Shoulder Muscle Recruitment Patterns During Commonly Used Rotator Cuff Exercises: An Electromyographic Study

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Background and Purpose
Graduated rotation exercises performed with the arm by the side are commonly used to improve rotator cuff (RC) muscle function. The aim of this study was to compare the pattern of recruitment of the RC muscles with that of other shoulder muscles that rotate the shoulder joint during these exercises.

Subjects
The nondominant shoulders of 15 subjects who were healthy were tested.

Methods
Activity in the infraspinatus, supraspinatus, subscapularis, latissimus dorsi, pectoralis major, and posterior deltoid muscles was recorded. Low-, medium-, and high-intensity rotation exercises were performed with a pulley system.

Results
As the intensity of both internal and external rotation exercises increased, activity increased in a systematic manner in all muscles capable of producing rotation torque during concentric and eccentric contractions.

Discussion and Conclusion
The results indicate that, in people who are healthy, the motor strategy used to deal with increasing rotation resistance with the arm in a pendant position is to gradually increase activity in all shoulder rotation torque-generating muscles.
Shoulder Muscle Recruitment Patterns During Rotator Cuff Exercises

The shoulder (glenohumeral) joint has a high degree of mobility to enable the hand to perform a multitude of varied tasks. To maintain shoulder joint stability without compromising mobility, compression of the humeral head into the glenoid fossa by the surrounding musculature is paramount. The most important muscles providing this dynamic stabilizing force are the muscles of the rotator cuff (RC)—subscapularis, supraspinatus, infraspinatus, and teres minor.

During movement at the shoulder joint, the RC muscles function in a coordinated manner to keep the humeral head centered in the glenoid fossa. The shoulder joint compression force created by synchronous contraction of the RC muscles enables the humerus to pivot on its head within the glenoid fossa during shoulder movements. This compression force limits the potential humeral head translation generated by muscles producing shoulder movements that otherwise might make the shoulder unstable or cause impingement. Either a collective reduction in force of the RC muscle group or an isolated reduction in force from any of the RC muscles increases potential humeral head translation and reduces the force required to produce subluxation of the humeral head.

Because of their critical role in providing dynamic stability at the shoulder joint, exercises to improve RC muscle function are commonly used during shoulder rehabilitation. Because the RC muscles produce rotational torque at the shoulder, rotation exercises are used to rehabilitate and strengthen these muscles. During RC muscle rehabilitation, shoulder rotation exercises are commonly performed dynamically with the arm by the side (pendant position), beginning with low load resistance and gradually increasing the resistance as rotation strength increases.

Although it is presumed that gradually increasing resistance will result in greater activity in the RC muscles during rotation exercises with the arm in a pendant position, no research evidence is available to confirm this assumption. Because other shoulder muscles can produce shoulder internal and external rotation, motor strategies used to recruit these muscles in preference to the RC muscles at different load levels are a possibility.

Previous research under high-load conditions with subjects who were healthy indicated that, during rotation exercises with the arm in a pendant position, many shoulder rotation torque-generating muscles are recruited at levels similar to those of the RC muscles. A motor strategy used to recruit all shoulder rotation torque-generating muscles at high levels during high-intensity rotation exercises would be expected. However, at submaximal resistance levels, a number of shoulder rotator muscle recruitment strategies are possible. Because no studies have investigated the differential recruitment of the RC muscles and other muscles that rotate the shoulder joint at low to moderate resistance levels, it is not known to what extent submaximal exercises involve RC muscle activity. If the RC muscles are minimally recruited during submaximal rotation exercises in the pendant position, then gradually exercised in this position—which are commonly used to improve RC muscle function—would not be indicated.

The aim of this study, therefore, was to compare the pattern of recruitment of the RC muscles with that of other shoulder muscles that rotate the shoulder joint during graduated rotation exercises performed with the arm by the side.

Method

Subjects
Fifteen subjects (11 women and 4 men) with a mean age of 27 years (range = 18–42 years) participated in this study. All subjects had not experienced pain in the nondominant shoulder for at least 2 years and had never sought treatment—that is, no medication, physical therapy intervention, or surgery—for nondominant shoulder dysfunction. The nondominant arm was defined as the arm with which subjects did not write.

