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Electromyographic Analysis of the Infraspinatus and Deltoid Muscles During
Shoulder External Rotation Exercises With and
Without a Towel Roll

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A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of
Master of Science

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ABSTRACT

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Master of Science

Standing and sidelying external rotation exercises produce high activation of the deltoid and infraspinatus. Holding a towel roll under the arm at 30° shoulder abduction during these exercises may decrease deltoid activity and increase infraspinatus activity. The objective was to determine if the addition of a towel under the arm during standing and sidelying external rotation affects EMG activity of the infraspinatus, middle and posterior deltoid, and pectoralis major, compared to the no towel condition. 20 male volunteers (age; 26 ± 3 , height; $1.80 \text{ m} \pm .07 \text{ m}$, weight; $77 \text{ kg} \pm 10 \text{ kg}$) had right dominant hand, bilaterally healthy shoulders with no current cervical pathology, and no skin infection or lesion of the shoulder. Maximal voluntary isometric contraction for the infraspinatus, middle and posterior deltoid, and pectoralis major and external rotation in standing and sidelying with and without a towel roll were performed. Normalized average and peak EMG amplitude was compared between the towel conditions during standing and sidelying external rotation. Both infraspinatus and pectoralis major activity had no significant differences between the towel conditions in standing and sidelying ($P > .05$). In standing and sidelying, posterior deltoid activity was significantly greater with a towel roll ($.008 \leq P \leq .035$ and $.008 \leq P \leq .018$, respectively). Middle deltoid activity had no significant differences between the towel conditions in standing ($P > .05$). However, in sidelying, middle deltoid activity was significantly lower with a towel roll ($.011 \leq P \leq .000$). The only muscle activation change during standing external rotation with the application of a towel roll was an increase of the posterior deltoid. During sidelying external rotation, holding a towel roll decreased middle deltoid activity and increased posterior deltoid activity. Thus, this study indicates that holding a towel roll under the arm during standing external rotation exercise does not appear to produce desired effects on muscle activation. However, application of a towel roll under the arm could be recommended during sidelying external rotation exercise in order to possibly reduce the superior glide of the humerus, due to decrease muscle activation of the middle deltoid.

Keywords: towel roll, standing, sidelying, external rotation, EMG

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INTRODUCTION

Shoulder pain occurs in up to 67% of the population at some time in their lifetime.¹ Rotator cuff disorders are one of the most common causes of shoulder pain.²⁻⁶ During normal glenohumeral joint motion, all the rotator cuff muscles are activated together and cause stabilization of the humeral head in the glenoid fossa centrally.^{7, 8} During shoulder abduction, for example, superior movement of the humeral head with contraction of the deltoid and the supraspinatus is opposed by inferior movement of the humeral head with contraction of the infraspinatus, the teres minor, and the subscapularis.⁷⁻¹⁰

One of the most common rotator cuff exercises is an external rotation exercise that aims at strengthening the infraspinatus, which is the main external rotator muscle of the rotator cuff.⁹ Few authors¹¹⁻¹³ and, anecdotally, clinicians have suggested using the adduction strategy of using a towel roll between the arm and side of the body during the external rotation exercise, to stabilize the arm to the side of the body. The shoulder adduction force theoretically creates reciprocal inhibition of the abductor muscles, such as the deltoid.^{9, 12, 15} As a clinician, minimizing the deltoid muscle activation during shoulder exercise is important because that may reduce superior glide of the humeral head.^{9, 15} Reduction of the abduction movement may also provide more isolated muscle activation of the infraspinatus.^{9, 12} A previous study found that the contribution of the middle deltoid during standing external rotation with shoulder adduction was significantly lower at 10% maximal voluntary isometric contraction compared to standing external rotation alone.⁹ However, there was no significant increase of infraspinatus activity during standing external rotation with shoulder adduction at any load, compared to standing external rotation alone.^{9, 13, 16}

Sidelying external rotation exercise has also been used in clinics as often as standing external rotation exercise.¹² A few authors found that muscle activation of the infraspinatus and the teres minor was the highest in sidelying external rotation exercise compared to other external rotation exercises.^{13, 16} However, sidelying external rotation exercise had higher middle deltoid activity than standing external rotation exercise.^{13, 16} Kolber et al¹² recommends use of a towel roll to reduce the middle deltoid activity during sidelying external rotation exercise, but there is no study to show the effect of a towel roll on muscle activation during sidelying external rotation exercise.

Another possible positive effect of a towel roll is less tension is produced on the supraspinatus and infraspinatus tendons in the 30° shoulder abducted position than in the 0° shoulder abducted position¹⁷, which may also increase blood flow to the tendon by reduction of compression force from humeral head to these tendons.¹⁸

The purpose of this study was to compare muscle activity of the infraspinatus, posterior and middle deltoid, and pectoralis major during standing external rotation exercise with and without a towel roll (30° vs 0° shoulder abducted positions) and during sidelying external rotation exercise with and without a towel roll (30° vs 0° shoulder abducted positions). Our hypothesis was that there would be increased activation of the infraspinatus and decreased activation of the middle deltoid during standing and sidelying external rotation with a towel roll.

METHODS

Design

The experiment was a controlled laboratory study, with one independent variable (with and without a towel roll). The dependent variable was the amplitude of the infraspinatus, middle and posterior deltoid, and pectoralis major electromyography (EMG) activity.

Subjects

Twenty male volunteers (age; 26 ± 3 , height; $1.80 \text{ m} \pm .07 \text{ m}$, weight; $77 \text{ kg} \pm 10 \text{ kg}$) were recruited and all signed an informed consent that was approved by the Institutional Review Board. All subjects had to meet five criteria to participate in this study: 1) right dominant hand; 2) no current pathology in the cervical region; 3) no history of shoulder pathology or surgery; 4) no skin disease or lesion on the shoulder region; and 5) no infection of the shoulder region.

