Original Research

Electromyographic Analysis of the Shoulder Girdle Musculature During External Rotation Exercises

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Background: Implementation of overhead activity, a key component of many professional sports, requires an effective and balanced activation of the shoulder girdle muscles, particularly during forceful external rotation (ER) motions.

Purpose: To identify activation strategies of 16 shoulder girdle muscles/muscle segments during common shoulder ER exercises.

Study Design: Descriptive laboratory study.

Method: Thirty healthy subjects were included in this study, and 16 shoulder girdle muscles/muscle segments were investigated (surface electrode: anterior, middle, and posterior deltoid; upper, middle, and lower trapezius; serratus anterior; teres major; upper and lower latissimus dorsi; and upper and lower pectoralis major; fine wire electrodes: supraspinatus, infraspinatus, subscapularis, and rhomboid major) using a telemetric electromyography (EMG) system. Five ER exercises (standing ER at 0° and 90° of abduction, with underarm towel roll, prone ER at 90° of abduction, side-lying ER with underarm towel) were studied. Exercise EMG amplitudes were normalized to EMG at maximum ER force in a standard position. Univariate analysis of variance and post hoc analysis applied on EMG activity of each muscle were used to assess the main effect of the exercise condition.

Results: Muscular activity differed significantly among the ER exercises ($P < .05$ to $P < .001$). The greatest activation for anterior and middle deltoid, supraspinatus, upper trapezius, and serratus anterior occurred during standing ER at 90° of abduction; for posterior deltoid, middle trapezius, and rhomboid during side-lying ER with underarm towel; for lower trapezius, upper and lower latissimus dorsi, subscapularis, and teres major during prone ER at 90° of abduction; and for the clavicular and sternal part of the pectoralis major during standing ER with underarm towel.

Conclusion: Key glenohumeral and scapular muscles can be optimally activated during specific ER exercises, particularly in positions that stimulate athletic overhead motions.

Clinical Relevance: These results enable sports medicine professionals to target specific muscles during shoulder rehabilitation protocols while minimizing the effect of others, providing a foundation for optimal evidence-based exercise prescription. They also provide information for tailored muscle training and injury prevention in overhead sports.

Keywords: overhead sports; electromyography; shoulder exercises; external rotation; rehabilitation

Effective overhead activity, a key element of many professional sports such as baseball, cricket, swimming, tennis, and volleyball, requires effective activation of shoulder girdle muscles during forceful rotational movements to produce a healthy balance between mobility and functional stability of the shoulder.[3,8,11,16,45,47] Several shoulder pathologies such as rotator cuff tears, subacromial impingement syndrome, internal impingement, joint laxity, labral lesions, and scapular dyskinesis are common in overhead athletes, arguing the need to develop effective training, injury prevention, and rehabilitation strategies.[8,9,16,18,27,50,59]

The glenohumeral (GH) joint presents a greater range of motion than any other human body articulation. The osseous structure provides limited intrinsic stability to the shoulder joint[61] so that functional stability is mainly

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achieved through integrated contribution of the joint capsule, ligaments, and synchronized activity of the surrounding GH musculature.[8,33] The rotator cuff muscles, chiefly the supraspinatus, infraspinatus, and subscapularis, contribute substantially to normal shoulder function by compressing the humeral head into the concaved glenoid and hence maintain joint stability during arm elevation and overhead activities.[45,59,61] In overhead sports, adequate activation of the rotator cuff muscles is critical for both satisfactory force development and stabilization of GH joint during the cocking and acceleration phases.[14] Three parts of the deltoid interact with the rotator cuff in a coordinated manner to establish the muscle force couple necessary for arm elevation.[58] The pectoralis major, latissimus dorsi, and teres major generate synchronized adduction moments during arm elevation and abduction around the glenohumeral and scapulothoracic joints, and together with the subscapularis, inferiorly stabilize the shoulder.[1,31]

A balanced scapular muscle function is also integral to achieving optimal shoulder position, motion, and stability. In addition to its anatomic function within the GH and acromioclavicular joints and as a linkage between the upper extremity and the trunk, the scapula provides a stable base for the attachment of key muscles contributing to dynamic GH stability and upper extremity motion.[9,11,51] Therefore, scapular stability is crucial for the effective production of force from muscles originating from the scapula. As described by Kibler and McMullen,[27] scapular stabilizers: (1) maintain a constant center of GH rotation once the arm, scapula, trunk, and body are in motion; (2) provide scapular motion along the thoracic wall; (3) elevate the acromion to provide clearance of the rotator cuff during GH rotation, thereby avoiding impingement; and (4) link the upper extremity to the trunk in a kinetic chain and facilitate transmission of forces from the feet on the ground to the hand.

