Relative contributions of infraspinatus and deltoid during external rotation in healthy shoulders

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Balanced forces around the shoulder are important for normal function; however, rehabilitation guidelines are not well defined because the muscle contributions and optimal exercise technique to recruit them are poorly understood. This study aimed to determine (1) the conditions of resisted isometric external rotation that optimized the contribution of infraspinatus and (2) the load of external rotation at which the adduction strategy was most effective at reducing deltoid contributions. Eighteen subjects with healthy shoulders (n = 36) performed resisted isometric external rotation at 3 increasing loads—10%, 40%, and 70% of their maximal resisted external rotation voluntary isometric contraction—with and without adduction. Surface electromyographic activity of the infraspinatus, posterior and middle deltoid, and pectoralis major was recorded and normalized against the average activity of all 4 muscles, representing each muscle's relative contribution to the task. To optimize the relative contribution of the infraspinatus with the least deltoid involvement during isometric external rotation, a load between 10% and 40% maximal voluntary isometric contraction is appropriate. At low loads, use of the adduction strategy during external rotation reduces middle deltoid involvement. In contrast, the posterior deltoid is activated in parallel with the infraspinatus at low loads and may even act as an adductor with the arm by the side. This study provides a useful guide to optimize rehabilitative exercises for rotator cuff dysfunction; in particular, highlighting that activation of the deltoid could be counterproductive to infraspinatus retraining. (J Shoulder Elbow Surg 2007;16: 563-568.)

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Normal motion of the glenohumeral joint relies on co-contraction of the rotator cuff muscles acting in force couples for stabilization of the humeral head centrally in the glenoid fossa during shoulder movement.[9,13,27,28] In the coronal plane, the inferior translatory and compressive forces generated by the infraspinatus, subscapularis, and teres minor counterbalance the superior pull of the deltoid and supraspinatus. In the transverse plane, balance of the subscapularis and the infraspinatus-teres minor controls anteroposterior movement of the humeral head.[6] This co-contraction limits superior humeral head translation during shoulder movement.[12] Rotator cuff and scapular muscle dysfunction and subsequent force couple imbalance is hypothesized to cause increased superior humeral head migration and impingement of the subacromial structures.[27]

Although patients with subacromial impingement due to rotator cuff dysfunction usually undergo physiotherapy before surgery is considered, physiotherapy rehabilitation programs are varied in their form and success, and many patients are ultimately offered surgery to relieve their pain.[21] During rotator cuff retraining programs for the shoulder, external rotation (ER) exercises are commonly used with the intention of improving the stabilizing ability of the infraspinatus and teres minor and assist in restoring balance of the force couples.

The posterior deltoid, a shoulder external rotator,[19] is also active during this exercise, however. Furthermore, the middle deltoid similarly has been shown to be active during ER,[26] possibly because patients tend to abduct during ER exercises, especially at higher loads of resistance. This activation of the deltoid with its potential to create superior humeral head translation is likely to be counterproductive to an infraspinatus retraining program, especially in the early stages of rehabilitation.

Holding a magazine or towel between the lateral chest and upper arm to minimize the tendency to abduct during ER exercises theoretically reduces the contribution of deltoid with the aim of providing more isolated infraspinatus activation. Colloquially referred to as the *adduction strategy*, it is advocated by a number of authors,[1,5,22,30] with little scientific evidence. Recently, Reinold et al[26] investigated the adduction strategy during ER at 1 load in a healthy population but found no significant difference in the electromyographic (EMG) activation of the infraspinatus or deltoid during ER with adduction and ER alone.

Given the interest in an exercise to isolate the infraspinatus optimally, the aims of this study were to determine (1) the conditions of resisted isometric ER that optimized the contribution of the infraspinatus and (2) whether the adduction strategy was effective at reducing posterior and middle deltoid contributions, and if so, at which load of ER. As muscle contraction properties change with increasing load due to changes in motor unit recruitment[11] and reflex gain,[20] relative contributions of the infraspinatus and deltoid muscles were investigated with surface EMG when isometric ER was performed with and without adduction at low, medium, and high loads with a view to recommending the best combination to achieve the aims.