Procedures

A tester instructed all subjects as to what to do before the trial. Subjects picked days for practice and experiment sessions. The practice session and the experiment session were separated by at least seven days. The right dominant shoulder of each subject was used for both practice and experiment sessions.

For the practice session, the subjects practiced four maximal voluntary isometric contractions (MVICs) and four external rotation exercises. Figures 1, 2, 3, and 4 show the four MVIC positions^{19, 20}. Figures 5, 6, 7, 8, 9, 10, 11, and 12 show the four external rotation exercises.

The 30° angle of shoulder abduction was confirmed by placing an inclinometer (MiE, Medical Research *Ltd*, UK) on the lateral-middle part of the upper arm while the shoulder was adducted against a towel roll. The thickness of the towel roll was adjusted to each subject, so that 30° shoulder abduction was maintained for all subjects. The right dominant elbow was fixed to 90° by using an elbow brace (HEX Elbow Brace, BREG Inc, Vista, CA) set at 90° . The starting position of the shoulder external rotation for all exercises was at neutral shoulder rotation (0° shoulder external rotation). In the concentric phase, the shoulder was externally rotated to maximum (external rotation range of motion, $74.4^\circ \pm 10.8^\circ$), and then the shoulder was internally

rotated to the neutral position in the eccentric phase. The speed of the repetitions was controlled by a metronome, which was set to one beat per second. Each concentric and eccentric phase was performed during one beat (about 74.4°/s).

For the standing external rotation exercise with and without a towel roll, all subjects used a green colored elastic band (TheraBand, Hygienic Corporation, Akron, OH), which was defined as heavy resistance. Distance (260 cm) between the end of the elastic band and a hand gripper at the starting position was maintained for all subjects. For sidelying external rotation, all subjects used a 4-lb dumbbell as resistance. All subjects were allowed to practice these exercises until they became familiar.

For the experiment session, all subjects did not have pain or soreness in the shoulder region from the practice session. Prior to applying the surface electrodes to the skin, the skin near the surface electrode locations was cleaned so as to reduce skin impedance. This included the shaving of hair, scraping the skin smoothly with sandpaper, and wiping the area with an alcohol swab. Disposable pre-gelled Ag-AgCl surface electrodes (BIOPAC Systems, Inc., Goleta, CA) with 2 cm interelectrode distance were used to record surface EMG activity. The electrodes were placed over four muscles: the infraspinatus, the middle and posterior deltoid, and the sternal part of the pectoralis major. Figure 13 showed the locations of the electrodes for these muscles.²¹ The same tester placed the electrodes on all subjects in order to maintain consistency.

After applying the electrodes, a tester confirmed the electrode signals from each muscle by having the subjects stand and isometrically contract the muscles being tested. Each isometric contraction position of these muscles were same as the MVIC positions showed in Figures 1, 2, 3, and 4.

The surface electrodes were attached to the surface EMG system (MP150, BIOPAC Systems, Inc., Santa Barbara, CA). Signals were amplified (DA100B, BIOPAC System Inc., Santa Barbara, CA) from disposable, pre-gelled Ag-AgCl electrodes. The input impedance of the amplifier was 1.0 mega-ohm, with a common mode rejection ratio of 90 dB, band-pass filters from 10 to 500 Hz and a signal to noise ratio of 70 dB and a gain of 1000. EMG data were collected at 1000 Hz. Filtered EMG signals were converted to a root mean square (RMS) signal with a 50 msec moving window.

Prior to starting electromyography (EMG) measurement, all subjects performed warm-up with holding a 1-lb dumbbell and one set of 20 repetitions of pendulum (Figure 14), shoulder flexion, extension, abduction, and external and internal rotations.

Data collection for each subject began with three sets of 4-second MVIC for each muscle to normalize the EMG data. The MVIC testing position was same as the MVIC positions for the practice session (Figures 1, 2, 3, and 4). Resting time between each set was at least three minutes so as to reduce the fatigue effect.

The experimental trials were performed exactly the same as they were in the practice session. One set of 10 repetitions of each exercise was performed with three minutes resting time and EMG signals were recorded for 10 seconds for each trial. Recording was started after the second repetition. The metronome was set at one beat per second, 20 seconds for 10 repetitions; so the 10-second recording captured between the third and seventh repetitions. The recorded EMG signals were normalized by expressing both average and peak EMG values of the subject's five repetitions for each muscle for each trial as a percentage of the MVIC of the same muscle. Testing order was counterbalanced to minimize the fatigue effect. In addition, an accelerometer (Tri-axial Accelerometer 50G, BIOPAC Systems, Inc., Goleta, CA) was placed on the distal,

lateral side of the right forearm during the trials in order to confirm each concentric and eccentric contraction phase on the surface EMG system.

