Electromyographic Activity of Selected Shoulder Muscles in Commonly Used Therapeutic Exercises

**Background and Purpose.** The purpose of this study was to evaluate and compare the muscle activity of the supraspinatus, infraspinatus, teres minor, and lower trapezius muscles during commonly prescribed therapeutic exercises in subjects with and without shoulder pathology. **Subjects.** Twenty healthy subjects (9 male, 11 female) and 20 subjects with recurrent unilateral shoulder pain and weakness (14 male, 6 female), aged 18 to 40 years (X=28, SD=5.8), participated in this study. **Methods.** Subjects performed each of the following exercises using a hand-held weight: prone lateral (external) rotation, sidelying lateral rotation, and arm elevation in the scapular plane. Indwelling fine-wire electrodes recorded electromyographic (EMG) activity during each exercise. The EMG activity in five phases of concentric contraction of each exercise was averaged and divided into three equal time intervals. Mean EMG values normalized to maximal activity for the entire phase of concentric contraction and for each of the three intervals were used in subsequent analyses. **Results.** Two-way repeated-measures analyses of variance (ANOVA)s revealed between-group differences only in the prone lateral rotation exercise. Compared with subjects without shoulder pathology, subjects with shoulder pain showed significantly greater EMG activity in the infraspinatus muscle and less activity in the supraspinatus muscle during this exercise. **Conclusion and Discussion.** These results suggest that the pattern of muscle activation during specific shoulder movements in patients with shoulder pain may be related to pathology. Future studies are needed to determine whether an imbalance in neuromuscular control is a factor contributing directly to shoulder dysfunction or whether such an imbalance is secondary to some pathology. [Ballantyne BT, O'Hare SJ, Paschall JL, et al. Electromyographic activity of selected shoulder muscles in commonly used therapeutic exercises. Phys Ther. 1993;73:668-682.]

**Key Words:** Electromyography; Exercise, general; Muscle performance, upper extremity; Shoulder; Upper extremity, shoulder.

Therapeutic exercises are used by physical therapists as an integral component of the rehabilitation of rotator cuff injuries. Exercise protocols are established on the basis of what is known of the functional anatomy and biomechanics of the shoulder complex, previous electromyographic (EMG) studies, and clinical experience. These protocols are primarily directed toward (1) increasing tension-generating capability, flexibility, and endurance in isolated muscles that demonstrate deficiency and (2) restoring the normal kinematics of glenohumeral (GH) and scapulothoracic motion.

To produce normal motion, muscles controlling the shoulder complex must function together in a well-coordinated and efficient manner. Only recently have investigators begun to analyze the patterns of muscle activation in normal, uninjured shoulders during the performance of therapeutic exercises that are routinely used in the clinic. The goal of these studies has been to determine which exercises are most useful in activating specific muscles of the shoulder joint complex. Limited information is available evaluating whether patterns of EMG activity are similar to normal patterns when shoulder pathology exists.

In 1982, Jobe and Moynes suggested that supraspinatus muscle activity...
could be isolated from the activity of other rotator cuff muscles during elevation of the arm in the scapular plane with full medial (internal) rotation of the GH joint, a maneuver commonly referred to as the “empty can” (EC) exercise. A more recent study by Townsend et al. showed similar results. They reported peak activity in the EC exercise to be 74% of that elicited during a maximal voluntary isometric contraction (MVIC), in which subjects performed the exercise in a seated position while holding a light weight. A valuable comparison made in this study was the evaluation of arm elevation in both the frontal and scapular planes. Performing elevation in the frontal plane was not found to significantly activate the supraspinatus muscle according to the criteria used by these authors. These results are in contrast to those reported by Blackburn et al., whose subjects produced the greatest supraspinatus muscle activity when positioned prone while lifting the arm into horizontal abduction at 100 degrees and maintaining extreme lateral (external) rotation. Making direct comparisons between studies is complicated, however, by methodological differences in the quantification of EMG data and the amount of resistance used in each of the exercises.