MATERIALS AND METHODS

The study included 18 subjects aged older than 30 years with healthy shoulders bilaterally who were selected from a sample of convenience. Individual subjects were tested using a repeated-measures experimental design in a single testing session. Potential subjects were excluded if they had a history of shoulder pathology or surgery, current cervical pathology, or known systemic inflammatory conditions. Ethical approval was obtained from the University of South Australia's Human Research Ethics Committee.

Surface EMG activity from the infraspinatus, posterior deltoid, middle deltoid, and pectoralis major was recorded using circular, self-adhesive, silver/silver chloride surface electrodes (Triode, Thought Technology, Montreal, Canada) with a fixed interelectrode distance of 2 cm. Before the surface electrodes were applied, the subject's skin was prepared to reduce skin impedance, as recommended by Hermens et al,[14] which consisted of shaving hair, wiping the area with an alcohol swab, abrading gently with sandpaper, and wiping the area again with an alcohol swab. Assessment of skin impedance, using an impedance meter (XI-1 Electrode Impedance Tester, OXFORD Medical Systems, Abingdon, United Kingdom), revealed this skin preparation technique consistently lowered skin impedance below the accepted level of 5 kilo-ohms[14] when the subject felt a light, stinging sensation.

The electrodes were applied centrally over the muscle bellies (Figure 1), as described by Cram et al,[8] by using conductive gel. The surface electrode for the infraspinatus was positioned 4 cm inferior and parallel to the scapular spine on the lateral aspect over the infrascapular fossa. An electrode was positioned over the posterior deltoid, 2 cm inferior to the lateral border of the spine of the scapula and angled parallel to the muscle fibers. For the middle deltoid, the electrode was placed 3 cm below the acromion over the muscle mass on the lateral upper arm. An electrode was positioned horizontally on the chest wall over the sternal portion of the pectoralis major, 2 cm from the axillary fold, to verify adduction was occurring. To improve consistency, the same investigator positioned the electrodes each time, and electrodes were not moved between the test movements.

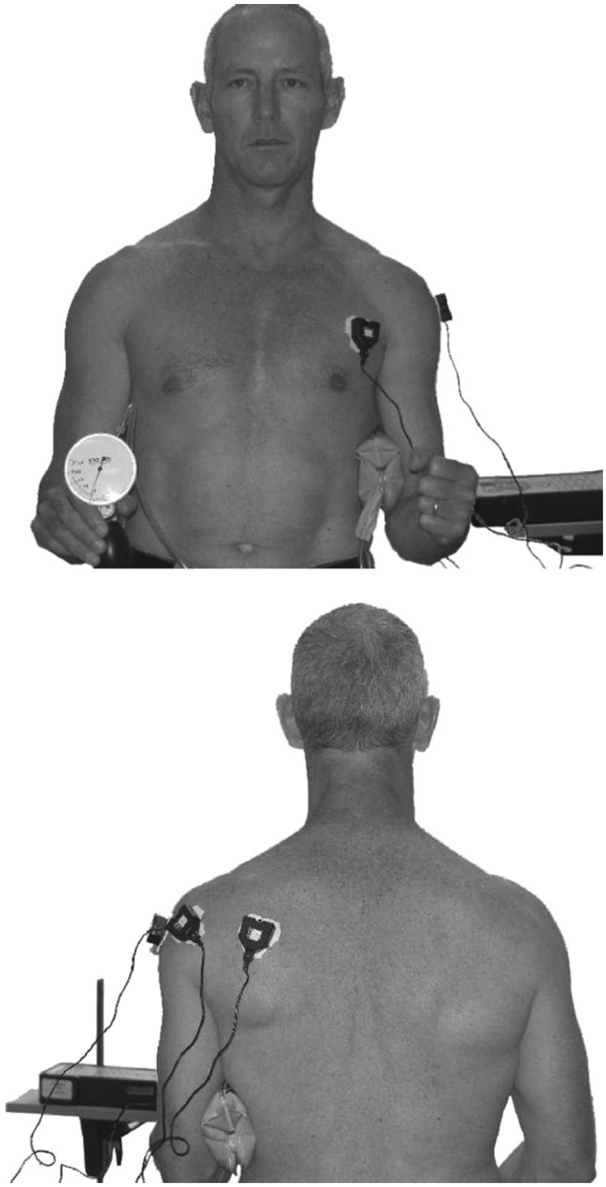

Figure 1 Surface electrode set up during experiment anterior *(top)* and posterior *(bottom)*.