Statistical Analysis

Paired t-tests were used to compare normalized average and peak EMG activity of each muscle during standing and sidelying external rotation with a towel roll versus without a towel roll. Statistical significance was set at $P < .05$. The significant level for all t-test comparisons was adjusted using the false discovery rate procedure ($P < .008 \sim .05$).^{22, 23} The false discovery rate adjustment procedure is one of numerous multiple comparisons adjustment techniques and was chosen for this analysis because it increases the statistical power of the multiple comparisons.²³

RESULTS

Tables 1 and 2 provide data for normalized average and peak EMG activity of each muscle during standing and sidelying external rotation with and without a towel roll. The following contraction phases of the posterior deltoid in standing position had significantly greater activity in the towel condition than the no towel condition: total average ($P = .016$); concentric average ($P = .026$); eccentric average ($P = .006$); total peak ($P = .035$); and eccentric peak ($P = .008$). The following contraction phases of the posterior deltoid in sidelying position had significantly greater activity in the towel condition than the no towel condition: total average ($P = .013$); concentric average ($P = .015$); eccentric average ($P = .018$); total peak ($P = .009$); concentric peak ($P = .008$); and eccentric peak ($P = .014$). Middle deltoid activity in standing position had no significant difference between the towel condition and the no towel condition ($P > .05$). The following contraction phases of the middle deltoid in the sidelying position had significantly less activity in the towel condition than the no towel condition; total average ($P = .009$); eccentric average ($P = .000$); total peak ($P = .001$); concentric peak ($P = .011$); and

eccentric peak ($P = .003$). However, infraspinatus and pectoralis major activity in both standing and sidelying positions had no significant difference between the towel condition and the no towel condition ($P > .05$). False discovery rates are listed on Tables 1 and 2 as well.

The only muscle activation change during the standing external rotation exercise with a towel roll was an increase of the posterior deltoid. During the sidelying external rotation exercise, the only muscle change with a towel roll was an increase of the posterior deltoid and a decrease of the middle deltoid.

DISCUSSION

Shoulder external rotation exercise has been used as one of the common rotator cuff exercises.^{9, 11-13} However, external rotation exercise not only activates the rotator cuff but also highly activates the middle and posterior deltoid, which is not desired in rotator cuff rehabilitation because the rotator cuff may be unable to overcome superior glide of the humeral head by the deltoid.^{7-10, 13, 15} A few authors^{12, 14-16} have claimed that creating shoulder adduction force by placing a towel roll under the arm during shoulder external rotation exercise may create reciprocal inhibition, which may reduce deltoid activity and isolate the infraspinatus, which possibly increases infraspinatus activity. However, Bitter et al⁹ and Reinold et al¹³ reported that standing shoulder external rotation exercise with a shoulder adduction force did not produce greater activation of the infraspinatus than standing shoulder external rotation alone. In this study, we compared average and peak EMG activity of the infraspinatus, middle and posterior deltoid, and pectoralis major during standing and sidelying external rotation with a towel roll (30° shoulder abduction) and without a towel roll (0° shoulder abduction). Our data are in agreement with these previous studies^{9, 13} that holding a towel roll during standing external rotation does not produce greater activation of the infraspinatus. Furthermore, we found that sidelying external

rotation with a towel roll did not increase activation of the infraspinatus, although middle deltoid activity was reduced. This finding may be explained by the idea that the middle deltoid only abducts the humerus. Thus, regardless of increased or decreased middle deltoid activity during external rotation with a controlled force, isolation of the infraspinatus, which rotates the humerus externally, does not occur unless activation of the other external rotator muscles decreases. Our study and previous studies^{9, 13} support this idea since infraspinatus activation did not change despite of a decrease or no change in activation of the middle deltoid during the external rotation exercises between the towel conditions.

Bitter et al⁹ found only low loads (10% MVIC) during standing isometric external rotation with shoulder adduction decreased activity of the middle deltoid. However, our study did not show decreased activation of the middle deltoid during standing external rotation exercise with a towel roll. This may be due to the fact that our study used higher resistance and isotonic contraction compared to Bitter's study⁹. Instead, activation of the middle deltoid was decreased when a towel roll was used during sidelying external rotation. A possible explanation to this is that most of our subjects seemed to have a difficult time stabilizing a towel roll under the arm during sidelying external rotation. That might activate the other adductor muscles, such as the latissimus dorsi and posterior deltoid, as an alternative to the pectoralis major to hold a towel roll. In this way, reciprocal inhibition could reduce middle deltoid activity.

Previous cadaver studies^{17, 18} found that 30° shoulder abduction position produced less tension on the supraspinatus and infraspinatus tendons than 0° shoulder abduction position and also increased blood flow to the tendons by reduction of compression force from humeral head to these tendons. Kolber et al¹² suggested that using a towel roll to hold the arm at 30° shoulder abduction position during standing and sidelying external rotation exercises may produce a better

outcome for rotator cuff rehabilitation if the reciprocal inhibition of the deltoid and reduction in tension of the supraspinatus and infraspinatus tendons on the humeral head occur at the same time. Our data suggest that holding a towel roll during sidelying external rotation exercise might reduce the tension of these tendons because of possible reduction in superior glide of the humeral head by decreased activity of the middle deltoid.

Our data showed that activation of the posterior deltoid increased during both standing and sidelying external rotation with a towel roll. This result may imply that the posterior deltoid helps shoulder adduction, which is consistent with findings of previous cadaver studies.^{24, 25} Also, the posterior deltoid externally rotates the humerus. However, previous cadaver studies^{24, 25} have shown that the angle of shoulder abduction does not change the external rotation moment arm of the posterior deltoid. Using the same load between the towel conditions and no change in external rotation moment arm between 0° and 30° abduction indicate that an increase in activation of the posterior deltoid in the towel condition during external rotation exercises may be due to an increase in adduction force, but not an increase in external rotation force. Our findings could support this because infraspinatus activation did not decrease in the towel condition even though posterior deltoid activation increased.