Infra spinatus and teres minor muscles have been shown to parallel each other in both pattern and extent of activity in many of the movements that have been tested. Jobe and Moxnes found this to be true in sidelying lateral rotation (SLR) with the arm held close to the side and the elbow flexed 90 degrees. Townsend and co-workers supported this finding, reporting that the SLR exercise elicited the most activity in the teres minor muscle and was the second most effective exercise in activating the infraspinatus muscle. Both muscles were active over approximately 50% of the duration of the exercise and reached levels of activation near 80% to 85% of MVIC. Other investigators report success in selectively activating the infraspinatus and teres minor muscles in prone lateral rotation (PLR) with the upper arm supported and the elbow flexed to 90 degrees. Similar findings have been reported for other functional and sport-specific movements that require GH abduction with full lateral rotation.

One of the few studies to include a group of subjects with an identifiable shoulder pathology suggested that neuromuscular imbalance in activating shoulder muscles during the execution of a skilled motor behavior may be an important etiological factor to be considered in evaluating shoulder dysfunction. No studies have been reported that determined whether such an imbalance is detectable in a group of patients involved in a rehabilitation program. The purpose of this study, therefore, was to evaluate and compare muscle activity in the supraspinatus, infraspinatus, teres minor, and lower trapezius muscle in subjects with and without shoulder pathology who performed commonly used therapeutic exercises. This information may be useful to therapists in prescribing the most efficient and effective therapeutic exercise programs designed to ameliorate dysfunction.

Method

Subjects

Subjects for this study were divided into two groups. Twenty subjects (9 men, 11 women) with no history of shoulder pathology comprised one group. A second group consisted of 20 individuals (14 men, 6 women) who reported recurrent unilateral shoulder pain of at least 6 months' duration that limited their occupational or recreational activities. Subjects in this group either were former or current patients treated for shoulder pain at a local outpatient clinic or were recruited from the community. Both groups of subjects ranged in age from 18 to 40 years (X=28, SD=5.8).

A thorough examination of the shoulder complex, including routine clinical tests of strength, stability, posture, range of motion (ROM), and so forth, was performed on each subject. Criteria for subject selection in the group with shoulder pain included (1) unilateral shoulder pain that persisted for not longer than 24 to 36 hours after strenuous upper-extremity activity and (2) unilateral weakness in lateral rotation and abduction in the scapular plane, with or without clinical signs of GH joint instability. These criteria are consistent with a stage II impingement syndrome involving fibrosis and tendinitis of the rotator cuff, as described by Neer.

Weakness was assessed using manual muscle testing (MMT) procedures as outlined by Yocum. Testing of the lateral rotators was done with both arms adducted at the side and the

BT Ballantyne, PT, is Associate Instructor, Physical Therapy Graduate Program, The University of Iowa, 2600 Steindler Bldg. Iowa City, IA 52242-1008 (USA). Address all correspondence to Mr Ballantyne.

SJ O'Hare, PT, is Staff Therapist, Edward Hospital, Naperville, IL 60560.

JL Paschall, PT, is Staff Therapist, Pacific Institute of Rehabilitation, Roseburg, OR 97470.

MM Pavia-Smith, PT, is Staff Therapist, Gary Nedevaid and Associates, Leila Hospital, Battle Creek, MI 49010.

AM Pitz, PT, is Staff Therapist, University of Iowa Hospitals and Clinics, Iowa City, IA 52242.

GL Soderberg, PhD, PT, FAPTA, is Director and Professor, Department of Physical Therapy, Creighton University, 2500 California Plaza, Omaha, NE 68178. He was Director and Professor, Physical Therapy Graduate Program, The University of Iowa, at the time the study was conducted.

Ms O’Hare, Ms Paschall, Ms Pavia-Smith, and Ms Pitz were students at The University of Iowa at the time the study was conducted.

This study was approved by the Human Subjects Committee of the College of Medicine at The University of Iowa.

This article was submitted October 6, 1992, and was accepted May 18, 1993.
elbows flexed to 90 degrees. Abduction was tested with both arms elevated to 90 degrees in the plane of the scapula while maintaining maximal medial rotation. Unilateral weakness was defined as an inability to maintain the affected arm in the test position against maximum resistance applied at the wrist. All subjects were able to accept moderate resistance on the affected side in each test position, equivalent to an MMT grade of Good according to the grading system of Daniels and Worthingham.10

Glenohumeral joint stability was assessed in the anterior, posterior, and inferior directions using the "load and shift maneuver" described by Silliman and Hawkins.11 These tests involved the application of a directional force to the humeral head with the arm abducted to 60 degrees. With the subject fully relaxed, the examiner palpated the apex of the humeral head as the force was applied and observed the relative amount of passive translation that occurred between the tip of the acromion and the head of the humerus. Using these maneuvers, instability was defined as relative translation of the humeral head 1 to 2 cm from the resting position of the joint before the force was applied.