The surface electrodes were attached to the MyoScan Pro electrode sensor (Model 9401/50Hz, Thought Technology, Montreal, Quebec, Canada). The EMG activity of the muscles was filtered (20-500 Hz) and amplified (×1000). The raw EMG signal was then converted to a root mean square (RMS) signal within the MyoScan Pro sensor to quantify the raw signal. The sensors were attached to the ProComp+ EMG encoder (Thought Technology), which sampled the RMS signal at 32 samples/s. A fiberoptic cable transmitted the RMS data to the laptop computer. The computer software Biograph 1.01 (Thought Technology) produced a waveform of the RMS data and displayed this on the computer screen.

The subject was seated on a backless chair in the standard starting position: feet flat on the floor, knees at approximately 90° flexion, sitting up straight with the arm by the side in neutral humeral rotation and 90° elbow flexion (Figure 1). A calibrated force transducer (Mecmesin Advanced Force Gauge, Model AFG-250N, Mecmesin Ltd, Horsham, United Kingdom) mounted on a custom-made, height-adjustable stand, was positioned slightly proximal to the radial styloid and used to quantify the force exerted upon isometric ER. This position was marked to ensure consistent placement throughout the experiment.

The subject performed 1 resisted ER maximal voluntary isometric contraction (MVIC) against the force gauge, which recorded the highest force reached. This force was used to determine the loads at which the subject was required to perform subsequent ER contractions for the experiment. These test loads were 10%, 40%, and 70% of the subject's ER MVIC and were chosen to address drawbacks of previous research in the area, in which muscle activation was only investigated at 1 load,[15,25,26] and to give a more complete picture of muscle activation over a range of intensities. The 3 loads were chosen based on the principles of physiologic muscle motor unit recruitment[11] and reflex gain,[20] and from this, it was theorized that these 3 loads would result in different patterns of muscle activation.

Once the test loads were determined, the subject performed a series of 7 different muscle contractions in a random order. These were resisted isometric ER at 10%, 40%, and 70% MVIC against the force gauge and resisted isometric ER at 10%, 40%, and 70% MVIC against the force gauge, while maintaining resisted isometric adduction to 40 mm Hg against a pressure biofeedback unit (PBU; Chattanooga Australia Pty Ltd, Brisbane, Queensland, Australia, Patent No. 657277) positioned between the subject's lateral chest wall and upper arm, midway between the elbow and the axilla. A seventh contraction-resisted isometric adduction to 40 mm Hg against the PBU was performed to verify that the adduction component activated the shoulder adductor muscles. The pressure dial and screen of the force gauge were positioned where both the subject and investigator could see them, allowing simultaneous monitoring of both the ER and adduction forces.

Subjects were required to hold each muscle contraction at the target force (±5%) for 10 seconds. An audio alarm was used to ensure the subject remained within the ER loading target range for 10 seconds, during which the EMG activity was recorded on the computer. The protocol was then repeated at each loading level and on the other shoulder.

The mean RMS generated by BioGraph 1.01 for each muscle during the 2 to 7 second period of each contraction was used to normalize the data. The method of normalization expressed each muscle's EMG activity during each contraction as a percentage of a reference value, essentially indicating its relative contribution to the task. Each muscle contraction had its own reference value, which was the average of all 4 muscles' mean RMS during that contraction.[8] Each muscle's relative contribution was found by expressing its mean RMS as a fraction of the reference value.