In this study, greater EMG activity of the posterior deltoid and no change in EMG activity of the middle deltoid with a towel roll during standing external rotation were different from findings of two previous studies.^{9, 13} This may be due to the different testing methods. Bitter et al⁹ performed isometric contraction at different loads, and the shoulder abduction angle was less than 10°. Reinold et al¹³ performed isotonic contraction with a 10-repetition maximum by using a dumbbell, and the shoulder abduction angle was less than 15°. Even though our testing methods were different, a previous study¹³ and our study imply that a shoulder adduction

strategy during isotonic standing external rotation exercise does not appear to produce greater activation of the infraspinatus and less activation of the middle deltoid with the arm between 0° and 30° shoulder abduction positions. Therefore, holding a towel roll during standing external rotation may not produce desired effects on muscle activation, compared to the no towel condition.

This is the first study, to our knowledge, to compare the effects on muscle activation between the towel conditions during sidelying external rotation exercise. Our study suggests that shoulder adduction strategy during sidelying external rotation exercise does not appear to produce greater activation of the infraspinatus with the arm at 30° shoulder abduction position. However, during sidelying external rotation, holding a towel roll at 30° shoulder abduction position appears to decrease activation of the middle deltoid. For that reason, we recommend that a towel roll should be placed under the arm during sidelying external rotation exercise in order to possibly reduce superior glide of the humeral head in the early stages of shoulder rehabilitation.

Our study has several limitations. In order to maintain a consistent position for comparison between trials, each subject's elbow was fixed to 90° by an elbow brace and range of external rotation for with and without a towel roll in each position was controlled during data collection. All subjects tested had shoulders with no pathology, and our results cannot be assumed valid for shoulder pathology patients. Furthermore, this study tested only one set of 10 repetitions for each exercise, so we do not know how these muscles will behave with fatigue if the volume of exercise increases. Finally, our study used only green colored TheraBand (260 cm long) in the standing position and a 4-lb dumbbell in the sidelying position for all subjects. Future studies should consider: 1) recruiting more numbers of asymptomatic and symptomatic

subjects; 2) using different loads during isotonic external rotation exercises; and 3) collecting data from different shoulder muscles, such as latissimus dorsi and teres minor.

CONCLUSION

Overall, our study found no significant differences in infraspinatus, middle deltoid, and pectoralis major activity between the towel conditions during the standing external rotation exercise. The only significant increase observed was posterior deltoid activity with a towel roll. Our study also revealed no significant differences in infraspinatus and pectoralis major activity between the towel conditions during sidelying external rotation exercise. However, posterior deltoid activity was significantly greater and middle deltoid activity was significantly less in the towel condition. Thus, this study indicates that when clinicians prescribe standing shoulder external rotation exercises, placing a towel roll under the arm does not appear to produce enhanced effects on muscle activation. On the other hand, application of a towel roll under the arm could be recommended during sidelying external rotation exercise in order to possibly reduce the superior translation of the humerus, due to decrease muscle activation of the middle deltoid.

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Table 1. Normalized (% of MVIC) Average and Peak EMG Activity During Standing External Rotation Exercise With and Without a Towel Roll (Mean \pm SD). Asterisks indicate significant difference between the towel conditions ($P < .05$). Significant differences existed for most of the posterior deltoid contraction phases.

Muscle	Contraction	Without a Towel (% of MVIC)	With a Towel (% of MVIC)	P-Value	Adjusted P-Value
Infraspinatus	Total Average	44.2 \pm 21.0	44.7 \pm 23.8	0.860	0.042
	Concentric Average	60.1 \pm 30.6	61.1 \pm 36.2	0.814	0.033
	Eccentric Average	29.2 \pm 11.9	27.2 \pm 11.8	0.159	0.008
	Total Peak	57.6 \pm 33.8	56.5 \pm 31.9	0.781	0.025
	Concentric Peak	79.1 \pm 49.4	80.0 \pm 49.7	0.892	0.050
	Eccentric Peak	35.5 \pm 16.8	33.0 \pm 14.9	0.329	0.017
Posterior Deltoid	Total Average	13.9 \pm 8.2	19.5 \pm 15.1	0.016*	0.025*
	Concentric Average	16.8 \pm 10.7	24.8 \pm 22.0	0.026*	0.033*
	Eccentric Average	11.0 \pm 6.0	14.2 \pm 8.7	0.006*	0.008*
	Total Peak	17.0 \pm 11.4	24.0 \pm 21.2	0.035*	0.042*
	Concentric Peak	20.6 \pm 15.2	30.6 \pm 32.9	0.074	0.050
	Eccentric Peak	13.3 \pm 7.8	17.8 \pm 11.6	0.008*	0.017*
Middle Deltoid	Total Average	11.3 \pm 8.4	10.8 \pm 9.4	0.639	0.033
	Concentric Average	12.0 \pm 8.8	12.3 \pm 10.5	0.815	0.042
	Eccentric Average	10.5 \pm 8.2	9.2 \pm 8.4	0.166	0.008
	Total Peak	12.5 \pm 8.9	11.5 \pm 9.4	0.610	0.025
	Concentric Peak	13.0 \pm 9.5	13.3 \pm 11.1	0.863	0.050
	Eccentric Peak	11.8 \pm 8.9	9.7 \pm 7.9	0.306	0.017
Pectoralis Major	Total Average	6.9 \pm 5.5	8.1 \pm 6.6	0.133	0.025
	Concentric Average	6.9 \pm 5.4	8.3 \pm 6.4	0.101	0.008
	Eccentric Average	6.9 \pm 5.7	8.0 \pm 6.8	0.178	0.042
	Total Peak	5.4 \pm 4.3	6.9 \pm 5.3	0.135	0.033
	Concentric Peak	5.5 \pm 4.2	7.4 \pm 5.8	0.126	0.017
	Eccentric Peak	5.3 \pm 4.4	6.5 \pm 5.1	0.191	0.050

Table 2. Normalized (% of MVIC) Average and Peak EMG Activity During Sidelying External Rotation Exercises With and Without a Towel Roll (Mean \pm SD). Asterisks indicate significant difference between the towel conditions ($P < .05$). Significant differences existed for all of the posterior deltoid contraction phases and most of the middle deltoid contraction phases.