Among the other factors evaluated were posture, impingement, crepitus, and ROM. Subjects were observed from the front, side, and back for gross postural abnormalities that might relate to shoulder dysfunction. As indicated in Table 1, the most common finding was upper-extremity medial rotation in standing. The impingement tests used were those described by Neer and Welsh12 and Hawkins and Kennedy.13 Table 1 presents the positive signs most frequently found in the clinical examinations of subjects with shoulder pathology. None of these patients had signs of acute inflammation or reported a history of subluxation or dislocation. We excluded from participation subjects who had (1) received a cortisone injection in the 2 years prior to testing or (2) undergone any corrective surgical procedures for their shoulder problem. All subjects provided their informed consent prior to participation in the study.

### Instrumentation

The EMG data were acquired using standard indwelling, fine-wire electrodes.14 Each electrode consisted of two 50-μm wires that were inserted into a 27-gauge hypodermic needle with 1 to 2 mm of insulation burned from the end. The wires were bent to allow 3 mm of wire to extend back over the beveled tip of the needle. All electrodes were gas sterilized prior to use. The EMG signals were led to a high-impedance (15 mΩ at 100 Hz) differential amplifier (Model GCS-67) following on-site preamplification. The combined preamplifier and main amplifier system permitted a gain of 500 to 10,000 with a bandwidth of 40 Hz to 4 kHz. The common mode rejection ratio was 87 dB at 60 Hz.

A custom-made electrogoniometer was designed using a precision potentiometer15 (10 kΩ) with a lightweight movable arm that was mounted on an adjustable boom. The movable arm was secured to the subject's arm to determine the ROM pertinent to each exercise. The signal from the electrogoniometer was cabled to a DC amplifier (Model ELG-67) with an input voltage range of ±1 V. The electrogoniometer was calibrated to allow conversion of the voltage output to the equivalent degrees of motion. The electrogoniometer signal and EMG data were continuously displayed on an oscilloscope to monitor signal quality and recorded on FM tape at a speed of 38.1 cm (15 in) per second. The frequency response of the FM recorder16 was DC to 5,000 Hz. To assist in confirming proper electrode function, EMG data were input into a Grass audio monitor.

### Procedure

Prior to data collection, we determined the weight to be used in each exercise on the basis of hand-held dynamometric measurements. An investigator placed the dynamometer just proximal to the ulnar styloid process when the subject's arm was placed at the end range of each exercise position. The subject was instructed to maintain that position against the examiner's resistance. When the subject was no longer able to overcome the resistance without substitution of other muscles, the value displayed on the dial of the dynamometer was recorded in kilograms of force. Substitution was defined as any deviation in position of any part of the shoulder complex or trunk from the initial isometric position. To standardize the amount of weight used, 25% of the average of three dynamometric measurements in

---

*California Fine Wire Co, 338 S 4th St, PO Box 446, Grover City, CA 93433.

1Therapeutics Unlimited Inc, 2835 Friendship St, Iowa City, IA 52245.

2Spectrol, San Gabriel, CA 91776.

3Model 7313, Tektronix Inc, Howard Vollum Industrial Park, PO Box 500, Beaverton, OR 97077.

4Model 3969A, Hewlett-Packard Co, 3000 Hanover St, Palo Alto, CA 94303.

5Model AM7, Grass Instrument Co, 101 Old Colony Ave, Quincy, MA 02169.

6Model DPP-25KG, Chatillon, 7609 Business Park Dr, Greensboro, NC 27409.

