Title:

Electromyographic Analysis of Shoulder Girdle Muscles during Common Internal Rotation Exercises

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Abstract

Background: High level throwing performance requires the development of effective muscle activation within shoulder girdle muscles particularly during forceful internal rotation (IR) motions.

Study Design: Controlled Laboratory Descriptive Study

Purpose: To investigate activation pattern of 16 shoulder girdle muscles/muscle sub-regions during three common shoulder IR exercises.

Method: EMG was recorded in 30 healthy subjects from 16 shoulder girdle muscles/muscle sub-regions (surface electrode: anterior, middle and posterior deltoid, upper, middle and lower trapezius, serratus anterior, teres major, upper and lower latissimus dorsi, upper and lower pectoralis major; fine wire electrodes: supraspinatus, infraspinatus, subscapularis and rhomboid major) using a telemetric EMG system. Three IR exercises (standing IR at 0^o and 90^o of Abduction, and IR at Zero-Position) were studied. EMG amplitudes were normalized to EMG_{max} (EMG at maximal IR force in a standard position) and compared using one-way repeated-measures analysis of variance (ANOVA).

Results: There were significant differences in muscles' activation across IR exercises ($p<0.05$–$p<0.001$). Rotator cuff and deltoid muscles were highly activated during IR at 90° of Abduction. Latissimus dorsi exhibited markedly higher activation during IR at Zero-Position. While upper trapezius had the highest activation during IR at Zero-Position, middle and lower trapezius were activated at highest during IR at 90^o of Abduction. The highest activation of serratus anterior and rhomboid major occurred in IR at Zero-Position and IR at 90^o of Abduction, respectively.

Conclusions: Studied exercises have the potential to effectively activate glenohumeral and scapular muscles involved in throwing motions. Results provide further evidence for developing rehabilitation, injury prevention, and training strategies.

Key Words: Electromyography; Internal Rotation Exercises; Rehabilitation; Shoulder Muscle Activation

Level of Evidence: 4, Controlled laboratory study

INTRODUCTION

The glenohumeral joint (GHJ) is the most mobile joint in the human body due to its bony structure which requires the coordinated activation of shoulder complex musculature to achieve functional stability during movements.[1] The activation of key rotator cuff (RC) muscles is a fundamental contributor to shoulder joint stability (centring the humeral head into the glenoid) and efficient force development during arm elevation and overhead activities such as throwing.[2-4] The parts of the deltoid work along with the RC to develop force couples required for arm motion during elevation and rotation. Pectoralis major, latissimus dorsi, and teres major produce coordinated adduction moments during GHJ elevation and abduction. Concurrent activation of these muscles and the subscapularis stabilize the GHJ inferiorly.[5]

A synchronised contribution from scapular musculature is also critical for optimal positioning, stability, and functioning of the shoulder complex. In addition to linking the upper extremity and trunk, the scapula provides insertion points for several muscles involved in scapulohumeral and scapulothoracic motions.[6,7] Scapular stabilizers play substantial roles in maintaining the center of glenohumeral rotation during arm-scapula-trunk motion, raising the acromion during glenohumeral rotation to increase subacromial space, and transition of forces from the feet to the hand by kinetically linking the upper extremity to the trunk.

During rotational motions, a coordinated balance between mobility and functional stability is essential for the safe transmission of the high forces placed on the shoulder complex. Yet, repetitive forceful movements may impose stress on the GHJ beyond the physiologic limits of composing tissues and lead to injury. For example, cadaveric studies have shown that vigorous abduction and external rotation (e.g. late cocking phase of throwing motion) in the presence of decreased subscapularis muscle force can lead to forceful internal impingement due to significant increase in GHJ contact pressure.[8] Furthermore, biceps pulley lesions caused by repetitive forceful IR above the horizontal plane can potentially lead to internal impingement by causing frictional impairment between the pulley system and the subscapularis tendon and the anterior superior glenoid rim.[9, 10] Earlier electromyohgraphy EMG studies have documented shoulder girdle muscle activation during common internal rotation (IR) exercises to support the development of evidence-based rehabilitation and injury prevention programs.[2, 6, 11] The results, however, remain inconclusive and uncertainty exists regarding optimal IR exercises that elicit optimal activation and strengthening of key shoulder girdle muscles. Furthermore, the majority of previous studies compared the EMG activity of a limited number of muscles during exercises.