Muscle	Contraction	Without a Towel (% of MVIC)	With a Towel (% of MVIC)	P-Value	Adjusted P-Value
Infraspinatus	Total Average	41.5 \pm 18.4	42.2 \pm 25.0	0.770	0.042
	Concentric Average	56.8 \pm 28.2	58.5 \pm 37.8	0.657	0.033
	Eccentric Average	26.1 \pm 9.4	25.9 \pm 12.7	0.922	0.050
	Total Peak	50.2 \pm 24.8	52.4 \pm 32.4	0.465	0.017
	Concentric Peak	68.1 \pm 38.6	71.7 \pm 50.2	0.508	0.025
	Eccentric Peak	32.3 \pm 12.1	34.2 \pm 17.8	0.340	0.008
Posterior Deltoid	Total Average	10.2 \pm 4.9	14.2 \pm 8.9	0.013*	.025*
	Concentric Average	10.6 \pm 6.0	15.6 \pm 11.2	0.015*	.042*
	Eccentric Average	9.8 \pm 4.1	12.7 \pm 7.1	0.018*	.050*
	Total Peak	16.4 \pm 7.7	21.5 \pm 11.1	0.009*	0.017*
	Concentric Peak	16.4 \pm 9.2	22.2 \pm 11.8	0.008*	0.008*
	Eccentric Peak	16.4 \pm 6.9	21.4 \pm 11.4	0.014*	0.033*
Middle Deltoid	Total Average	19.5 \pm 16.5	16.4 \pm 16.9	0.009*	0.033*
	Concentric Average	17.9 \pm 17.0	16.3 \pm 16.9	0.215	0.050
	Eccentric Average	21.2 \pm 16.2	16.5 \pm 17.0	0.000*	0.008*
	Total Peak	24.0 \pm 13.1	18.9 \pm 14.5	0.001*	0.017*
	Concentric Peak	22.1 \pm 13.2	17.7 \pm 13.9	0.011*	0.042*
	Eccentric Peak	24.8 \pm 13.0	19.8 \pm 15.4	0.003*	0.025*
Pectoralis Major	Total Average	16.0 \pm 20.9	14.2 \pm 10.1	0.565	0.042
	Concentric Average	16.4 \pm 20.8	14.7 \pm 9.6	0.601	0.050
	Eccentric Average	15.6 \pm 21.0	13.6 \pm 10.6	0.531	0.025
	Total Peak	14.6 \pm 12.9	16.7 \pm 9.7	0.321	0.017
	Concentric Peak	15.1 \pm 13.4	18.0 \pm 10.6	0.203	0.008
	Eccentric Peak	14.0 \pm 12.5	15.2 \pm 8.6	0.559	0.033



Figure 1. MVIC Position of the Middle Deltoid. The shoulder was abducted to 0° , and the subjects pulled a cable laterally, in order to create a shoulder abduction force.



Figure 2. MVIC Position of the Posterior Deltoid. The shoulder was abducted to 0° , and the subjects pulled back a cable, in order to create a shoulder extension force.



Figure 3. MVIC Position of the Infraspinatus. The shoulder was abducted to 0° with neutral shoulder rotation, and the elbow fixed to 90° . The subject pulled a cable in the external rotation direction, in order to create a shoulder external rotation force.



Figure 4. MVIC Posture of the Pectoralis Major. The shoulders were bilaterally abducted to 0° bilaterally with the palmar surfaces of the hands together, and the elbows were flexed to 90°. Subjects pressed the palmar surfaces of the hands against each other.



Figure 5. Starting Position of Standing External Rotation Alone.



Figure 6. End of Concentric Phase of Standing External Rotation Alone.



Figure 7. Starting Position of Standing External Rotation With a Towel Roll.



Figure 8. End of Concentric Phase of Standing External Rotation With a Towel Roll.



Figure 9. Starting Position of Sidelying External Rotation Alone.



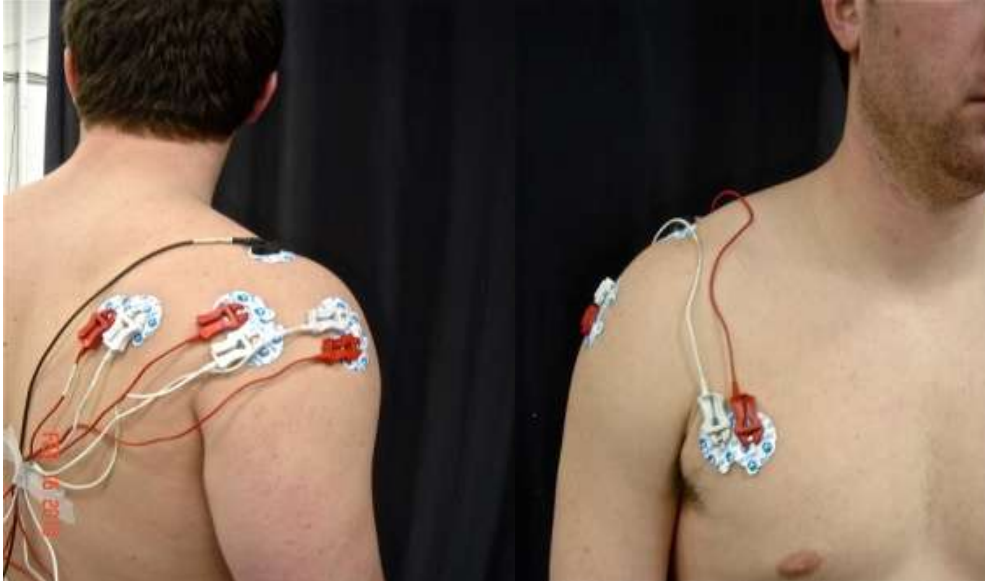
Figure 10. End of Concentric Phase of Sidelying External Rotation Alone.