Table 1. Most Frequent Positive Clinical Signs Among Subjects With Shoulder Pathology (n=20)

<table>
<thead>
<tr>
<th>Clinical Sign</th>
<th>Percentage of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation of upper-extremity medial rotation in standing posture</td>
<td>35</td>
</tr>
<tr>
<td>Anterior glenohumeral joint instability</td>
<td>40</td>
</tr>
<tr>
<td>Impingement</td>
<td>25</td>
</tr>
<tr>
<td>Crepitus</td>
<td>50</td>
</tr>
</tbody>
</table>

---

670 / 29

Physical Therapy / Volume 73, Number 10 / October 1993
each of the test positions was calculated for each subject. Based on a pilot study, this load was chosen to avoid producing fatigue or pain, particularly in subjects with shoulder pathology, and to minimize the need for substitution. Values obtained in kilograms were converted to pounds and subsequently rounded to the nearest pound.

Following an explanation of the experimental procedure, subjects were positioned prone on a plinth and the skin overlying the muscles to be tested was cleansed with alcohol. The electrodes were inserted into the supraspinatus, infraspinatus, teres minor, and lower trapezius muscles according to the locations described by Delagi and Perotto. After withdrawal of the needle, the free ends of the wires were bared of insulation with the flame of a match and connected to the preamplifier assembly. Each preamplifier was placed approximately 2.5 cm (1 in) from the electrode insertion site, avoiding bony prominences. The reference electrode was placed on the wrist contralateral to the side tested. Prior to testing, we verified electrode placement and adjusted amplifier gain settings by monitoring the EMG signals on an oscilloscope while providing manual resistance to each of the muscles under consideration.

The exercises chosen, primarily on the basis of their clinical use, were prone lateral rotation (PLR), sidelying lateral rotation (SLR), and the "empty-can" (EC) exercise. Exercises were performed in a random order, with subjects completing seven repetitions of each exercise. The PLR exercise required the subject to lie prone with the arm abducted 90 degrees and the elbow at 90 degrees of flexion. The subject moved from neutral to a position of full lateral rotation of the GH joint. In the SLR exercise, the subject was positioned sidelying with the humerus aligned parallel to the trunk and the elbow flexed 90 degrees. From a starting position with the forearm resting on the abdomen, the subject moved to a position of full lateral rotation. The EC exercise was performed with the subject standing. The exercise required the subject to elevate the arm in the scapular plane while maintaining full medial rotation. Subjects were instructed not to elevate their arms beyond 90 degrees.

The timing of each exercise was guided by a metronome set at 44 beats per minute, which corresponded to approximately 66% of the arm moved through a 90-degree arc of motion. Subjects practiced each exercise without the weight until performance met velocity requirements. That is, if subjects were completing each repetition of the exercise in reasonably good time with the beat of the metronome, their exercise velocity was judged to be appropriate. The number of practice trials ranged from three to five. Subjects were given verbal commands to begin and end each exercise trial. If EMG or electrogoniometer artifact was detected during a trial, attempts were made to improve signal quality and the trial was repeated. Typically, the aberrant signals were easily identified as randomly occurring, large-amplitude, low-frequency waveforms presumably resulting from movement artifact. If the problem could not be corrected, the data for that muscle were not included in the analyses. In only 5 of the 40 subjects tested, data were not obtained from one of the four muscles of interest in one of the exercises.

The ensemble averages were then divided into three equal time intervals. This was done to better characterize the pattern of response of each muscle to the changing demands for muscle activity during the execution of these exercises. In our view, if between-group differences did exist, those differences would be most apparent at those times when the greatest demands were placed on the muscle. Such differences might otherwise be obscured if only data over the entire period of the exercise were analyzed.

From the averaged signal, mean values for the entire phase of concentric contraction and for each of the three intervals within this phase were calculated and recorded. Each subject's EMG values for each muscle were subsequently normalized as a percentage of the highest mean value in any

**Data Reduction**

Electromyographic and electrogoniometric signals were transferred from FM tape to a microcomputer at a sampling rate of 1,000 Hz per channel through a 12-bit analog-to-digital converter for off-line analysis. DATAPAC II software was used to full-wave rectify and smooth the EMG data using a 50-millisecond time constant. The same time constant was applied to smooth the electrogoniometric data without prior rectification.