Before recruitment, volunteers underwent a screening physical examination by an experienced physical therapist to ensure that they had normal shoulder range of motion, normal scapulohumeral rhythm (as assessed by visual inspection), and no pain during maximum voluntary isometric internal and external rotation contractions of the nondominant shoulder. Subjects gave written informed consent before participating in the study.

Instrumentation

Intramuscular wire electrodes were inserted into the infraspinatus, supraspinatus, subscapularis, latissimus dorsi, and pectoralis major muscles by use of 23-gauge hypodermic needles as canulas. These electrodes consisted of 2 insulated wires 0.14 mm in diameter and with 3 mm of the insulation coating stripped from their ends. The electrode insertion site for the subscapularis muscle was standardized as described by Kadaba et al; all other placements of intramuscular electrodes were standardized as described by Geiringer. Two silver chloride surface electrodes 10 mm in diameter and with centers approximately 25 mm apart were placed over the belly of the posterior deltoid muscle midway.
between the posterior lateral edge of the acromion and the deltoid insertion point; a third surface electrode was placed over the acromion as a ground electrode.

The intramuscular wire electrodes were taped down near the insertion sites to prevent them from being accidentally removed during the experiment and to minimize movement artifacts. All electrodes were attached to an 8-channel electromyography (EMG) signal distribution box, which was strapped to the contralateral side of each subject’s back. The EMG signals were amplified (ISO-DAM8-8 amplifier*) with a gain of 1,000 and band-pass filtered between 10 Hz and 5 kHz. The EMG signals then were sent to an oscilloscope (VC-85†) for viewing and a laboratory computer for storage at a sampling rate of 2,000 Hz.

Resistance exercises were performed with a pulley system and weights (Figure). A load cell (X Tran, S1W-2KN‡), placed in series with the rope of the pulley, measured force during data collection. The signal from the load cell was amplified and acquired in synchrony with the EMG signals.

A digital camera (MV600i§) capturing movement at 25 frames per second was placed overhead to record the exercises in the transverse plane in order to measure shoulder rotation range of motion. Rotation angle was determined by measuring the angle between the sagittal plane and the center of the handle by which the subject applied the load, with the center of rotation being the acromion, as marked with the ground electrode. The sagittal plane was identified by use of a grid that was marked on the floor and that consisted of parallel lines perpendicular to the line of action of the pulley. The subject’s feet were placed parallel to this grid. An audio trigger was used during recording to synchronize the EMG signal recording with the camera recording.

The speed of execution of each exercise was standardized by use of a metronome set at 60 beats per minute. Each exercise was completed in 8 seconds. The concentric and eccentric phases of each exercise took 4 seconds each.

**Experimental Protocol**

Shoulder internal and external rotation exercises, performed with the arm by the side and the elbow flexed to 90 degrees, were investigated in the nondominant shoulder. Maximum shoulder internal and external rotation strength was measured in each subject at 10 to 20 degrees from the subject’s maximum inner range of motion by fixing the rope of the pulley system to the wall. Rotation strength was measured in this position to ensure that exercises could be performed through the full rotation range because this is where mechanical advantage is small. Torque was calculated by use of the force measured by the load cell, the length between the axis of shoulder rotation and the center of the pulley handle, and the angle between the rope of the pulley and the forearm, as measured by the camera overhead. The highest torque produced

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* World Precision Instruments, 175 Sarasota Center Blvd, Sarasota, FL 34240.
† Nihon Kohden Kogyo Co Ltd, Tokyo, Japan.
‡ Applied Measurement Australia Pty Ltd, 14 Dalgety St, PO Box 159, Oakleigh, Victoria 3166, Australia.
§ Canon, Tokyo, Japan.
from 3 attempts represented maximum rotation strength. The maximum torque then was used to determine low-intensity (10%–20% of maximum strength), medium-intensity (45%–55% of maximum strength), and high-intensity (60%–70% of maximum strength) levels for both shoulder internal and shoulder external rotation exercises. Weights corresponding to these exercise intensities were prepared for use during the experiment while the subjects practiced correct shoulder rotation exercise techniques.

Surface electrodes were positioned after abrasion with glasspaper and wiping with alcohol to achieve impedances of <5 kΩ across electrodes. Fine intramuscular wire electrodes were inserted into the subscapularis, supraspinatus, infraspinatus, pectoralis major, and latissimus dorsi muscles. Correct intramuscular electrode placement was confirmed by performing a submaximal contraction of a movement expected to produce a large amount of activity in the muscle of interest and one in which very little or no activity would be expected to occur.