Figure 11. Starting Position of Sidelying External Rotation With a Towel Roll.



Figure 12. End of Concentric Phase of Sidelying External Rotation With a Towel Roll.



Figures 13. Placement of Surface Electrodes. For the infraspinatus, the electrodes were positioned 4 cm inferior and parallel to the scapular spine on the lateral aspect over the infrascapular fossa. For the middle deltoid, the electrodes were positioned 3 cm below the acromion process over the muscle mass on the lateral upper arm. For the posterior deltoid, 2 cm inferior to the lateral border of the scapular spine, and the electrodes were angled parallel to the muscle fibers. For the sternal part of the pectoralis major, the electrodes were placed horizontally on the chest wall over the middle part of the pectoralis major, 2 cm from the axillary fold. A ground electrode was positioned over the acromion process on the right shoulder.



Figure 14. Position of Pendulum. The subjects performed the pendulum motions in clockwise and counterclockwise directions.

Prospectus

Chapter 1

Introduction

Shoulder pain occurs in up to 67% of the population at some time in their lifetime.¹ Rotator cuff disorders are one of the most common causes of shoulder pain.²⁻⁶ In a cadaver study, 32% had partial-thickness tears of the rotator cuff.⁷ Partial-thickness tears of the rotator cuff usually involve the supraspinatus and/or infraspinatus tendons.⁸⁻¹⁰

During normal glenohumeral joint motion, all the rotator cuff muscles are activated together and cause stabilization of the humeral head in the glenoid fossa centrally^{11, 12} During shoulder abduction, for example, superior movement of the humeral head with contraction of the deltoid and the supraspinatus is opposed by inferior movement of the humeral head with contraction of the infraspinatus, the teres minor, and the subscapularis.¹¹⁻¹⁴

Usually patients who have rotator cuff disorders have conservative treatment initially, such as rotator cuff strengthening exercises.^{4, 5, 12, 15} Rotator cuff strengthening exercises have been found to be effective for the reduction of shoulder pain.^{16, 17} In order to strengthen the rotator cuff effectively, the clinician has to understand the loads placed on specific muscles by specific rotator cuff exercises. There have been several studies that showed activation of different muscles of the shoulder complex during rotator cuff exercises, such as shoulder external and internal rotations and shoulder abduction.^{13, 18-25} However, some exercises are still based on empirical clinical experience.^{5, 25}

One of the most common rotator cuff exercises is an external rotation exercise that aims at strengthening the infraspinatus and teres minor, which are the main external rotator muscles of the rotator cuff.^{13, 19, 25, 26} A few authors²⁶⁻²⁸ and, anecdotally, clinicians have suggested using the adduction strategy of using a towel roll between the arm and side of the body during the external

rotation exercise, to stabilize the arm to side of the body.²¹ The shoulder adduction force theoretically creates reciprocal inhibition of abductor muscles, such as the deltoid and supraspinatus.^{13, 26, 28} As a clinician, minimizing the deltoid muscle activation during shoulder exercise is important especially in the early stages of rehabilitation because that may reduce superior slide of the humeral head.^{13, 28} Reduction of the abduction movement may provide more isolated muscle activation of the infraspinatus and teres minor.^{13, 26} A previous study found that the contribution of the middle deltoid during standing external rotation with shoulder adduction (about 15%) was significantly lower at 10% maximal voluntary isometric contraction compared to standing external rotation alone (about 23%).¹³ However, there was no significant increase of infraspinatus activity during standing external rotation with shoulder adduction at any loads, compared to standing external rotation alone.^{13, 21, 25}

Another possible positive effect of a towel roll is to produce less tension on the supraspinatus and infraspinatus tendons in the 30° shoulder abducted position than in the 0° shoulder abducted position²⁹, which may also increase blood flow to the tendon by reduction of compression force from humeral head to these tendons.³⁰ This is particularly important for the patient who has supraspinatus or infraspinatus tendon tears or inflammation during rehabilitation.

Sidelying external rotation exercise has also been used in clinics as often as standing external rotation exercise.²⁶ A few authors found that muscle activation of the infraspinatus and the teres minor was the highest in sidelying external rotation exercise compared to other external rotation exercises.^{21, 25} However, sidelying external rotation exercise had higher middle deltoid activity than standing external rotation exercise.^{21, 25} Kolber et al²⁶ recommends use of a towel roll to reduce the middle deltoid activity during sidelying external rotation exercise, but there is

no study to show the effect of a towel roll on muscle activation during sidelying external rotation exercise.

The purpose of this study is to compare activation of the infraspinatus, posterior deltoid, and middle deltoid during standing external rotation exercise with and without a towel roll (30° vs 0° shoulder abducted positions) and during sidelying external rotation exercise with and without a towel roll (30° vs 0° shoulder abducted positions).

Research Questions

Is there different muscle activation (1) between the standing external rotation in 0° shoulder abduction with no towel and the standing external rotation in 30° of shoulder abduction with a towel roll; and (2) between the sidelying external rotation in 0° shoulder abduction with no towel and the sidelying external rotation in 30° shoulder abduction with a towel roll?