Overhead athletic motion requires a delicate balance between mobility and functional stability to allow safe transmission of powerful rotational forces. However, repetitive stress on the shoulder joint during such movements can exceed physiologic limits of the GH capsule, glenoid labrum, and rotator cuff (RC) musculature, and thus result in injury. Electromyographic (EMG) studies have described the activity of both GH and scapular muscles during common exercises to guide evidence-based and sport-specific rehabilitation programs.[7,9,14,37,39] EMG studies of the GH musculature in overhead sports have mainly focused on the detrimental effect of superior humeral head migration in relation to high deltoid activity.[46,47,56,63] Furthermore, EMG studies of both the GH and scapular stabilizers in overhead sports have predominantly analyzed activity of the muscles in association with movement phases such as cocking and follow-through phases of the pitch/serve, which require considerable external and internal rotation.[19,25,26] Collectively, EMG studies have underpinned the need for coordinated motion of the scapula and humerus for efficient arm movement and optimal joint stability. This notion has been further supported by several EMG studies showing alterations in GH and scapular kinematics after fatigue of the external rotators and scapular stabilizers, respectively.[9,53,57]

While previous studies in sports medicine and orthopaedics have reported the activity of muscles during selected activities and exercises, there is a lack of comprehensive data regarding shoulder musculature activation strategies during common external rotation exercises. This knowledge would guide the planning of effective training programs and establish sound evidence for developing optimal rehabilitation and training programs for overhead athletes with and without shoulder pathology. This study aimed to provide such a knowledge base by comprehensive measurement of the EMG activity of 16 shoulder girdle muscles/muscle segments during commonly prescribed shoulder external rotation exercises.

METHODS

Participants

A total of 30 physically active healthy volunteers (15 male, 15 female) with normal shoulder examination, no previous shoulder injury, and no pain with activities of daily living were recruited from hospital staff and students at the University of Liverpool, Liverpool, United Kingdom. All participants were involved in moderate levels of exercise/physical activity. The mean (±SD) age, height, and weight for the entire group was 33.1 ± 9.9 years, 1.71 ± 0.08 m, and 70.5 ± 12.7 kg. The study received approval from the local research ethics committee, and all patients gave written informed consent prior to their participation.

Exercises

Exercise conditions are described in Table 1. Participants were tested for 5 external rotation (ER) shoulder exercises in a random order: standing ER at 0° of abduction (ER at 0°ABD), standing ER with underarm towel roll (ER with underarm towel), standing ER at 90° of abduction (ER at 90°ABD), prone ER at 90° of abduction (prone ER at 90°ABD), and side-lying ER at 0° of abduction with underarm towel roll (side-lying ER with underarm towel). The execution of each exercise using correct upper body positioning (scapula in particular) and posture was precisely demonstrated by 1 of the investigators prior to measurement, and participants were given time to familiarize themselves with the exercise. Participants performed 12 cycles of each exercise with a weight (1 kg) in hand according to a metronome set at 60 beats per minute (each concentric and eccentric phase was performed during 1 beat). Synchronized video recording (25 frames/s, 50 fields/s) enabled accurate ER phase definition. One of the investigators closely monitored the accurate body positioning and execution of exercises. Participants were given time to rest between the exercises.

Electromyography Measurements

A TeleMyo 2400 G2 Telemetry System (Noraxon Inc) and associated software (MyoResearch XP) were used for signal acquisition, processing, and analysis. Signals were differentially amplified (CMRR, >100 dB; input impedance,

TABLE 1
Description of Shoulder ER Exercises Performed for EMG Recording[a]

Exercise	Description
ER at 0°ABD	Standing ER at 0° of ABD
ER at 90°ABD	Standing ER at 90° of ABD
ER with underarm towel at 0°ABD	Standing ER at 0° of ABD with a towel roll placed between elbow and body
Prone ER at 90°ABD	Laying on stomach with arm off the bed, elbow at 90° of flexion and shoulder at 90° of abduction; patient externally rotates the shoulder toward the ceiling
Side-lying ER with underarm towel	Side-lying with a towel placed between elbow and body, arm fully adducted to side and internally rotated, with elbow flexed at 90°; patient externally rotates the shoulder up toward the ceiling

[a]ABD, abduction; EMG, electromyography; ER, external rotation.