Following data transfer, the processed signals were displayed on a computer monitor. Five phases of exercises using concentric contractions were chosen based on signal quality and consistency of performance, as indicated by total ROM and velocity. The events were selected at the beginning and end of the ROM, requiring concentric muscle contractions on the basis of change in direction of the electrogoniometer trace. Events were marked on the basis of observation, as illustrated in Figure 1, with the phases of concentric contraction bounded by pairs of vertical lines. Five events were chosen in order to obtain an ensemble average of the EMG data from each individual.

The ensemble averages were then divided into three equal time intervals. This was done to better characterize the pattern of response of each muscle to the changing demands for muscle activity during the execution of these exercises. In our view, if between-group differences did exist, those differences would be most apparent at those times when the greatest demands were placed on the muscle. Such differences might otherwise be obscured if only data over the entire period of the exercise were analyzed.

From the averaged signal, mean values for the entire phase of concentric contraction and for each of the three intervals within this phase were calculated and recorded. Each subject's EMG values for each muscle were subsequently normalized as a percentage of the highest mean value in any
three exercises would be expressed as a proportion of the activity in the third exercise interval.

Because of between-subject differences in the pattern of muscle usage in complex motor activities, the exercise interval in which the highest mean EMG activity occurred in each muscle was anticipated to vary among subjects. An indication of this variability is reflected in the distribution of exercise intervals used to normalize EMG data for each muscle. Table 2 summarizes the locations of the intervals most frequently found to elicit the highest EMG activity for each muscle. As is shown, the highest EMG values generally occurred in one of only three exercise intervals for each muscle. Most commonly, this occurred in the third interval of either the EC or PLR exercise, as would be predicted because the influence of gravity was at its maximum in these positions.

### Data Analysis

A two-way (group×ROM) repeated-measures analysis of variance (ANOVA) was used to assess significant differences in the total ROM between subject groups in each of the three exercises. To evaluate between-group differences in EMG among the three exercises, a two-way (group×exercise) repeated-measures ANOVA procedure was performed separately for each muscle. For these analyses, the mean normalized EMG values over the entire averaged ROM were compared across exercises for each muscle.

The same repeated-measures design (group×interval) was used for each exercise to detect differences in the level of muscle activity across exercise intervals for each muscle. The mean normalized EMG within each of these intervals was used to determine differences in muscle activity between groups and among intervals. Because across-muscle comparisons were not appropriate, analyses for each muscle and each exercise were conducted separately, thus yielding 12 additional ANOVAs (four muscles×three exercis-
Table 3. Summary Statistics for Range of Motion (ROM) by Group and Exercise

<table>
<thead>
<tr>
<th>Group</th>
<th>Exercise*</th>
<th>ROM (°)</th>
<th>X</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects without</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>shoulder pathology</td>
<td>EC</td>
<td>87.5</td>
<td>15.3</td>
<td></td>
</tr>
<tr>
<td>(n=20)</td>
<td>PLR</td>
<td>83.2</td>
<td>8.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SLR</td>
<td>85.9</td>
<td>25.6</td>
<td></td>
</tr>
<tr>
<td>Subjects with</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>shoulder pathology</td>
<td>EC</td>
<td>86.2</td>
<td>10.5</td>
<td></td>
</tr>
<tr>
<td>(n=20)</td>
<td>PLR</td>
<td>80.9</td>
<td>11.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SLR</td>
<td>89.0</td>
<td>20.6</td>
<td></td>
</tr>
</tbody>
</table>

*EC=“empty can,” PLR=prone lateral rotation, SLR=sidelying lateral rotation.

Specific differences were determined from a post hoc analysis using a Bonferroni adjusted t test for multiple pair-wise comparisons while maintaining an alpha level of .05 for significance in each of the analyses.

**Results**

Statistical analysis of the ROM data revealed no significant differences in ROM between groups or across exercises. Table 3 presents the descriptive statistics for this portion of the analysis. In analyzing the mean EMG activity over the entire phase of concentric contraction of each exercise, no significant group difference was revealed in any of the muscles tested. A significant effect due to exercise, however, was found in all four muscles. These data are summarized in Figure 2, showing which exercises were most effective in producing activity in each muscle.