Normalized data from the left and right sides were compared by using repeated measures analysis of variance[24] to determine if pooling of the data from both sides was appropriate. Data were analyzed with SPSS 13 software (SPSS Inc, Chicago, IL). Significance was set at values of $\alpha < 0.05$. Significant results were investigated further using multiple comparison *t* tests with Bonferroni correction,[24] in which α is divided by the number of possible comparisons to protect against a type 1 error.[23]

The sample size was based on pilot data collected from the first 7 subjects with a type 1 error of 0.05 and type 2 error of 0.20 (statistical power of 80%) and calculated in SAS 9.1 software (SAS Institute Inc, Cary, NC). Effect size was based on observed differences because the estimated effect size for the method of normalization was unknown. The sample size required to test the hypotheses with these levels of error was estimated to be 35.

RESULTS

Subjects

Eighteen subjects (12 women, 6 men) completed the entire protocol. Mean ± SD demographic data were age, 42.17 ± 7.64 years; height, 170.36 ± 9.73 cm; and weight, 69.89 ± 15.67 kg. All subjects were right-hand dominant. There was no statistically significant difference between the normalized left and right side EMG data for any muscle under any condition ($P > .05$), and as such, the data were pooled for subsequent analyses, increasing the sample size to 36 shoulders.

Relative electromyograph contributions

The relative contributions of the muscles during the test conditions are shown in Figures 2 and 3. During ER alone and ER with adduction, the contribution of the infraspinatus was significantly greater at 40% MVIC than at 10% or 70% MVC ($P < .001$). The contribution of the posterior deltoid was significantly higher at 40% and 70% MVIC than at 10% MVIC ($P < .001$) during both ER alone and ER with adduction. The contribution of the middle deltoid was significantly greater at 70% MVIC than at 10% or 40% MVIC during ER alone ($P < .001$). At 10% MVIC, the adduction strategy significantly reduced the contribution of the middle deltoid ($P < .001$). At all loads of ER with adduction, the contribution of the middle deltoid was significantly less than that of the infraspinatus ($P < .001$). There were no differences between

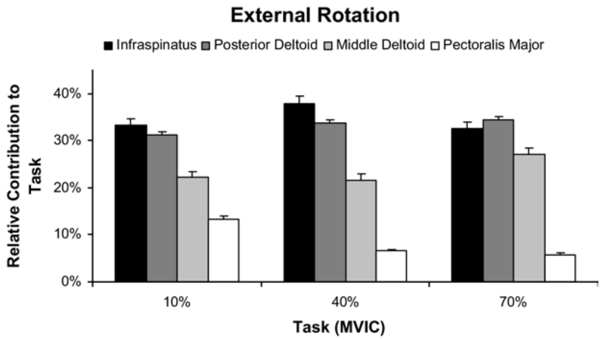

Figure 2 Relative contributions of muscles (*black,* infraspinatus; *dark gray,* posterior deltoid; *light gray,* middle deltoid; *white,* pectoralis major) during external rotation are presented as mean ± standard error of mean. *MVIC,* Maximal voluntary isometric contraction.

the activation of the infraspinatus and the posterior deltoid during any task.

DISCUSSION

Previous studies have documented positions of ER in which the infraspinatus is maximally activated, for example, side-lying ER[4,26] and prone ER[4]; however, these positions also resulted in high levels of deltoid activation. Overactivation of the deltoid is not desired in early rotator cuff rehabilitation because the infraspinatus may be unable to overcome the assumed humeral head–elevating effect of the deltoid. Recently, ER with the arm by the side was reported to activate the middle and the posterior deltoid least compared with other ER exercises.[26]

Various forms of resistance are used during exercises in rotator cuff retraining programs.[5,21,22,29] When these exercises are prescribed, it is a common concept arising from the principle of overload[3] that if an exercise is improving the patient's condition, doing more or increasing the intensity will result in greater improvements. However, when resistance training is part of a rehabilitation program, the function and contribution of relevant muscles at various exercise loads must be considered.