>100 Mohm; gain, 500 dB), digitized at a sampling rate of 3000 Hz, and band-pass filtered at 10 to 500 Hz and 10 to 1500 Hz for surface and fine-wire electrodes, respectively.[24,52] Electrocardiogram signal contamination was eliminated using an adaptive cancellation algorithm.

Disposable, self-adhesive pregelled Ag/AgCl bipolar surface electrodes with 10-mm-diameter conducting area and 20-mm interelectrode distance (Noraxon Inc) were used to record the EMG from anterior, middle, and posterior deltoid (AD, MD, PD); upper, middle, and lower trapezius (UT, MT, LT); upper and lower latissimus dorsi (ULD, LLD); upper and lower pectoralis major (UPM, LPM); serratus anterior (SA); and teres major (TM), consistent with established guidelines.[10,41] Skin was prepared by shaving and using abrasive paste (Nuprep; Weaver and Co). Crosstalk was minimized by the careful placement of suitably sized electrodes parallel to the muscle fibers based on standard anatomic criteria. Fine-wire electrodes were used to record signals from the supraspinatus (SSP), infraspinatus (ISP), subscapularis (SUBS), and rhomboid major (RHOM).[5,41] Bipolar disposable hook-wire electrodes (Nicolet Biomedical, Division of VIASYS) were inserted using a hygienic technique according to Basmajian and De Luca.[5]

Raw EMG signals from 10 ER exercise cycles (the first and last ER exercise cycles were omitted) were full-wave rectified and smoothened (100 ms root mean square [RMS]). For normalization purposes, the EMG was recorded during a standardized production of a maximum ER force (maximum voluntary isometric contraction [MVC]) using a shoulder Nottingham Mecmesin Myometer with an accuracy of ±0.1% of full-scale and a 1000-N capacity (Mecmesin Ltd) while seated, shoulder in a neutral position, elbow in 90° of flexion tucked to the side of the body, and forearm in neutral position (EMG_{max}). EMG data were collected for 5 seconds during 3 trials, and the mean was taken as EMG_{max}, which was used as a reference value for the normalization of EMG amplitudes during ER exercises.

Data Analysis

Descriptive statistics are reported and displayed for each individual muscle as mean ± standard deviation (SD) or standard error of the mean (SEM), as appropriate. The mean average muscle action amplitude (the mean of the average EMG activity during the entire ER range of motion for each exercise) was normalized to the ER MVC ($\%EMG_{max}$), averaged, and used for analysis. A univariate analysis of variance was performed to determine whether ER exercise conditions had a statistically significant effect on mean EMG activity of each muscle tested (within-exercise differences) ($\alpha = .05$). A post hoc analysis for multiple pairwise comparisons (Bonferroni) was then applied to make specific comparisons among the 5 ER exercises and determine individual effect differences. The level of statistical significance was set at $P < .05$ unless otherwise noted. The Statistical Package for Social Sciences (SPSS) release 20.0 for Windows (IBM Corp) was used for data analysis.

RESULTS

Table 2 and Figure 1 summarize and compare the mean activation of muscles during ER exercises.

Deltoids

Exercise condition had a significant main effect on the activity of AD ($F_{4,\ 136} = 22.89$, $P < .001$), MD ($F_{4,\ 142} = 19.95$, $P < .001$), and PD ($F_{4,\ 142} = 14.12$, $P < .001$). AD and MD activations were significantly higher during ER at 90°ABD compared with other ER exercises ($P < .001$). PD activity during prone ER at 90°ABD, side-lying ER, and ER at 90°ABD was significantly higher than ER at 0°ABD and ER with underarm towel ($P < .001$).

Rotator Cuff

A statistically significant main effect of exercise condition was found for the activity of SSP ($F_{4,\ 125} = 4.13$, $P = .004$) and SUBS ($F_{4,\ 118} = 6$, $P = .0002$), but not for ISP ($F_{4,\ 50} = 0.6$, $P = .7$). SSP activity was significantly higher in ER at 90°ABD compared with all other ER exercises except side-lying ER ($P = .01$-.02). SUBS activation was significantly higher during prone ER at 90°ABD compared with ER at 0°ABD and ER with underarm towel ($P = .001$-0.007). ISP showed a greater tendency toward higher activation, albeit not significantly, during prone ER at 90°ABD.