To evaluate how the muscle was activated within each exercise, mean normalized EMG values for the three intervals of an exercise were compared in each of the muscles tested. No group difference was found in any of the muscles evaluated in the EC exercise. The data, therefore, were averaged across all subjects. The ANOVAs revealed a significant main effect for exercise interval for all muscles. In the EC exercise, both the supraspinatus and lower trapezius muscles showed progressively increasing activity throughout the ROM (Fig. 3). Infraspinatus and teres minor muscles were only minimally active (<10%) in this exercise.

Similarly, the analyses for the SLR exercise demonstrated effects due only to the exercise interval for each of the muscles tested, without a significant group effect. Relatively moderate amounts (20%-60%) of EMG activity were elicited in each of the four muscles, with the infraspinatus and teres minor muscles being most active in the second and third exercise intervals (Fig. 4).

Table 4 summarizes the results of the pair-wise comparisons between intervals for each muscle and each exercise. Only the probability values for those interval comparisons for which a significant difference was found are reported.

Table 4 shows that in the PLR exercise, EMG activity was different in each of the interval comparisons for all of the muscles under investigation. Although the presence of pathology did not influence muscle activity in either the EC or SLR exercise, the PLR

---

Figure 2. Means and standard errors (vertical bars) for normalized electromyographic (EMG) values over the entire concentric phase of each exercise for each muscle. Asterisk (*) indicates significant difference from prone lateral rotation (PLR); plus sign (+) indicates significant difference from sidelying lateral rotation (SLR) (P<.05). (EC=“empty-can” exercise.) Figure represents combined data from both subjects with shoulder pathology (n=20) and subjects without shoulder pathology (n=20).
exercise showed a group effect in both the supraspinatus and infraspinatus muscles (Figs. 5A and 5B). The ANOVA and subsequent follow-up analysis for the supraspinatus muscle revealed a group \times interval interaction in which the EMG activity in intervals 2 and 3 was higher in the subjects without shoulder pathology than in the subjects with shoulder pathology. In the analysis for the infraspinatus muscle, a significant group main effect indicated that the mean normalized EMG elicited during the PLR exercise was consistently higher in the subjects with shoulder pathology than in the subjects without shoulder pathology throughout the entire ROM. No group effect was demonstrated for either the teres minor or lower trapezius muscles in this exercise (Figs. 5C and 5D).

**Discussion**

The ROM data from the electrogoniometer were assessed in order to establish that EMG values from the ensemble averages were analyzed over comparable portions of the ROM in each exercise. As shown in Table 3, the greatest variability was observed in the SLR exercise. This result was anticipated because the starting and ending positions were least well-defined for this exercise, depending heavily on subject comfort and flexibility.

A major factor contributing to variability was that five subjects without symptoms and four subjects with shoulder pathology had ROM values between 100 and 125 degrees for the SLR exercise. Compared with other members of their respective groups, these subjects began the exercise in a position of relatively more medial rotation and ended in one of greater relative lateral rotation. Although this resulted in a larger arc of motion for these individuals, the degree of overlap with intervals used for other subjects was not considered significant and we believe this should not have affected the overall interpretation of the EMG results. Similar circumstances explain the variability in the other two exercises.

The choice of exercises included in this investigation was based in part on previous work demonstrating the relative specificity of each exercise in activating the muscles of interest. Because of the limited number of exercises, no inferences should be made regarding the optimal exercise for a given muscle. The relative effectiveness of each of the exercises in eliciting muscle activity, however, is shown in the results of the group \times exercise analyses, which generally confirm
Table 4. Interval Comparisons by Muscle and Exercise

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Muscle</th>
<th>EC</th>
<th>SLR</th>
<th>PLR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 vs 2</td>
<td>1 vs 3</td>
<td>2 vs 3</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>.0001</td>
<td>.0001</td>
<td>.0032</td>
<td>.0001</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>.010</td>
<td>.0001</td>
<td>.0013</td>
<td>.0001</td>
</tr>
<tr>
<td>Teres minor</td>
<td>.0004</td>
<td>.0004</td>
<td>.0001</td>
<td>.0001</td>
</tr>
<tr>
<td>Lower trapezius</td>
<td>.0004</td>
<td>.0001</td>
<td>.0025</td>
<td>.0049</td>
</tr>
</tbody>
</table>

*Probability values for significant pair-wise differences between intervals.

EC = "empty can," SLR = sidelying lateral rotation, PLR = prone lateral rotation.

earlier reports found in the literature (Fig. 2).