With all electrodes in situ, subjects performed 3 maximum voluntary isometric contractions (MVICs) for each muscle under investigation in order to normalize the EMG signals. The movements used to generate the MVICs are listed in Table 1. Each MVIC was sustained for 3 seconds, during which time subjects viewed the oscilloscope for visual feedback and verbal encouragement was provided. The highest EMG level observed during all trials was used. Before the exercise protocol was begun, the resting EMG activity was recorded over a 5-second period.

A total of 6 exercise conditions were executed. The exercise protocol was block randomized such that subjects started with either shoulder internal or shoulder external rotation exercises. Within each block, low-, medium-, and high-intensity rotation exercises were performed in random order. After completion of the first block of exercises, the resting EMG activity was recorded again for 5 seconds before the second block of 3 randomly assigned exercises was begun.

Data Analysis

The data for each subject were analyzed with MATLAB, version 6.1. The raw EMG signals were high-bandpass filtered (eighth-order zero-lag Butterworth filter) at 10 Hz to remove any direct-current offsets and movement artifacts. The EMG signals then were rectified and low-bandpass filtered (eighth-order zero-lag Butterworth filter) at 2 Hz. The MVICs and the baseline EMG signals were processed in the same manner. The EMG signals were normalized by first subtracting the baseline EMG signals from both the EMG signals and the MVIC activity levels, then dividing the EMG signals by the MVIC activity levels, and finally multiplying by 100%.

The camera recording of each exercise for each subject was digitized to determine the times at which the subject’s shoulder was externally rotated 20 degrees from the sagittal plane, in neutral rotation (0°), and internally rotated 20 degrees from the sagittal plane during the internal rotation exercise. During the external rotation exercise, the times at which the subject’s shoulder was internally rotated 20 degrees, in neutral rotation (0°), and externally rotated 20 degrees and 40 degrees were determined. Both concentric and eccentric phases of shoulder internal and external rotation exercises were analyzed.

The normalized EMG patterns for each muscle for each exercise for each subject were used for analysis. The muscle activity levels across the range of angles in each direction of movement were averaged. Two-
factor (muscle × exercise intensity) repeated-measures analyses of variance (ANOVA) were conducted to determine differences in the average muscle activity levels for different exercise intensities and muscles. The muscle factor had 3 levels (subscapularis, pectoralis major, and latissimus dorsi muscles for internal rotation and infraspinatus, supraspinatus, and posterior deltoid muscles for external rotation), and the exercise intensity factor had 3 levels (low, medium, and high). The analysis was conducted separately for both internal and external rotation directions and for both contraction types (concentric and eccentric). When significant differences were observed in either the main effects or the interaction effects, a Tukey honestly significant difference post hoc test was conducted to determine differences among the levels. An alpha level of .05 was used to determine significance. All statistical analyses were conducted with Statistica, version 7.1.

Results
The results of the 2-factor repeated-measures ANOVA for the internal rotation exercises investigated indicated that the average activity levels in the subscapularis, pectoralis major, and latissimus dorsi muscles, that is, the muscles that internally rotate the shoulder, showed similar patterns of change with increasing intensity, as indicated by a nonsignificant interaction effect ($F=1.40; df=4.56; P=.24$). The activity in these 3 muscles increased significantly ($F=54.6; df=2.28; P<.001$) with increasing internal rotation exercise intensity during both concentric and eccentric contractions. The activity levels in these 3 muscles also were significantly different ($F=3.82; df=2.28; P<.05$).

The Tukey post hoc test revealed that, for both concentric and eccentric directions, the activity level in the pectoralis major muscle was significantly greater than that in the latissimus dorsi muscle, whereas there was no significant difference in the activity level between the pectoralis major and subscapularis muscles or between the subscapularis and latissimus dorsi muscles. During the concentric phase of the low-intensity internal rotation exercise, the subscapularis muscle activity level was $16\%\pm4\%$ of the MVIC, and it reached $51\%\pm14\%$ of the MVIC during high-intensity exercise; the pectoralis major muscle activity level ranged from $23\%\pm4\%$ of the MVIC during low-intensity exercise to $51\%\pm9\%$ of the MVIC during high-intensity exercise (Tab. 2). The average activity level in the latissimus dorsi muscle was approximately half that in the subscapularis and pectoralis major muscles for all internal rotation exercise intensities during concentric contractions, ranging from $10\%\pm2\%$ of the MVIC at low intensity to $28\%\pm6\%$ of the MVIC at high intensity (Tab. 2). The average activity levels in the muscles that do not internally rotate the shoulder—the infraspinatus, supraspinatus, and posterior deltoid muscles—were less than $6\%$ of the MVIC during all of the internal rotation exercises tested.