Pectoralis Major

Exercise condition had a significant main effect on the activity of both UPM ($F_{4,\ 131} = 14.84$, $P < .001$) and LPM ($F_{4,\ 130} = 6.26$, $P = .0001$). Both UPM and LPM had significantly higher activation during ER with underarm towel compared with other ER exercises ($P = .007$-.0003). The activity of UPM was also higher during ER at 0°ABD compared with ER at 90°ABD and prone ER ($P < .05$).

TABLE 2
Normalized Mean Muscle Activation (% EMG_{max} ± SEM) during ER Exercises[a]

	ER at 0°ABD		ER at 90°ABD		ER With Underarm Towel		Prone ER at 90°ABD		Side-Lying ER With Underarm Towel	
Muscle	Mean %	SEM	Mean %	SEM	Mean %	SEM	Mean %	SEM	Mean %	SEM
AD	30.4	5	126.2	20.5	20.7	3.7	16.9	2.8	21.4	3.2
MD	10.7	2.2	68.2	10.5	9.7	1.5	22.8	3.2	28.8	4.2
PD	6.4	1.4	26.8	4.3	7.1	1.0	29	3.9	29.4	3.9
UT	32	6.7	72	9.8	42.8	7.6	29.6	4.7	20.4	3.4
MT	26.8	3.4	44	4.8	27.9	2.4	59.5	13.6	67.9	11.2
LT	23	3.1	51.9	4.6	25.6	2.7	85.1	10.5	61.6	6.2
SA	37.1	5.1	160.1	21.1	40.4	5.7	127	28	40.4	4.2
TM	18.2	1.8	36.7	3.2	26.5	2.7	68.4	7	50.5	4.8
ULD	20.1	2.9	53	7.2	22.3	3.8	63.8	8.6	51.5	7.2
LLD	15.8	2.6	34.8	5.2	16	3	51.8	8.7	45.9	7.8
UPM	70.2	9.2	31.2	3.5	108.8	15.1	32	2.2	41.2	3.7
LPM	62	10.2	39.9	3.8	96.8	15.6	37	2.7	47.7	9.1
SSP	32.6	3.7	59.9	6.9	30.7	3.9	30.5	6.6	40.5	8.2
ISP	28.2	3.2	30.7	3.2	32.9	4.8	38	6.2	29.9	6.4
SUBS	32.4	3.3	75.2	12.4	45	7	104.2	19.4	85.6	14.3
RHOM	32.7	4.8	59.2	6.3	35.4	4.8	61.9	15.3	81.5	19.3

[a]ABD, abduction; AD, anterior deltoid; EMG_{max}, electromyography amplitude at maximum external rotation force in a standard position; ER, external rotation; ISP, infraspinatus; LLD, lower latissimus dorsi; LPM, lower pectoralis major; LT, lower trapezius; MD, middle deltoid; MT, middle trapezius; PD, posterior deltoid; RHOM, rhomboid major; SA, serratus anterior; SEM, standard error of the mean; SUBS, subscapularis; SSP, supraspinatus; TM, teres major; ULD, upper latissimus dorsi; UPM, upper pectoralis major; UT, upper trapezius.

Latissimus Dorsi

A statistically significant main effect of muscle condition on muscle activity was detected for ULD ($F_{4,\ 137} = 10.4$, $P < .001$) and LLD ($F_{4,\ 131} = 8.23$, $P < .001$). Activation of both ULD and LLD was significantly higher in prone ER at 90°ABD and side-lying ER with underarm towel compared with ER at 0°ABD and ER with underarm towel (P = .01-<.001). Activation of ULD was also higher during ER at 90°ABD compared with standing ER at 0°ABD and ER with underarm towel (P = .002-.006).

Teres Major

Exercise condition had a significant main effect on the activity of TM ($F_{4,\ 138} = 22.2$, $P < .001$). The highest TM activation occurred in prone ER at 90°ABD compared with all other exercises (P = .03 to <.001). The next highest activation was observed in side-lying ER with underarm towel, which was markedly higher than ER at 90°ABD and ER with underarm towel (P = .03 to <.001).

Serratus Anterior

Exercise condition had a significant main effect on the activity of SA ($F_{4,\ 134} = 12.7$, $P < .001$). The activation of SA in ER at 90°ABD and prone ER at 90°ABD was significantly greater than other ER exercises (P = .003 to <.001).