The infraspinatus is an external rotator of the glenohumeral joint,[19] but it is also an important stabilizing muscle. David et al[9] demonstrated this stabilizing function in a pattern mirroring that demonstrated in the knee and lumbar spine during dynamic stabilization.[7,17] Therefore, as part of the transverse force couple, the infraspinatus fulfils a primary stabilizing role around the shoulder rather than a principle torque-producing role. In contrast, the mechanical properties of the posterior and middle deltoid compared with the infraspinatus support them having a primary torque-producing role rather than a stabilizing role.[18] Based on this premise, retraining of the stabilizing ability of the posterior rotator cuff with ER exercises should be tailored for developing muscular endurance, which is accomplished by performing high repetitions of the exercise at low loads.[3]

Accordingly, the load at which ER exercises are performed and the addition of adduction at different loads may be important to optimize the contribution of the infraspinatus and minimize the deltoid involvement. This would diminish the potential for superior humeral head translation that may accompany abduction if the deltoid is preferentially activated over the infraspinatus.

In this study, the method of normalization allowed for an assessment of both the magnitude of activation and relative contribution to the task of the muscles. Simple analysis of raw EMG activity will show a

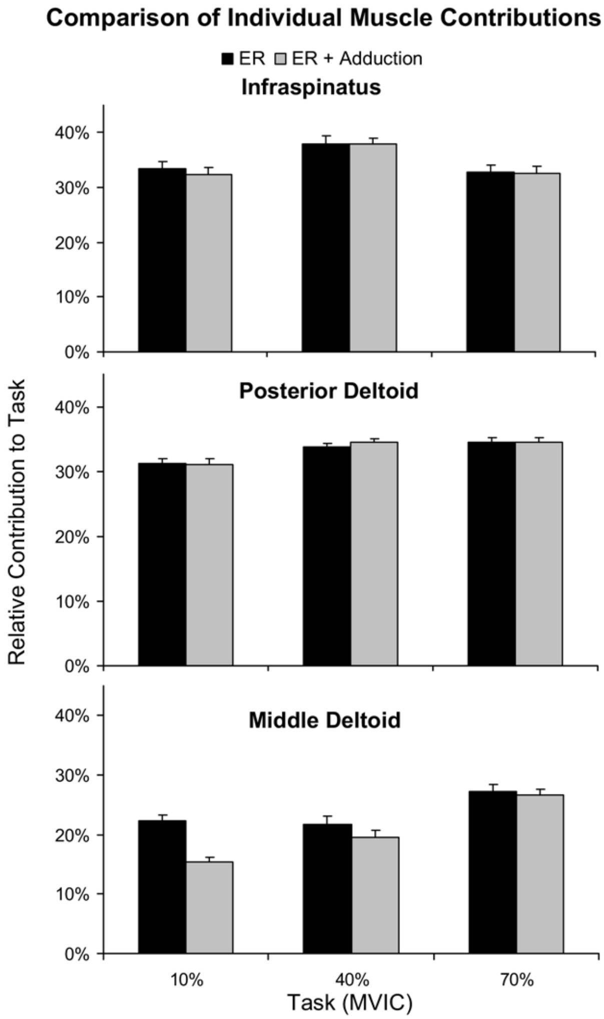

Figure 3 Comparison of individual muscle contributions of the infraspinatus, posterior deltoid, middle deltoid, and pectoralis major muscles in external rotation (*ER, black*) and ER with adduction (*gray*). MVIC. Results are presented as mean ± standard error of the mean. *MVIC,* Maximal voluntary isometric contraction.

higher level of EMG activity at high load compared with low load due to increased motor recruitment.[8] Upon normalization, the contribution of the infraspinatus appeared to decrease at 70% MVIC because the contribution of the middle deltoid increased at this load. This method of normalization also avoided inherent limitations of the more common reference to MVIC, including problems with reliability and validity of a MVIC,[8,10] particularly in subjects with pain. Avoidance of this latter limitation allows data to be compared with studies of subjects who have rotator cuff dysfunction. For this reason, this normalization method should be the preferred method for investigation of relative muscle function around the shoulder, because it reduces the amount of muscle testing to accumulate the required data and thus minimizes the potential for pain in symptomatic subjects.