As expected, the EC exercise was clearly the most effective in activating the supraspinatus muscle. Of the 16 exercises evaluated by Townsend et al., the EC exercise was second only to the military press exercise in eliciting supraspinatus muscle activity, thereby supporting our result. In the lower trapezius muscle, the PLR exercise elicited the most activity, whereas the EC exercise was least effective for this muscle. This trend reflects the role of the lower trapezius muscle as a stabilizer of the scapula and agrees favorably with those researchers who argue that this muscle participates minimally in GH abduction below 90 degrees. Although Moseley et al. reported that SLR did not qualify as an exercise that significantly challenged the lower trapezius muscle, the amount of resistance used was not standardized across subjects or across exercises within a subject and may account for the result that differs from our own. No previous report of lower trapezius muscle activity during PLR could be found.

The PLR and SLR exercises proved equally effective in eliciting activity from the infraspinatus and teres minor muscles, reflecting their functional roles as prime movers in lateral rotation. These same exercises were evaluated by Blackburn et al., who reported significantly greater activity in infraspinatus and teres minor muscles in the PLR exercise than in the SLR exercise. Their result, however, may have been due to the method used to quantify EMG activity, as comparisons of muscle activity were made between exercises only at a time when the arm was perpendicular to gravity. Thus, EMG activity in the final position of the PLR exercise was compared with that in the middle of the ROM of the SLR exercise, a method that in our opinion severely limits the interpretation of those findings.

The results of the group x interval analyses show that the general pattern of muscle activity within each of the three exercises was similar for subjects with and without shoulder pathology. For each muscle, a characteristic pattern of activity was demonstrated in each of the exercises studied. Only one of the three exercises (ie, PLR) showed significant between-group differences. These differences were related to the extent to which the supraspinatus and infraspinatus muscles were activated in normal as compared with pathologic shoulders. Subjects with shoulder pathology were found to have significantly greater activity in the infraspinatus muscle and less activity in the supraspinatus muscle as the GH joint was laterally rotated in a prone position (Figs. 5A and 5B). In our view, these findings sug-
gest an imbalance in the activation of the posterior rotator cuff muscles during specific shoulder movements. Our analysis, however, was of EMG values, rather than ratios, and our data therefore did not directly examine the issue of imbalance (relative values). Whether an imbalance in muscle activity is part of the primary pathology contributing to shoulder dysfunction or is secondary to some other pathology cannot be discerned from the results of this study.

Imbalances have been identified in pathologic shoulder motion in other studies, either in the form of torque ratios or EMG activity. Using isokinetic strength testing, Warner and colleagues\(^2\) showed that medial/lateral rotation torque ratios were higher in the shoulders of patients classified as either having GH joint instability or impingement problems. In addition, an association between lateral rotator weakness, anterior GH joint instability, and impingement syndrome was found. A similar association was characteristic of the subjects with shoulder pathology in our study. All of the subjects with shoulder pathology demonstrated asymmetrical weakness in MMT of the lateral rotators, and four of the eight subjects who exhibited positive clinical signs of anterior GH joint instability also showed a positive sign for impingement.

Lending further support for our hypothesis, Glousman and co-workers\(^6\) reported an imbalance in muscle activity in a group of athletes with chronic anterior instability of the GH joint in various shoulder muscles throughout the five phases of a throwing motion. Of particular interest was the finding that athletes with GH joint instability demonstrated significantly greater infraspinatus muscle EMG activity during the early cocking phase of throwing, a motion somewhat analogous to the PLR exercise in our study in that the arm is maintained in an abducted position as the GH joint is laterally rotated.

In addition to muscle imbalance, impingement and instability problems have also been associated with im-

proper mechanics of the GH joint. Howell et al\(^20\) demonstrated that the normal posterior translation of the humeral head that accompanies lateral rotation of the GH joint was absent in a group of patients with anterior shoulder instability. Previous authors\(^21-25\) have proposed that the posterior rotator cuff musculature plays a critical role in the dynamic stabilization of the GH joint.