Trapezius

A statistically significant main effect of exercise condition was found for the activity of UT ($F_{4,\ 140} = 8.49$, $P < .001$), MT ($F_{4,\ 138} = 5.1$, $P = .001$), and LT ($F_{4,\ 142} = 18.43$, $P < .001$). UT was significantly higher during ER at 90°ABD and was significantly higher than with all other exercises (P = .03-.0003). MT had higher activity during side-lying ER with underarm towel compared with ER at 0°ABD and ER with underarm towel (P = .005-.007). LT had markedly higher activation during prone ER at 90°ABD compared with other exercises except side-lying ER with underarm towel (P = .002 to <.001). LT also had higher activation level during side-lying ER with underarm towel compared with ER at 90°ABD and ER with underarm towel.

Rhomboid Major

Exercise condition had a significant main effect on the activity of RHOM ($F_{4,\ 249} = 6.58$, $P < .001$). Its greatest activation detected during side-lying ER with underarm towel was markedly higher than ER at 0°ABD and ER with underarm towel (P = .001-.0001).

DISCUSSION

Current trends in the rehabilitation of overhead athletes emphasize the importance of tailored and individualized programs for re-establishing muscle balance and strength by selectively targeting dysfunctional and weakened GH and scapular muscles. Furthermore, there is increasing emphasis on functional rehabilitation of overhead athletes through main sport-specific exercises and in positions that mirror the capsular strain and muscular length–tension relationships during sport competition (eg, ER and internal rotation [IR] at 90°ABD).[44,59,61,62]