There is, thus a lack of comprehensive data regarding shoulder musculature activation strategies during common internal rotation exercises. This knowledge would guide the planning of effective training programs, and establish a base of evidence for developing optimal rehabilitation and training programs for overhead athletes with and without shoulder pathology. The purpose of this study was to provide such a knowledge base by comprehensive measurement of the EMG activity of 16 shoulder girdle muscles/muscle segments during commonly prescribed shoulder IR exercises.

METHODS

Participants

Thirty healthy volunteers (15 male; 15 female) with normal upper limb clinical examination and no history of upper limb painful conditions were recruited for participation in the study. The mean (±SD) age, height and weight for the whole group was 33.1±9.9 y, 1.71±0.08 m, and 70.5±12.7 kg, respectively. This study received approval from local research ethics committee and written informed consent was obtained from participants. The data were collected in a university laboratory setting.

EMG Measurements

Signal acquisition, processing and analysis were performed using a TeleMyo 2400 G2 Telemetry System (Noraxon Inc., Arizona; USA). Signals were differentially amplified (CMRR>100 dB; input impedance>100 Mohm; gain 500 dB), digitized at a sampling rate of 3000 Hz and band-pass filtered at 10-500 Hz and 10-1500 Hz for surface and fine-wire electrodes, respectively. A cancellation algorithm was applied to remove ECG signal contamination.

Disposable Ag/AgCl bipolar surface electrodes with 10mm conducting area and 20mm inter-electrode distance (Noraxon Inc., Arizona, USA) were used to record the EMG from anterior, middle, and posterior deltoid (AD, MD, PD, respectively), upper, middle and lower trapezius (UT, MT, LT, respectively), upper and lower latissimus dorsi (ULD, LLD, respectively), upper and lower pectoralis major pectoralis major (UPM, LPM, respectively), serratus anterior (SA), and teres major (TM), consistent with established guidelines (SENIAM).[12,13] Bipolar hooked fine-wire electrodes (Nicolet Biomedical, Division of VIASYS, Madison, USA) were used to record signals from supraspinatus (SSP), infraspinatus (ISP), subscapularis (SUBS), and rhomboid major (RHOM) according to Basmajian and DeLuca.[14]

The dominant shoulder was tested in all participants. Figure 1 demonstrates the relative locations of surface and fine-wire EMG electrodes.

Raw EMG signals from ten IR exercise cycles (the first and last IR exercise cycles were omitted) were full-wave rectified and smoothed (100 ms root mean square [RMS]). For normalization purpose, EMG_{max} was recorded during a standardized production of maximal IR force (MVC) using a shoulder Nottingham Mecmesin Myometer with an accuracy of ±0.1 % of full-scale and 1,000 N capacity (Mecmesin Ltd., Slinfold, UK) while seated, shoulder in a neutral position, elbow in 90° flexion tucked to the side of body, and forearm in neutral position. Data were collected during three 5-second contractions, and the average of three trials was taken as EMG_{max} which was used as a reference value for EMG amplitude normalization during IR exercises.