Cain et al\(^23\) have suggested that, in addition to controlling lateral rotation, the infraspinatus and teres minor muscles are capable of reducing the strain in passive structures that constrain the motion of the humeral head in the glenoid fossa by pulling the humeral head posteriorly in the normal shoulder. In the presence of instability, the lateral rotators might be expected to increase activity in an attempt to position the humeral head appropriately in the glenoid fossa, thereby preventing an already unstable joint from producing excessive strain of the ligamentous capsule and other soft tissues surrounding the joint. Such an explanation seems tenable to account for the increase in infraspinatus muscle activity observed in our study, given the proportion of subjects with shoulder pathology who demonstrated anterior GH joint instability.

Contributing further to the loss of stability of the GH joint was the diminished activity found in the supraspinatus muscle in the PLR exercise. In the third interval of PLR, mean normalized supraspinatus muscle EMG activity was 33% lower in subjects with shoulder pathology. This finding may represent a pain-inhibited response to impingement of that muscles’ tendon. From an anatomical perspective, the supraspinatus muscle would be more vulnerable to impingement in PLR than in either of the other exercises. In SLR, the arm remained adducted at the side of the body, a position in which lateral rotation would not be expected to compromise the area of the coracoacromial space. Similarly, in the EC exercise, the arm was maintained in maximal medial rotation, thereby placing the insertion of the su-

The appearance of an imbalance in muscle activation in only one of the three exercises investigated suggests that further research is needed to determine whether these differences are a common finding among subjects with shoulder pathology. In particular, studies that show similar differences in muscle activity during more functional movements would be useful in determining whether these relationships have meaningful implications in daily activities. Interestingly, an imbalance was found only in the exercise that placed the arm in an abducted, laterally rotated position. This finding would suggest that future studies examining functional movements that present a similar challenge to the stability of the GH joint may be most likely to reveal relationships that resemble those found in these simple exercises.

**Conclusions**

The results of this study showed that persons with and without rotator cuff pathology use similar patterns of muscle activity to perform common therapeutic exercises. The unique between-group differences found in the relative extent to which the supraspinatus and infraspinatus muscles were activated during the PLR exercise suggest that an imbalance in neuromuscular control may be a factor contributing to shoulder dysfunction in some individuals. Such an imbalance could either be part of the primary pathology leading to dysfunction or a compensatory strategy related to instability or impingement. Because differences were revealed in only one of the three exercises stud-
ied, further investigation is needed to determine whether these relationships have meaningful implications in more functional movements. If these relationships prove to be a common finding among subjects with shoulder pathology, future prospective studies that investigate various treatments applied to this population would be useful to assist in developing more specific protocols designed to correct dysfunction.

References


Commentaries

Following are two commentaries on "Electromyographic Activity of Selected Shoulder Muscles in Commonly Used Therapeutic Exercises."

Ballantyne and colleagues collected data to support the argument that patients with glenohumeral joint pathology demonstrate a different pattern of electromyographic (EMG) activity of some shoulder muscles during selected movements as compared with asymptomatic subjects. The authors concluded, therefore, that an imbalance may exist in the pattern of muscle activation during some shoulder movements in patients with shoulder pain. We believe, however, that there are several issues related to the design of this study that need to be considered when interpreting the meaningfulness of the authors' conclusion. Our queries to the authors relate to what appears to be an unclear rationale for subject selection and, most importantly, to the development of a theoretical argument for explaining the meaningfulness of the results.

The method of patient selection appears to be unclear for two reasons. First, the subjects in the patient group were found by the authors to have a variety of impairments, which may have indicated the presence of numerous pathologies. The heterogeneity of the patient sample is an important issue because the authors in their discussion attempt to explain some of their results based on an impairment (glenohumeral joint instability) that they felt existed in only four of their subjects. Given a more homogeneous sample, the authors may have been able to better explain their results.

Second, the reliability of measurements used for subject inclusion is suspect. The authors required that subjects in the patient group had unilateral weakness of the abductors and lateral (external) rotators but used a method of muscle testing that has no demonstrated evidence of reliability within the grade range used. There are data and theoretical arguments to support the notion that manual muscle test judgments above the grade of Fair are unreliable. We are curious as to why the authors chose not to use an instrument such as a hand-held dynamometer to identify patients with weakness. There are some data to support the reliability of measurements of the shoulder obtained with a hand-held dynamometer.

Many of the other examination procedures used for describing the patient