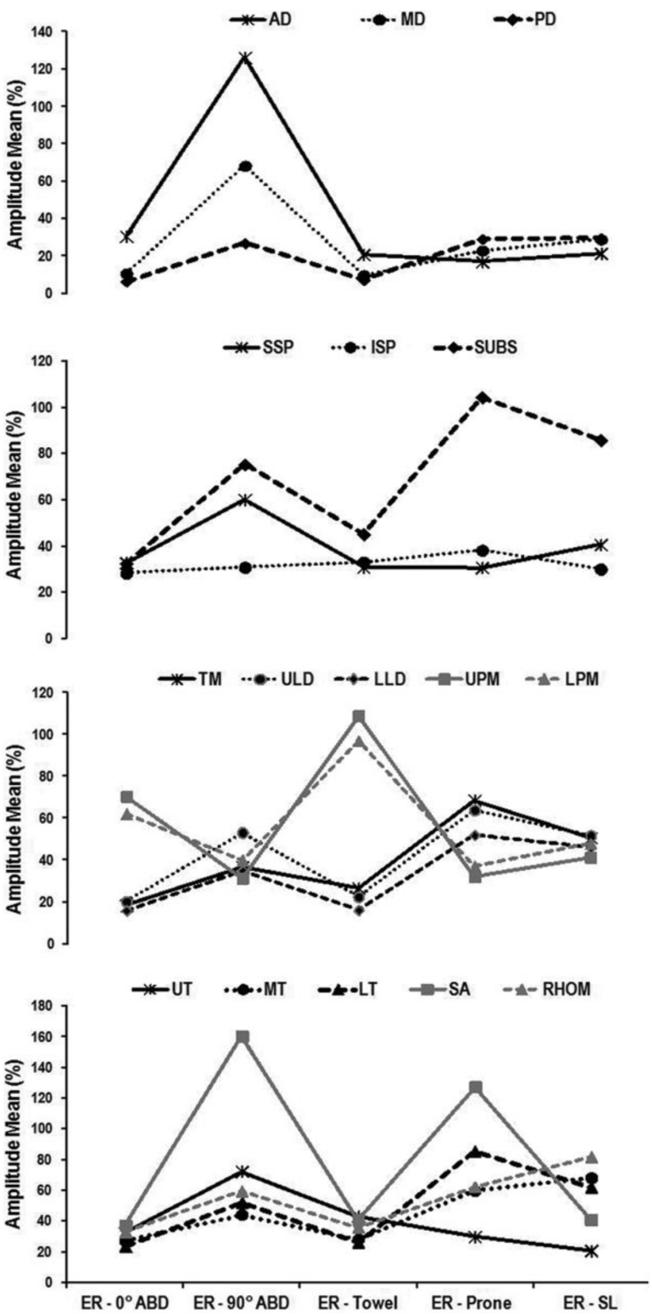

Figure 1. Mean normalized electromyographic (EMG) activation of all muscles expressed as a percentage of maximum voluntary isometric contraction (MVC) (amplitude mean %) across 5 shoulder external rotation (ER) exercises. All EMG amplitudes were normalized to the reference value determined from ER MVC in a standard position. ABD, abduction; AD, anterior deltoid; ISP, infraspinatus; LLD, lower latissimus dorsi; LPM, lower pectoralis major; LT, lower trapezius; MD, middle deltoid; MT, middle trapezius; PD, posterior deltoid; RHOM, rhomboid major; SA, serratus anterior; SL, side-lying; SUBS, subscapularis; SSP, supraspinatus; TM, teres major; ULD, upper latissimus dorsi; UPM, upper pectoralis major; UT, upper trapezius.

In view of the important role of balanced external-internal rotation strength for effective shoulder function during overhead sporting activities, several EMG studies have reported the activation strategies of GH and scapular musculature during shoulder rotational exercises, yet with inconsistent results and recommendations regarding optimal exercises.[‖] ER exercises have received the most research attention, as inadequate ER strength appears to be an important underlying factor in the development of shoulder pathologies in overhead sports.[15,49,60]

In the present study, the activity of RC muscle SSP was highly activated during ER at 90°ABD. This is in line with the finding of a functional RC EMG study that reported a larger average SSP activity during dynamic ER at 90°ABD to stabilize the shoulder joint and maintain arm position with a weight.[55] This increased activity can be attributed to the simultaneous contribution of SSP to both abduction and ER in this position.[12] Previous EMG studies have also reported substantial SSP activation during concentric ER exercises.[30,31,38,47]

Sufficient activation of ISP is fundamental during overhead throwing for the development of force at the shoulder to prevent joint distraction. In the current study, a tendency for greater ISP activation was observed in prone ER at 90°ABD followed by side-lying ER. In a comparative study of 3 ER exercises, Ballantyne et al[4] reported both prone ER at 90°ABD and side-lying ER to be equally effective in eliciting ISP activity. Comparing the same exercises, Blackburn et al[6] found greater ISP activity during prone ER at 90°ABD. In another study, Reinold et al[46] reported greater ISP activation in side-lying ER with underarm towel, yet it was not different from that of prone ER at 90°ABD. These findings, combined with that of Townsend et al,[56] who found the greatest ISP activity during horizontal abduction in ER, suggest that better ISP activation may be achieved during prone ER exercises in abducted shoulder positions (90°-100°).

SUBS had its greatest activation during prone ER at 90°ABD. Despite observations of its multifunctionality during different phases of overhead sports,[13,16,34,44,56] EMG investigations have mainly focused on SUBS activation in relation to IR exercises due to its primary function as the internal rotator of the humerus. Accordingly, knowledge on its contribution to shoulder ER exercises is limited and contradictory.[13,31,56] In an EMG study of shoulder rotational exercises at various intensities with the arm by the side, Dark et al[12] reported minimal SUBS activation during ER exercises. A relatively high activation of SUBS found in the present study during ER exercises performed in an abducted position (90°ABD) may be attributed to the abductor moment arm of the SUBS[48] and its other functions such as GH stabilization during sport-specific overhead activities.[13,40,56]

In the present study, the activation of both AD and MD were significantly higher in standing ER at 90°ABD compared with other ER exercises, consistent with their role as effective abductors at greater abduction angles. Greater

‖ References 4, 6, 12, 13, 37-39, 46, 51, 56.

activation of PD during prone ER at 90°ABD is in agreement with that of Reinold et al,[47] who reported significantly greater activity of PD during prone ER at 90°ABD and ER at 90°ABD compared with ER with underarm towel. They did not study AD activity.

Several EMG studies have attempted to identify the exercises that produce the greatest RC activity with the lowest deltoid involvement to avoid the detrimental effect of superior humeral head migration caused by strong AD and MD activity.[45,47,54,63] While the resultant force vector of the deltoids and RC muscles during ER at 90°ABD has been shown to provide an assistive compressive force rather than superior humeral head migration in healthy athletes,[42] this exercise may be disadvantageous to athletes with shoulder pathology, particularly if the RC is affected (eg, impingement syndrome). Hence, our results suggest avoiding ER at 90°ABD in athletes with RC pathology due to markedly higher activation of both AD and MD. In view of the moderate activity of RC muscles with lower deltoid involvement (MD in particular) observed for side-lying ER with underarm towel and standing ER with underarm towel, these rehabilitation exercises may be more beneficial for athletes with RC pathology. It has been suggested that using an underarm towel roll when performing standing or side-lying ER exercises reduces the compensatory shoulder abduction forces (adduction strategy) leading to greater isolation of the external RC (ISP in particular) from the larger shoulder muscles such as MD.[18,29,45]