Results of the present study indicated that performing isometric ER at around 40% MVIC optimized the contribution of the infraspinatus ($P < .001$). There was also a clear difference in the relative contribution of the posterior and middle deltoid. Although no differences were found between the activation of the infraspinatus and the posterior deltoid during any task, the middle deltoid contributed least at low-medium loads (10%-40% MVIC), and its activation was significantly reduced when ER with adduction was performed at 10% MVIC ($P < .001$). These findings suggest that the posterior deltoid may contribute more to shoulder adduction when the arm is by the side and relatively little to humeral head elevation, and this appears consistent with the direction of the muscle fibers. Consequently, the infraspinatus cannot be isolated from the posterior deltoid when the arm is by the side, but it can be relatively isolated from the middle deltoid.

This finding has implications for shoulder rehabilitation where, especially in the early stages, excessive middle deltoid activity with its associated risk of humeral head elevation should be avoided. Results of this study suggest that to optimize the contribution of the infraspinatus with the least middle deltoid involvement during resisted isometric ER, low loads of between 10% and 40% MVIC with adduction are required. This would retrain the infraspinatus in a manner consistent with its stabilizing role. Above these loads, the reliance on the infraspinatus for ER was reduced, consistent with the torque-producing role of the deltoid and the tendency to abduct the shoulder, making it harder for the middle deltoid to remain relatively inactive.

These findings however, cannot be extrapolated to the injured shoulder. This study identifies a pattern of muscle activation around the shoulder and provides a normal reference for future comparison with symptomatic populations, such as those with rotator cuff dysfunction.

The adduction strategy during ER has been an important component of many exercise programs to eliminate deltoid activity and thus retrain the infraspinatus more effectively than with ER alone. Although Reinold et al[26] did not support the use of the adduction strategy during ER, the present study found that the strategy was effective at reducing the contribution of the middle deltoid at low loads compared with ER alone ($P < .001$). The present study also found that the adduction strategy did not significantly change the contributions of the infraspinatus or the posterior deltoid at any load. These differences are perhaps explained by the fact that Reinold et al[26] only tested muscle activation at 1 load, whereas testing in the present study was conducted at 3 different loads, giving a more complete picture of muscle activation over a range of contraction intensities. Further, methodologic differences such as normalization to MVIC and using isotonic ER with hand weights rather than isometric loading may also account for the variation.

Unlike the effect on the middle deltoid, adding adduction to ER did not inhibit the posterior deltoid as was anticipated. The posterior deltoid is a very weak abductor in the plane of scapular flexion[2] but less well defined in other directions. Given the alignment of the posterior deltoid muscle fibers, it is possible that in the testing position, the deltoid was acting as an adductor.

Hinterwimmer et al[16] suggested that the increase in size of the subacromial space was related to adducting forces in the healthy shoulder, predominantly related to the increased activity in the posterior rotator cuff. However, because the current study revealed no difference in the posterior deltoid and infraspinatus activity under any condition, it may be that the change in the subacromial space reported by Hinterwimmer et al[15] was a result of a reduction in the middle deltoid rather than an increase in posterior rotator cuff activity.

This study has limitations that must be considered when interpreting the results. The subjects tested had healthy shoulders and cannot be assumed to have the same muscle activation patterns as patients with shoulder pathology, thus limiting extrapolation. However, the results do provide a baseline for assessment of the muscle activation pattern in the abnormal shoulder. Although isotonic loading is more common in clinical practice, isometric testing allowed more accurate quantification of the ER force. Further, by testing only 1 repetition of each movement, no insight was provided into how the muscle behaves with fatigue or the different muscle activation patterns in isotonic muscle contractions.

CONCLUSION

If resisted isometric ER is performed clinically to retrain the infraspinatus, to maximize the relative contribution of the infraspinatus and with least deltoid involvement, resisted isometric ER should be performed with adduction at low-to-medium loads not exceeding 40% MVIC. The middle deltoid, which has an abduction and humeral head elevation effect, is activated at higher loads, but using the adduction strategy can reduce its effect. Activity of the posterior component of the deltoid is not significantly altered when adduction is added to ER and possibly contributes as an adductor during this movement. These recommendations may assist in the investigation and development of more effective rehabilitation strategies for patients with shoulder pathology and provide a useful baseline and methodology to review the muscle activation patterns in patients with clinical signs of subacromial impingement due to rotator cuff dysfunction.

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