Exercises

Exercises are demonstrated in Figure 2. Participants were tested for three shoulder IR exercises in a random order: isotonic standing IR at 0° and 90° of abduction (IR at 0°ABD and IR at 90°ABD) and IR at Zero-Position (Zero rotation of the humerus with arm elevated 155° in the scapular plane and elastic resistance applied against IR as described by Saha).[15] This particular exercise was chosen as during the cocking phase of throwing motion, the arm in moved into external rotation past the zero position; and then during the acceleration the arm is moved into forward internal rotation past the zero position again.[16] Each exercise was accurately demonstrated and participants were allowed time to familiarize themselves with the exercise. Participants performed 12 cycles of each exercise using either a 1 kg dumbbell in hand (IR at 0°ABD and IR at 90°ABD) or an elastic band (IR at Zero-Position) according to a metronome set at 60 beats per minute (each concentric and eccentric phase was performed during 1 beat). All participants were given a period of three-minute rest between each set of exercises to minimise the impact of fatigue on measurements.

Data analyses

Descriptive statistics are presented as mean $\pm$ standard deviation (SD) or standard error of the mean (SEM), as appropriate. A one-way repeated-measures analysis of variance (ANOVA) was used to determine the main effect of IR exercises on each muscle's activity. A Bonferroni post-hoc test was then applied for the comparative pair-wise analysis of mean normalized EMG ($\%EMG_{max}$) to detect significant differences in the activation of muscles across three exercises. The alpha level for statistical significance was set at $p<0.05$. SPSS release 20.0 for Windows (Armonk, NY: IBM Corp.) was used for statistical analysis.

RESULTS

Table 1 and Figure 3 present and compare the activation of muscles during IR exercises.

Deltoids: The highest activation of AD, MD, and PD occurred in IR at 90°ABD followed by IR at Zero-Position; both significantly higher than IR at 0°ABD ($p<0.001$). Collective deltoid (AD+MD+PD) activation in IR at 90^oABD and IR at Zero-Position was also markedly higher than IR at 0^o ABD (346.4% vs. 252.2% vs. 49.7%; p=0.006 - <0.001).

Rotator Cuff: The activity of SSP, ISP, and SUBS in IR at 90^oABD was significantly higher than IR at 0^oABD (p<0.05-<0.001). They also showed a similar trend towards higher muscle activity higher activation in IR at Zero-Position, but this difference was not statistically significantly different. As a group (SSP+ISP+SUBS), higher activation occurred in IR at 90^oABD compared to other exercises (325.0% vs. 94.0-188.3%; $p<0.05$).

Pectoralis Major: UPM and LPM activation did not vary across exercises. Both segments showed a trend towards higher muscle activity during IR at Zero-Position, but were not statistically significantly different.

Latissimus Dorsi: ULD had the highest activation in IR at Zero-Position, significantly higher than IR at 0^{o}ABD ($p<0.05$) followed by IR at 90^{o}ABD. The activity of LLD and combined segments (ULD+LLD) was similar across exercises.

Teres Major: There was no significant difference across exercises.

Trapezius: Highest UT activation occurred in IR at Zero-Position followed IR at 90^{o}ABD, both significantly higher than IR at 0^{o}ABD ($p<0.001$). MT and LT were activated considerably more in IR at 90^{o}ABD compared to other two exercises ($p<0.001$). MT activation was also higher in IR at Zero-Position than IR at 0^{o}ABD ($p<0.05$). Collective activation of the trapezius muscles (UT+MT+LT) was markedly higher in both IR at 90^{o}ABD and IR at Zero-Position compared to IR at 0^{o}ABD (230.2% vs. 64.3-158.8%; $p<0.001$).

Serratus Anterior: The highest SA activation occurred in IR at Zero-Position which was markedly higher than IR at 0^{o}ABD ($p<0.05$).

Rhomboid Major: RM had the highest activation in IR at 90^{o}ABD compared to other IR exercises ($p<0.001$). The activity was also markedly higher in IR at Zero-Position compared to IR at 0^{o}ABD ($p<0.05$).

DISCUSSION

The results of the present study provide additional support for the use of these common IR exercises. Furthermore, the results illustrate novel strategies for the selective activation of shoulder complex muscles during specific exercises, which may be helpful during implementation in training, injury prevention, and rehabilitation programs.

