	SD
3	8.47	5.28	5.13	1.66	6.05	4.35
4	7.74	4.91	6.35	4.09	7.04	4.10
5	8.45	6.21	6.30	2.42	7.27	3.41
6	10.20	4.98	5.71	1.99	7.75	3.86
7	12.03	5.46	10.10	4.22	8.44	4.03
8	20.98	8.94	15.53	6.42	14.31	6.17
9	24.37	9.92	17.56	6.66	12.79	6.07
IS						
1	2.937	1.4881	3.541	2.3081	4.734	3.9194
2	3.554	1.7779	3.381	1.5994	6.021	4.7448
3	4.669	2.375	5.396	2.548	9.835	8.9707
4	6.581	3.9393	7.428	3.6585	12.67	10.915
5	5.585	2.6298	7.588	3.8011	11.1	7.7673
6	9.412	4.3117	10.87	3.7106	15.12	9.5422
7	8.067	3.4308	10.65	4.5089	13.49	6.5689
8	12.44	5.3681	15.37	5.9876	19.34	8.9892
9	10.637	4.1546	13.32	5.1614	16.67	7.8623
SA						
1	2.20	2.19	1.93	1.79	1.90	2.94
2	1.90	1.17	1.30	0.75	2.22	4.84
3	5.60	3.91	5.06	3.16	5.13	3.22
4	7.40	4.54	5.90	2.64	7.61	5.02
5	8.45	5.01	6.79	3.50	7.48	3.27
6	15.18	9.76	10.64	3.99	11.39	7.86
7	11.28	6.65	8.56	3.70	8.26	4.79
8	17.09	9.26	12.26	4.81	11.64	6.78
9	11.98	7.56	8.25	3.69	8.49	4.96

EMG, electromyographic; *MVIC*, maximal voluntary isometric contraction; *SD*, standard deviation; *AD*, anterior deltoid; *MD*, middle deltoid; *PD*, posterior deltoid; *UT*, upper trapezius; *MT*, middle trapezius; *LT*, lower trapezius; *IS*, infraspinatus; *SA*, serratus anterior.
Activity levels are visually categorized into <10% of MVIC (*white*), 10%-20% of MVIC (*grey*), and >20% of MVIC (*dark*).

Bench and wall slides

Our results show that in a progressive exercise program from bench to wall slides, there was a consistent increase in EMG activity in all muscles involved, except the PD, though not always significant. For the primary muscle of interest, the AD, the muscle activity ranged from 6.08% of MVIC (exercise 2) to 39.63% of MVIC (exercise 8). These study results confirm that the AD muscle may be progressively activated through this set of exercises. In particular, the AD is significantly more activated when performing elevation in a closed chain against resistance (exercise 8) compared with open chain elevation (exercise 9). We may suggest that although the movement as such is similar, performing the exercise in a closed chain against resistance may benefit AD activity over an open chain performance.

In the meantime, muscle activity in the IS—the representative of RC activity in this study—never exceeded 15.86% of MVIC, indicating this muscle is only activated at a low level.[4,7] In general, muscle activity <20% of MVIC is considered low; 20%-50% of MVIC, moderate; and >50% of MVIC, high.[7] These low activity levels for the IS confirm the commonly followed expert opinion guideline to use low-load closed chain elevation exercises (closed chain without body weight on the shoulder) to train the shoulder into elevation with minimal RC load.[10]

With respect to the scapular muscles, significant increases in muscle activity were found by dividing the results into the 3 age categories. The main results of the comparisons are increased activity in the AD, IS, and MT in group 3 compared with group 1 and decreased activity in the LT in groups 2 and 3 compared with group 1. We have no research data with which to compare our results because age-related changes in EMG activity during these exercises have not yet been a topic of investigation. Using more muscle activity for the same task (as for the AD, IS, and

Table VI Post hoc analysis of age-related differences in EMG activity for 8 muscles across 9 exercises

Muscle	Interaction effect	Main effect of age	Main effect of exercise	Post hoc analysis for age differences (*P* value)
AD	.006	—	—	Exercise 3: group 3 > group 1 (.003) Exercise 4: group 3 > group 1 (.001) Exercise 5: group 3 > group 1 (.001)
MD	NS	NS	<.001	
PD	NS	NS	<.001	
IS	.01	—	—	Exercise 3: group 3 > group 1 (.020) Exercise 4: group 3 > group 1 (.031) Exercise 5: group 3 > group 1 (.005) Exercise 6: group 3 > group 1 (.025) Exercise 7: group 3 > group 1 (.003) Exercise 8: group 3 > group 1 (.007) Exercise 9: group 3 > group 1 (.005)
UT	NS	NS	<.001	
MT	.009	—	—	Exercise 3: group 3 > group 1 (.016) Exercise 4: group 3 > group 1 (.040) Exercise 5: group 3 > group 1 (.012) Exercise 7: group 3 > group 1 (.042) Exercise 8: group 3 > group 1 (.031)
LT	<.001	—	—	Exercise 6: group 1 > group 2 (.019) Exercise 7: group 1 > group 3 (.039) Exercise 8: group 1 > group 3 (.012) Exercise 9: group 1 > group 3 (<.001)
SA	<.001	—	—	—

EMG, electromyographic; *AD*, anterior deltoid; *MD*, middle deltoid; *NS*, not significant; *PD*, posterior deltoid; *IS*, infraspinatus; *UT*, upper trapezius; *MT*, middle trapezius; *LT*, lower trapezius; *SA*, serratus anterior.
Only age differences are analyzed. Statistically significant differences ($P < .05$) are noted. The age categories are as follows: group 1, 18-32 years; group 2, 33-46 years; and group 3, 47-60 years.