PM, LD, and TM muscles have mainly been examined during IR exercises, and little is known about their activity during ER exercises. We recorded segmental EMG from the upper and lower fibers of the PM (UPM and LPM) and LD (ULD and LLD), as these have been shown to contribute differently to shoulder movements. UPM acts as a humeral adductor in the early phases of abduction but becomes an effective abductor from 40° of abduction. LPM has one of the largest adductor moment arms. Collectively, PM is an effective humeral internal rotator and adductor at lower abduction angles.[1,32] In the present study, both UPM and LPM elicited greater activity during ER with underarm towel compared with other ER exercises. UPM also had greater activity in ER at 0°ABD compared with ER at 90°ABD and prone ER at 90°ABD. This greater activation of the PM segments during lower abduction may be attributed to their balancing co-contraction opposed to a loaded ER. On the contrary, Dark et al[12] reported that averaged PM activity during ER at 0°ABD did not exceed 6% of the MVC.

LD subregions have several actions, including adduction, extension, and internal rotation of the humerus as well as depression and adduction of the scapula.[1,22,32] The activation of both ULD and LLD was greatest during prone ER at 90°ABD, with ULD also having high activity during standing ER at 90°ABD. Myers et al[40] studied LD activation during several resistance exercises and found moderate activity of LD during ER at 90°ABD but not during ER at 0°ABD. Dark et al[12] found the averaged LD activity to be less than 6% of the MVC during ER at 0°ABD. These findings suggest that greater activation of the LD may be achieved in ER exercises in abducted positions. Peak moment arms of the LD subregions have been shown to be close to the midrange of abduction, likely because of superior movement of the lines of action of the LD with respect to the scapula during abduction.[1]

Similar to that of LD, the greatest TM activation occurred in prone ER at 90°ABD. EMG studies of TM during ER shoulder exercises are very limited, possibly because of its obvious primary functions as humeral adductor, extensor, and internal rotator.[1,22,32] In addition to its normal contribution to overhead sports,[16] TM activation may have clinical relevance: Increased TM activity during arm elevation and reaching tasks in patients with RC deficiency has been hypothesized to limit humeral head translation by exerting an inferiorly directed force to balance a superiorly directed deltoid force.[23]

Scapular Muscles

Efficient scapular muscle activity is critical for optimal performance in throwing and other overhead sporting activities such as the volleyball serve and spike, tennis serve and volley, and baseball pitching.[16,25] Among scapular muscles that primarily control coordinated scapular motion during arm movements (scapulohumeral rhythm), we examined 3 parts of the trapezius (UT, MT, and LT), the SA, and the RHOM major. While no significant difference was found in the activation of trapezius segments across ER exercises, UT, MT, and LT showed greater activation in standing ER at 90°ABD, side-lying ER with underarm towel, and prone ER at 90°ABD, respectively. It is clinically advantageous to improve the LT/UT and MT/UT activity ratios as several shoulder pathologies such as impingement syndrome have been associated with poor posture and muscle imbalance caused by more dominant UT.[9] The results of the present study suggest side-lying ER with underarm towel and prone ER at 90°ABD as the more beneficial exercises to enhance the LT/UT and MT/UT activity ratios. These recommendations, particularly prone ER at 90°ABD, are in agreement with those of Cools et al[9] and Ekstrom et al[14] but differ from that of McCabe et al,[37] who found the greatest LT/UT activity ratio during ER at 0°ABD when compared with some trapezius exercises. LT activity has been shown to have a tendency to lower activity at angles below 90°ABD, then increasing activity from 90° to 180°.[14,39,53]