Optimal performance of shoulder complex during both daily activities and sporting movements necessitates appropriately balanced activation of muscles responsible for shoulder mobility and functional stability.[1,3,7,17] The high occurrence of shoulder complex injuries highlights the need for implementation of sound evidence in developing rehabilitation, injury prevention, and training strategies.[1,2,6,15]

Current shoulder rehabilitation strategies give emphasis to correcting muscle imbalances and strength deficiencies through selectively activating dysfunctional muscles. Considering that a low ER/IR ratio has been suggested as a key risk factor for shoulder injuries,[18,19] several investigators have studied muscle activation patterns during shoulder rotational exercises, with inconsistent results.[11,20-22] EMG studies of IR exercises have mainly focused on the principal internal rotators such as SUBS and pectoralis muscles.[22-24] Moreover, there is growing interest in applying exercises in sport-specific positions that reflect capsular strain and muscular length-tension relationships throughout the shoulder complex during sport competition (e.g. ER and IR at 90°ABD) in order to facilitate enhanced functional rehabilitation.[23, 25]

Glenohumeral Muscles

In the present study, the highest activation of all deltoid sub-regions was found in IR at 90^{o}ABD followed by IR at Zero-Position. This is consistent with the role of MD and AD during dynamic arm abduction and with role of PD as humeral abductor and compressor in higher degrees ($>80^{o}$) of abduction.[5] This high activation of PD is contradictory to the reports of its ineffectiveness in generating abduction forces.[26,27] Hughes and An[28] reported a minimal force generation of 2 N for PD compared to 434 N for MD and 323 N for AD when the arm is positioned at 90^{o}ABD. It is generally suggested that exercises producing high levels of deltoid activity (MD in particular) are disadvantageous for majority of patients and athletes with shoulder injury due to significant impact on superior humeral head migration.[17, 23]

Similar to deltoids, RC muscles including SSP, ISP, and SUBS had their highest activation in IR at 90^{o}ABD followed by IR at Zero-Position. Jenp et al[29] reported substantial activity in the

SSP during shoulder IR. The activation patterns in the deltoids and RC demonstrated in the current study indicate a balanced motor strategy with similar contribution from both muscle groups for both stability (maintaining central position of the humeral head within the glenoid) and dynamic mobility of the GHJ in abducted positions. In order to counterbalance the impact of AD and MD activation on superior translation of the humeral head during shoulder abduction,[5] SUBS and ISP activation generates an inferior force which serves to minimize the risk of subacromial impingement.[30]

While standing IR at 90°ABD effectively activated both deltoid and RC muscles and may have functional advantages by replicating overhead and sport-specific positions,[31] the blend of abduction and rotation can impose high levels of stress on shoulder's ligaments and capsulolabral complex.[25] In the presence of RC pathology it is important to select exercises that generate high RC activation with minimal deltoid involvement. Hence, IR at 0°ABD with low-to-moderate activation of muscles may be considered in individuals who are at risk or suffering from shoulder complex injuries particularly impingement syndrome.

Previous researchers have placed an emphasis on SUBS activity during IR exercises particularly in relation to other large muscles involved in glenohumeral IR such as PM and LD.[22,23] It has been suggested that SUBS action during IR at 0°ABD is assisted by PM, LD, and TM. While EMG activation differences between high- and low skill pitchers has demonstrated the importance of SUBS conditioning (strength and endurance) in enhancing pitching ability and preventing injury,[32] the optimal position for selective activation of SUBS for muscle strengthening and strength testing remains unclear.[33] In addition to its role as internal rotator of humerus,[27] according to EMG studies of sport-specific activities SUBS also acts as shoulder abductor, anterior stabiliser, and humeral head depressor.[26,28,33,34] While some authors reported greater SUBS activity in IR at 90°ABD,[35] others found greater activation at 0°ABD.[22] Based on three dimensional (3-D) biomechanical studies, SUBS maximal force generation during IR at 90°ABD and 0°ABD is 1725N and 1297N, respectively[28] which is consistent with the current finding of higher SUBS activation at 90°ABD compared to 0°ABD.