Research Hypothesis

1. There is increased muscle activation of the infraspinatus during both standing and sidelying external rotation with a towel roll.
2. There is decreased muscle activation of the middle deltoid during both standing and sidelying external rotation with a towel roll.

Assumptions

1. Results of this study done in a lab will have relevance to the clinical setting.
2. Activation of the infraspinatus and teres minor muscles help the inferior slide of the humeral head.

3. Results of this study on collegiate population will apply to the general population.
4. All the volunteers in this study will be healthy and have never had shoulder injuries.

Limitations

1. There are a number of known limitations in use of surface EMG: crosstalk of neighboring muscles, skin impedance, movement of the muscle under the skin, and proper electrode placement.
2. Motivation of the subjects may affect the muscle activations during the experiment.

Definition of Terms

Abductor muscles of shoulder- A group of two muscles (the deltoid and the supraspinatus) that moves the humerus away from side of the body in the frontal plane.³¹

Adduction strategy- Hypothetically, an adduction force, which is created by adductor muscles, decreases contraction of abductor muscles.²⁸

Conservative treatment- A non-operative treatment program that consists of modalities (ice, heat, electronic stimulation, and ultrasound), stretch, and strengthening exercise.³²

External rotation- Rotation of a joint around its axis in a horizontal plane away from the middle of the body in the anatomical position.³³

Reciprocal inhibition- In theory, a contraction of the agonist muscle causes a reflex relaxation or deactivation in the antagonist muscle.³⁴

Maximal voluntary isometric contraction- A peak force of the isometric contraction measured by electromyography.³⁵

Sidelying external rotation exercise- In sidelying on the uninvolved side, a subject positions the humerus next to side of the torso, flexes the elbow at 90°, and rotates the humerus externally.³³

Standing external rotation exercise- In standing, a subject positions the humerus next to the side of the torso, flexes the elbow at 90°, and rotates the humerus externally.³³

Chapter 2

Review of Literature

This literature review will focus on principles of anatomy and function of the shoulder complex, rotator cuff exercises, and effects of a towel roll with an external rotation exercise, which are important to this study.

Databases and Key Words Searched:

Medline (Ebsco)

Medline (Pubmed)

Sportdiscus (Ebsco)

Web of Science (ISI)

Google Scholar

The chapter is organized by the following topics:

Anatomy and biomechanics of shoulder complex articulations

Anatomy and function of muscles in the shoulder complex

Scapulohumeral Rhythm

Rotator cuff injuries

Rotator cuff exercises

Effects of a towel roll during an external rotation exercise

Long-term effects of the rotator cuff exercises

The use of electromyography

Anatomy and Biomechanics of Shoulder Complex Articulations

Articulations. The shoulder complex has little bony congruity of its articulating surfaces in order to have the greatest range of motion of all joints.^{11,36} There are four articulations in the shoulder complex: the sternoclavicular joint, the acromioclavicular joint, the glenohumeral joint, and the scapulothoracic joint.³⁷ During shoulder motion, all these joints have to work together and share the over all motion to increase its range.^{11,36}

The sternoclavicular joint consists of the articulation of the clavicular notch of the sternum with the sternal end of the clavicle, which is the only direct connection between the upper extremity and the trunk.^{37,38} Its joint motions are clavicular retraction, protraction, elevation, depression, and anterior and posterior rotations relative to the thorax.³⁹ During full shoulder abduction or flexion, the clavicle posteriorly rotates to about 30°, elevates to about 36°, and retracts to 16°.^{39,40} However, the clavicle does not elevate after the shoulder abducts to 90°.³⁸ Because no muscle crosses the sternoclavicular joint, the clavicle must move as a combined segment, being pulled by means of the linkage of the coracoclavicular and acromioclavicular joint ligaments and by the muscles that move the scapula.³⁹

The acromioclavicular joint consists of the anterior margin of the acromion and the lateral end of the clavicle.^{37,38} Because the fibrous capsule around the joint is not strong, two ligaments, the conoid and the trapezoid, help to resist the forces imposed on the joint during shoulder motion.³⁸ These ligaments are referred to as the coracoclavicular ligament and suspend the scapula from the clavicle.³⁸ This joint has almost no motion in between 30° and 135° shoulder abduction, but there is about 15° of this angulation occurring in the early and late range of shoulder abduction.³⁸

The glenohumeral joint, a ball-and-socket joint, consists of the glenoid fossa of the scapula and the humeral head.^{11,37} The total surface of the glenoid fossa is three times smaller than that of the humeral head.¹¹ The glenoid fossa is fairly flat, but the humeral head is more curved.⁴¹ The glenoid fossa is shallower in the anterior-posterior direction than in the superior-inferior direction.⁴¹ As a result, the humeral head is less stable in the anterior-posterior direction than in the superior-inferior direction.¹¹ Stability of the glenohumeral joint is maintained by (1) static stabilizers, such as the glenoid labrum, capsular ligaments, and thick fibers of the subscapularis tendon, and (2) dynamic stabilizers, such as the rotator cuff and long head of the biceps brachii.³⁷ Its joint motions are flexion, extension, abduction, adduction, circumduction, horizontal abduction and adduction, and internal and external rotations of the humerus.^{37,39} The humerus has to externally rotate to about 80° during shoulder abduction or flexion in order to avoid the subacromial impingement between the greater tuberosity and the coracoacromial arch.^{38,39} This may explain why patients who have internal rotation contractures of the glenohumeral joint or external rotator cuff tears have difficulty in abducting the shoulder fully.^{38,39}