For the external rotation exercises investigated, the results of the 2-factor ANOVA indicated that the patterns of change in the activity levels in the infraspinatus, supraspinatus, and posterior deltoid muscles with increasing intensity were similar, as indicated by a nonsignificant interaction effect ($F=1.51; df=4.56; P=.21$). The activity in these 3 muscles increased significantly ($F=24.1; df=2.28; P<.001$) with increasing external rotation exercise intensity during both concentric and eccentric contractions. The activity levels in these 3 muscles also were signifi-

### Table 2

<table>
<thead>
<tr>
<th>Muscle</th>
<th>% MVIC, $\bar{X}\pm SE$</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Concentric</td>
</tr>
<tr>
<td></td>
<td>Low</td>
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<tr>
<td>Subscapularis</td>
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</tr>
<tr>
<td>Pectoralis major</td>
<td>23±4</td>
</tr>
<tr>
<td>Latissimus dorsi</td>
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<tr>
<td>Infraspinatus</td>
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<tr>
<td>Supraspinatus</td>
<td>0±0</td>
</tr>
<tr>
<td>Posterior deltoi</td>
<td>1±0</td>
</tr>
</tbody>
</table>

*a* Only data for the subscapularis, pectoralis major, and lattissimus dorsi muscles were included in the analysis of variance.

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# Shoulder Muscle Recruitment Patterns During Rotator Cuff Exercises

**Table 2.**

Muscle Activity (Percentage of Maximum Voluntary Isometric Contraction [% MVIC]) With Respect to Exercise Intensity During Internal Rotation Exercises

*StatSoft Inc, 2300 East 14th St, Tulsa, OK 74104.*
The Tukey post hoc test revealed that the activity level in the infraspinatus muscle was significantly greater than those in both the supraspinatus and the posterior deltoid muscles, whereas there was no significant difference in the activity levels in the supraspinatus and posterior deltoid muscles. During the concentric phase of the external rotation exercise, the infraspinatus muscle produced the highest average activity levels, ranging from 40%±7% of the MVIC at low intensity to 70%±14% of the MVIC at high intensity (Tab. 3); the average activity levels in the supraspinatus muscle ranged from 15%±3% of the MVIC at low intensity to 51%±14% of the MVIC at high intensity, and the posterior deltoid muscle activity levels ranged from 6%±1% of the MVIC at low intensity to 31%±4% of the MVIC at high intensity (Tab. 3). The average activity levels recorded in the subscapularis, pectoralis major, and latissimus dorsi muscles throughout the external rotation exercise at all intensity levels did not exceed 6% of the MVIC.

**Discussion**

As the intensity of both internal and external rotation exercises performed with the arm by the side increased, the activity of all of the muscles investigated, whose action is to internally and externally rotate the shoulder, increased in a systematic manner. Because no interactions were significant, all of the torque-producing muscles investigated during shoulder rotation exercises behaved in a similar fashion throughout the range of movement during both concentric and eccentric contractions and at low, medium, and high exercise intensities. Therefore, in subjects without shoulder symptoms, the motor strategy used to deal with increasing internal and external rotation resistance when the arm is by the side appears to be to gradually increase the activity in all shoulder rotation torque-generating muscles, including muscles that are part of the RC muscle group—the subscapularis muscle during internal rotation and the infraspinatus and supraspinatus muscles during external rotation.

In this study, similar average activity levels were recorded in the subscapularis, pectoralis major, and latissimus dorsi muscles throughout the external rotation exercise at all intensity levels tested, however, were approximately half those recorded in the subscapularis and pectoralis major muscles, ranging from 10% of the MVIC to 28% of the MVIC.