While previous authors have recommended SUBS strengthening exercises in adducted positions,[36] significantly higher activation of SUBS along with low-to-moderate activation of PM, LD, and, TM in IR at 90°ABD as demonstrated in the present study, suggest the preference of this exercise for selective SUBS activation. In an EMG study of IR at various positions, Suenaga et al[24] demonstrated high activation of LPM and UPM during resistive IR at 0°ABD compared to other positions. Decker et al[22] also demonstrated higher levels of PM and LD activation IR at 0°ABD compared to 90°ABD and suggested that IR at 90°ABD may be beneficial in strengthening the SUBS due to minimizing the contributions of larger muscle groups.

Scapular Muscles

Effective scapular muscle function is fundamental for maximized performance in both daily activities and overhead sports such as the volleyball serve and spike, the tennis serve, and baseball pitching.[17,34] Furthermore, current suggestions regarding the role of impaired scapular motions (e.g. aberrant muscle activation patterns and fatigue) in developing a dysfunctional shoulder complex and subsequent injury highlights the importance of integrating scapulothoracic musculature into shoulder complex rehabilitation programs.[6,37] Amongst scapular muscles that predominantly control synchronized scapular motion during arm movements, the present study assessed three parts of trapezius (UT, MT, and LT), SA, and RHOM major.

The main functions of the trapezius include upward rotation and elevation (UT), retraction (MT), and upward rotation and depression (LT) of the scapula. Importantly, LT activation supports posterior tilt and ER of the scapula during arm elevation which consequently decreases the risk of subacromial impingement.[38] The main body of existing literature focuses on trapezius activity during ER and sparse data are available regarding activity during IR exercises. While UT activation was found to be highest in IR at Zero-Position, MT and LT had their highest activation in IR at 90^oABD. It is clinically important to enhance the LT/UT and MT/UT activation ratios as a dominant UT (as compared to the other portions of the trapezius) has been linked to shoulder pathologies due to contributions of poor posture and muscle imbalances.[6] Hence, the current findings support IR at 90^oABD as the more advantageous exercise to enhance the LT/UT and MT/UT activation ratios over the other two studied exercises. This recommendation is in agreement with other authors who have reported relatively high MT activity during arm positions of 90° abduction and higher[2, 22] but not with those of Moseley et al[11] who reported low EMG activity of the MT during IR at 90^oABD. Higher LT activation in IR at 90°ABD is also consistent with previous reports of its increased activity from 90° to 180°.[2, 11]

Contribution of the SA to upward rotation, posterior tilt, and ER rotation of the scapula during arm elevation is important for preserving a healthy scapulohumeral rhythm.[2, 39] In the presence of a dysfunctional SA, an overactive UT may cause abnormal scapular motion (extreme scapular elevation and anterior tilt) and lead to muscle imbalance and functional shoulder impairment.[2,6,7,39] In the presence of scapular muscle imbalances such as disproportionate UT/SA activation/strength ratio, emphasis has been placed upon the selective activation of underactive muscles with the minimal involvement of hyperactive muscles for balance restoration.[6] The authors' observed noticeably higher activation of SA in IR at Zero-Position followed by IR at 90^oABD which represent a similar activation pattern to UT during the same exercises. While IR at Zero-Position may enhance scapular function in healthy athletes by mirroring shoulder positioning and motion patterns occurring during overhead and throwing performance,[40] it may need to be avoided in those with or at risk of subacromial impingement due to increased UT/SA activation ratio. While higher activation of SA during IR at elevated and abducted arm positions has been reported by previous authors[23, 41] there is a lack of information regarding IR at Zero-Position.