SA also plays a substantial role in maintaining normal scapulohumeral rhythm by contributing to all components of scapular 3-dimensional motion (upward rotation, posterior tilt, and ER) during arm elevation.[14,35] Furthermore, SA plays an important role during the acceleration phase of overhead sports by accelerating the scapula. Poor SA activation, if overpowered by UT activity, can lead to abnormal scapular motion and shoulder pathology due to excessive scapular elevation and anterior tilt.[9,11,14,28,35] According to Cools et al,[9] in the presence of scapular muscle imbalance, exercises that selectively activate the underactive muscles with minimal activation of the hyperactive muscles are key components of balance restoration. Hence, consideration must be given to scapular muscle balance by means of UT/SA activation/strength ratio. The present study found markedly greater activation of the SA in standing ER at 90°ABD and prone ER at 90°ABD compared with other ER exercises. These findings, considered along with UT activation, suggest prone ER at 90°ABD as the optimal ER exercise for activation of the SA because of minimal UT involvement (likely due to elimination of postural activation of the UT), followed by standing ER at 90°ABD. Other studies also reported relatively high SA activity during ER at 90°ABD, which also activated the RC muscles.[14,40] However, the choice of prone ER at 90°ABD to promote strength, balance, and coordination between UT and SA and the RC is supported by other findings of this study, including greater ISP activation and a greater LT/UT ratio.

RHOM functions as a scapular retractor, downward rotator, and elevator. It shows relatively high activation during the arm cocking and arm deceleration phases of throwing sports.[16] RHOM activation during ER exercises has been poorly examined, possibly because of technical difficulties in locating the muscle for in-dwelling EMG recording. The present study found a greater RHOM activity during side-lying ER with underarm towel followed by prone ER at 90°ABD. Myers et al[40] reported relatively high RHOM activity during standing ER at 0°ABD and 90°ABD but did not examine side-lying ER with underarm towel. Moseley et al[39] reported only minimal RHOM activity during ER at 0°ABD.

Any EMG study has inherent limitations. Applying established EMG guidelines together with our long-term experience of shoulder studies informed optimal electrode positioning. Considering uncertainties surrounding the reliability of manual muscle testing and related MVC for EMG amplitude normalization,[21] we normalized each muscle's EMG activity (mean RMS) during each ER exercise as a percentage of a reference value (ie, EMG_{max} during a standard ER position), allowing appropriate assessment and comparison of each muscles' contribution across the exercise. This method was appropriate for comparing activity of each individual muscle across the ER exercises (between-exercise) as the reference value is task dependent. Several studies have employed alternative normalization methods, as the use of the MVC method to study muscle activation remains questionable, particularly in relation to dynamic movements.[2,17,21,48] A similar method has been applied by previous studies (eg, maximum sprinting for normalizing the EMG during walking, maximum sprint cycling for normalizing the EMG during cycling). This normalization method avoided intrinsic limitations in reliability and validity associated with the more common reference to MVC.[10,20,36] This normalization method may have advantages for the examination of relative muscle function around the shoulder.

While measuring activation of biceps brachii would have provided valuable information in selecting ER exercises for patients with superior labral anterior posterior (SLAP) repairs/tears, it was not included in this study. We tested muscle activation during ER exercises only with a single load (1 kg) in hand to gain further insight into functional roles of the muscles contributing to GH stability. According to current studies, increasing load does not alter shoulder muscle recruitment patterns, and the functional role of muscles does not change with the greater muscle activity levels associated with increased loads.[7,12,43] While our study would have benefited from comparing muscle activations in individuals with and without shoulder pathology, the results from asymptomatic individuals have implications for the development of future studies of both asymptomatic and symptomatic subjects.

CONCLUSION

The present study reported muscle activation patterns of 16 muscles/muscle segments during common ER exercises to assist clinicians, physical therapists, and trainers with evidence-based selection of exercises. A greater activation of RC muscles (SSP and SUBS) during ER exercises at 90° of abduction (both prone and standing) supported the advantage of these exercises in healthy athletes as they biomechanically replicate the common sport-specific position in overhead sports. However, these exercises need to be avoided in athletes affected by RC pathologies such as tears and impingement syndrome due to detrimental effect of the AD and MD activity on superior humeral head migration. In the presence of these pathologies, side-lying ER with underarm towel and standing ER with underarm towel may be better as they produce moderate activation of RC muscles with a lower deltoid involvement. While integration of scapular muscles into training and rehabilitation programs is undoubtedly important, priority should be given to shoulder exercises that produce a high LT/UT/, MT/UT, and SA/UT ratio to allow a more optimal activation of the SA and LT. This will reinforce the scapular balance and prevent the development of pathological conditions such as impingement syndrome. The findings of this study support the use of prone ER at 90°ABD and side-lying ER with underarm towel as the more beneficial ER exercises for scapular balance as they are associated with enhanced activation of SA, MT, and LT but a lower UT involvement.

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