MT) possibly reflects a decrease in available strength due to the aging process, resulting in more activity for the same effort. On the other hand, decreased activity in the LT may reflect decreased quality of the scapular force couple responsible for functional stability. An additional hypothesis suggests that thoracic spine curvature may influence the shoulder girdle through muscular attachments and alteration of the length-tension relationship of the muscles attached to the scapula. It is possible that the older group showed decreased LT activity through increased thoracic kyphosis. However, the latter was not measured in this study. Nevertheless, future studies with larger sample sizes are needed to analyze in detail possible changes in muscle recruitment in healthy individuals in different age categories.

Levy exercises

For the Levy exercises, in general, muscle activity levels were low (<20% of MVIC), except for the AD during the inclined exercise (exercise 13; 32.7% of MVIC). These low levels may be explained by the low amount of external resistance given (only gravity of the arm or a 1-kg weight with the hand above the center of movement, minimizing the resistant level arm). It seems that the best way to increase muscle activity is by increasing the elevation angle of the shoulder (through inclination of the trunk) because for all 5 muscles measured, activity significantly increased from exercise 12 to exercise 13.

Comparison with previous EMG studies

Because exercise modalities and research methods differ among studies, it is difficult to compare our results with previous studies. Edwards et al[10] provided a list of exercises with increasing activity in the RC muscles in their systematic review. The exercises, similar to the bench and wall slides and Levy exercises in our study, also elicited low (<15% of MVIC) activity in the IS according to this review. However, deltoid activity during these exercises was not taken into account in this systematic review. With respect to the scapular muscles, Castelein et al[5] examined the wall slide as an exercise for measuring scapular muscle activity in healthy subjects and compared muscle activity with open chain elevation. Activity levels varied between 7.3% and 26.8% for the 4 muscles involved. Our results are in the same line, with a range from 9.5% to 33.7% for a similar exercise (exercise 7), except for the SA. Differences in the study populations between the 2 studies may possibly account for the differences in SA activity.

Table VII Mean EMG activity for 5 muscles during 4 variations of Levy exercises (exercises 10-13)

Exercise	% of MVIC									
	AD		MD		PD		UT		SA	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
10	8.18	4.67	2.43	1.72	1.4	1.37	1.54	0.93	2.54	1.5
11	10.35	4.48	2.96	1.97	1.21	0.56	1.42	0.86	3.13	2.2
12	12.09	4.28	4.06	2.76	1.9	1.1	2.14	2.66	4.08	2.55
13	32.7	10.35	17.39	15.14	3.47	1.62	15.94	11.31	8.7	5.3

EMG, electromyographic; *MVIC*, maximal voluntary isometric contraction; *AD*, anterior deltoid; *MD*, middle deltoid; *PD*, posterior deltoid; *UT*, upper trapezius; *SA*, serratus anterior; *SD*, standard deviation.
Activity levels are visually categorized into <10% of MVIC (*white*), 10%-20% of MVIC (*grey*), and >20% of MVIC (*dark*).

Strength and limitations

The major strength of this study is providing the clinician a progression of exercises with increasing AD and scapular muscle activity while the IS activity, as a representative of the RC, remains low. Moreover, age-related changes in muscle activity patterns were examined. These findings may be applied to exercise programs for an aging population with symptomatic degenerative RC tears. This study aims to assist clinicians in their clinical reasoning and exercise prescription decisions. However, as in every study, some limitations should be noted. First, the study was performed in healthy subjects in a wide age range, not totally reflecting the typical age category of patients with degenerative RC tears. It is unclear whether different muscle activity patterns would be apparent in the presence of an RC tear. It is known that patients with RC tears have different muscle recruitment mainly of the deltoid compared with healthy controls during elevation movements.[2,11] Future studies should examine muscle activity patterns during shoulder rehabilitation exercises in this specific population. Second, although the purpose was to recruit healthy individuals, RC tears could have been present in our population, in particular in the oldest age category. For the purpose of this study, we did not request documented imaging as an inclusion criteria for reasons of patient comfort and avoiding unnecessary imaging or radiation. However, patients in our oldest category might have asymptomatic RC tears. The small sample size in the middle age category should also be considered a limitation. The study was possibly underpowered for the subgroup analysis, and generalization of the results should be performed with caution. Moreover, possible differences in body mass index between the subgroups and sex-dependent differences in maximal voluntary contraction might have influenced our results. Third, we measured IS activity using surface electrodes, mainly for practical reasons to avoid the need for fine-wire EMG in view of the large sample. The use of surface EMG to measure IS activity is under debate,[3,23] and possible cross talk with other muscles might have influenced our results. However, given the low activity measured, it seems that the results are not influenced by other muscles that were highly activated.

Clinical implications and future directions

This study was designed from a clinical perspective, to assist the clinician in exercise choices, in particular seeking exercises with favorable activity in the AD and scapular muscles while limiting activity in the RC. These exercises may be beneficial for patients with symptomatic RC disorders. The clinician may apply these exercise progressions during nonoperative treatment, as well as during postoperative exercise treatment, related to RC disorders. Future studies are needed to examine muscle activity patterns during these exercises in patients with RC disorders, as well as to determine whether this proposed exercise program is efficient in the treatment of RC tears.

Conclusion

The aim of this study was to identify muscle recruitment levels in the deltoid, IS, and scapulothoracic muscles, measured by EMG, in a series of shoulder rehabilitation exercises. The results showed a progressive increase in AD activity in the proposed exercises with low activity in the IS and age-related changes in muscle activity in selected glenohumeral and scapulothoracic muscles during the exercise program. Increased activity in the targeted muscles may be achieved mainly by adding resistance to a wall slide and increasing inclination during the Levy exercises. The results allow the clinician to prescribe a progressive exercise program for patients with symptomatic degenerative RC tears with controlled load on the targeted muscles.

Disclaimer

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