All previous research on shoulder muscle activity during internal rotation exercises in a pendant upper-limb position (similar to that investigated in the present study) examined only high-load exercises under both dynamic and static muscle contraction conditions. The results of the present study are in agreement with the majority of this research, which also reported similar activity levels in the subscapularis and pectoralis major muscles, but do not support the findings of Hintermeister et al, who reported 40% higher activity levels in the subscapularis muscle than in the pectoralis major muscle during dynamic internal rotation exercises with high-load elastic resistance. All previous research comparing average activity levels in the latissimus dorsi muscle with those in the pectoralis major muscle during high-load internal rotation exercises supports the finding of lower latissimus dorsi muscle activity levels demonstrated in the present study.

In this study, the highest average activity levels during low-, medium-,
and high-load external rotation exercises with the arm by the side were recorded in the infraspinatus muscle and ranged from 40% of the MVIC to 70% of the MVIC. Although the average activity levels in both the supraspinatus and the posterior deltoid muscles were lower than those in the infraspinatus muscle at all load intensities, there was a similar increase in the average EMG activity of approximately 30% of the MVIC in both of these muscles from the low-load to the high-load external rotation exercises (supraspinatus muscle: 15% of the MVIC to 51% of the MVIC; posterior deltoid muscle: 6% of the MVIC to 31% of the MVIC). Once again, previous research on shoulder muscle activity during the same shoulder external rotation exercises as those investigated in the present study examined only high-load conditions. The results of the present study support the majority of this research, which reported high levels of infraspinatus muscle activity to 31% of the MVIC (infra- and external rotation exercises at all load levels tested, only the RC muscles were minimally activated (<6% of the MVIC), and during the external rotation exercises, the subscapularis muscle was minimally activated (<6% of the MVIC). In support of these results, low levels of activity in the infraspinatus and supraspinatus muscles were previously reported in studies investigating high-load shoulder internal rotation exercises with the arm by the side. It would seem, therefore, that in subjects who are healthy, the RC muscles are not recruited to stabilize the shoulder joint during shoulder rotation exercises with the arm by the side (ie, co-contraction), even as rotation resistance increases substantially.

These results indicate that, with the arm in the pendant position in people who are healthy, passive shoulder joint structures (eg, the superior shoulder capsule, the superior glenohumeral ligament, and the coracohumeral ligament) can provide an adequate stabilizing force to maintain the head of the humerus in the glenoid fossa under rotation load. Further research is needed to determine whether the motor strategy used to deal with increasing internal and external rotation resistance when the arm is by the side, as demonstrated by the subjects without shoulder dysfunction in the present study, also is used by people with shoulder dysfunction.

The results of this study provide further evidence that the supraspinatus muscle is an external rotator of the shoulder joint. During the high-load external rotation exercise, the supraspinatus muscle was recruited at approximately 70% of the average activity level in the infraspinatus muscle and at almost twice the average activity level in the posterior deltoid muscle. Although activity levels were lower than those demonstrated in the present study, previous research reported substantial supraspinatus muscle activity during high-load external rotation exercises. Despite the growing body of evidence for the role of the supraspinatus muscle in producing shoulder external rotation during concentric contraction, anatomy books rarely attribute this action to the supraspinatus muscle.

The fact that the supraspinatus muscle contributes to external rotation would help to explain the high predictive value of weakness in shoulder external rotation for the diagnosis of RC tears. Tears in the RC most commonly occur superiorly in the region of the insertion of the supraspinatus tendon. Although a superior tear in the RC will affect the function of most of the RC muscles because of the intricate blending of the RC tendons and the shoulder joint capsule, it will involve the supraspinatus tendon to a greater extent. Because of the role of the supraspinatus muscle in producing external rotation torque, weakness in shoulder external rotation would be a likely consequence of substantial injury to the supraspinatus tendon.

Conclusion

The results of the present study indicate that, in people who are healthy, the motor strategy used to deal with increasing internal and external rotation resistance when the arm is by the side is to increase activity in a systematic fashion in all shoulder rotation torque-generating muscles, including the RC muscles. In people without shoulder symptoms, graduated internal rotation exercises with the arm in the pendant position will recruit the anterior RC (subscapularis muscle), and graduated external rotation exercises will recruit the posterior RC (infra- and supraspinatus muscles). Further research is needed to determine whether this motor strategy also is used by people with shoulder dysfunction.
Dr Ginn and Dr Halaki provided concept/idea/research design, project management, and facilities/equipment. All authors provided writing and data collection and analysis. Ms Dark provided subjects.

The University of Sydney Human Ethics Committee approved the experimental procedures used in this study.

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References