RHOM contributes to scapular retraction, downward rotation, and elevation of scapula. In general, there is limited information on RHOM activation during shoulder exercises mainly because of technical complications in positioning intramuscular electrodes. It is suggested that several exercises used for the training and strengthening RC and other scapular muscles such as ER at 0°- and 90°ABD and prone horizontal abduction at 90°ABD with IR also efficiently provoke RHOM activity.[6,23] The results of the present study demonstrated markedly higher activation of RHOM activation in IR 90°ABD when compared to the other exercises. This is in agreement with findings of Myers et al[41] who reported relatively high RHOM activity during the same exercise.[11]

Technical Considerations and Study Limitations

The authors of the current study attempted to overcome inherent limitations of EMG and maximize the reliability of findings. Broad experience with shoulder girdle EMG informed accurate electrode positioning for optimal electrode positioning and EMG recording. EMG studies have employed alternative normalization methods such as the use of MVC to study muscle activation, however, use of an isometric contraction remains questionable particularly in relation to studying dynamic movements.[42-45] Hence, in view of conflicting opinions and uncertainties surrounding the reliability of MMTs and related MVC for EMG amplitude normalization,[42] the present study reported each muscle's EMG activity (mean RMS) during each IR exercise as a percentage of a reference value, i.e. EMGmax in a standard IR position, allowing appropriate assessment and comparison of each muscles' contribution across the exercises. A similar method has been applied by previous authors (e.g. maximum sprinting for normalizing the EMG during walking, maximum sprint cycling for normalizing the EMG during cycling).[43-45] This normalization method may have advantages for the examination of relative muscle function around the shoulder complex by minimizing intrinsic limitations in reliability and validity associated with communal reference to MVC as ther is no consensus as to which test generates maximal activation in all individuals in any given muscle.[46-48] While this normalization approach produced large EMG % values for some of the muscles, it was deemed appropriate for comparing activity of each individual muscle across the IR exercises (between-exercise comparison) as the reference value is task dependent. However, it may not be the preferred method for comparing activations between the muscles (between-muscle comparison) as maximum force production during the task used for normalization does not necessarily produce a maximum activation in the muscles under investigation.

Muscle activations during IR exercises were examined using a single load (1kg) in hand or against resistence from an elastic band in order to gain further insight into functional roles of the muscles contributing to glenohumeral stability. According to studies by other authors, increasing load does not alter shoulder muscle recruitment patterns and the functional role of muscles does not change with higher muscle activity levels associated with increased loads.[21,49,50] Considering the task-specific nature of shoulder muscle function, muscle recruitment strategy for a particular task such as IR is not expected to change with increasing resistance/load due to a systematic increase in the activity of all shoulder muscles involved in generating IR torque.[21, 49] However, applying different loads might have provided a greater information regarding the contribution of each muscle to maintaining glenohumeral stability when performing exercises. The clinical implications of current study findings with regard to symptomatic subjects are limited as this study included only asymptomatic participants. Finally, the use of arm support or placement of a rolled towel in the axilla for isolating or certain muscles without simultaneous deltoid activation was not considered in this study. This is particularly important for the focused rehabilitation of RC where minimal activation of the deltoid is desirable.

Conclusion

Activation patterns of 16 muscles/muscle sub-regions were reported during three common IR exercises in order to provide descriptive data reagarding their activation. Despite the fact that coactivation of deltoid and RC muscles standing IR at 90°ABD may provide a functional advantage by mirroring shoulder position and soft tissue mechanics (e.g. capsular strain and muscle fiber length-tension relationships) during overhead activities and sports, it can place high levels of stress on shoulder's tissues. Hence, IR at 0°ABD which generates low-to-moderate activation of muscles may be preferred in the rehabilitation of the individuals at risk or affected by shoulder injuries. Considering the current emphasis on the SUBS activity during IR exercises, findings of markedly higher activation of SUBS along with low-to-moderate activation of PM, LD, and, TM in IR at 90°ABD support the use of this exercise for selective SUBS activation. Considering the significance of incorporating scapular muscles into training and rehabilitation programs by means of enhanced LT/UT and MT/UT activity ratios, the current findings support the use of IR at 90°ABD for such purposes.

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