The scapulothoracic joint/interface is not a true joint because the scapula has no direct bony or ligamentous attachment to the axial skeleton.³⁷ The scapula lies on posterior-lateral side of the second through seventh ribs.³⁷ The scapula functions as a site of muscle attachment for the scapulohumeral and scapulothoracic muscles.¹¹ Its joint motions are scapular elevation, depression, abduction, adduction, anterior and posterior tilts, upward and downward rotations, and internal and external rotations.^{11,39} The position of the scapula is internally rotated at approximately 35°, upwardly rotated at 4°, and anteriorly tilted at 17°.^{11,39} Altered position and motion of the scapula in relation to the thoracic cage are called scapular

dysfunction/dyskinesis.⁴² The most frequent reason of scapular dysfunction is alteration of muscle activation or coordination as of injury to the scapulothoracic muscles or nerves, fatigue from repetitive muscle contractions, or inhibition by painful conditions around the shoulder.⁴³ For example, weakness of the serratus anterior muscle causes the ‘winging’ of the scapula, which is excessive internal rotation of the scapula.^{38, 44} Especially, altered activations of the upper and lower trapezius and serratus anterior muscles during shoulder abduction decrease upward rotation and posterior tilt of the scapula, which narrow the subacromial space.^{43, 45} Warner et al⁴² found that patients who had shoulder impingement were highly correlated to scapular dysfunction.

Anatomy and Function of Muscles in the Shoulder Complex

The rotator cuff consists of four muscles, of which their adjacent tendons blend together and create a hood over the humeral head and the glenohumeral joint capsule.^{6, 46} The superior-posterior rotator cuff is the supraspinatus; the inferior-posterior rotator cuff is the infraspinatus and teres minor; and the anterior rotator cuff is the subscapularis.⁴⁶ Contraction of the rotator cuff together is important for shoulder stability because it creates a compression force of the humeral head against the glenoid fossa and stabilizes the humeral head in the center of the glenoid fossa during the shoulder motion.^{11, 47}

Supraspinatus. The supraspinatus originates from the supraspinatus fossa of the scapula, and its tendon inserts onto the superior portion of greater tuberosity of the humerus.^{11, 46} An inferior portion of the tendon blends with a superior portion of the infraspinatus tendon about 15 mm proximal to the greater tuberosity.⁴⁶ Its action is abduction, flexion, and external rotation of the humerus.^{20, 47-51} The supraspinatus is a better humeral abductor in the scapular plane than in

the coronal plane.⁴⁸ Also, it has a greater moment arm in shoulder abduction in the early range of shoulder abduction.⁴⁸ Diederichsen et al⁵² and Reddy et al⁵³ reported that the supraspinatus had greater activity between 30° and 60° shoulder abduction than between 60° and 120° shoulder abduction. The shoulder flexion moment arm of the supraspinatus is greater in lower shoulder flexion angle.⁴⁸ The shoulder external rotation moment arm of the supraspinatus slightly decreases as the shoulder abduction angle increases.⁵¹

Subscapularis. The subscapularis originates from the subscapularis fossa of the scapula and inserts onto the lesser tuberosity on the humerus.¹¹ Its upper and lower parts are independently innervated by the upper and lower subscapular nerves, respectively^{54, 55} Its primary action is humeral internal rotation.^{11, 46, 51} This muscle produces a complex shoulder action. The actions of the upper part are humeral abduction, adduction, and flexion.⁴⁸ It acts as a humeral abductor in the early range (0° – 40°) of shoulder abduction, but becomes a humeral adductor after reaching 40° shoulder abduction.⁴⁸ The actions of the lower part are humeral adduction and flexion.⁴⁸ It becomes a more effective humeral adductor as the angle of shoulder abduction increases.⁴⁸ In addition, the subscapularis actively stabilizes the joint by resisting superior translation and posterior translation.^{12, 56, 57} An electromyographic (EMG) study showed that the activity pattern of the subscapularis during shoulder abduction was similar to the activity pattern of the anterior and middle deltoid, in order to resist superior translation of the humeral head.⁵⁸ At the same time, the subscapularis is a passive stabilizer because the dense collagen of its tendon, which fuses with the middle and inferior glenohumeral ligaments, helps to prevent the excessive anterior translation of the humeral head.¹¹

Infraspinatus and Teres Minor. The origin of the infraspinatus is the infraspinous fossa and the scapular spine of the scapula, and its insertion is the middle portion of greater tuberosity

on the humerus.^{11, 46} The origin of the teres minor is the inferior-lateral scapula and the infraspinatus fascia, and its insertion is the inferior part of the greater tuberosity on the humerus.^{11, 46} They are called the external rotator cuff because primarily rotate the humerus externally.¹² Maintaining the humerus in external rotation during shoulder abduction is extremely important because it clears the greater tuberosity of the humerus from the inferior surface of the coracoacromial arch.^{59, 60} Thus, humeral external rotation during shoulder abduction increases the subacromial space and allows the humerus to abduct further.^{59, 60} The infraspinatus itself generates about 55% of the total humeral external rotation force.⁶¹ The humeral external rotation moment arm of the infraspinatus increases as the shoulder abduction angle decreases.⁵¹ The infraspinatus produces the highest humeral external rotation activity at 0° shoulder external rotation with 0° shoulder abduction.⁵²

For the infraspinatus, the other actions are humeral abduction^{12, 48, 50-53} and humeral horizontal abduction.^{25, 50, 59} The muscle activity of the infraspinatus during shoulder abduction is higher between 30° and 90° than between 90° and 120°.^{52, 53} Its humeral abductor moment arm at 0° shoulder abduction with 45° shoulder external rotation is about 0.75 cm, with neutral rotation is 1.1 cm, and with 45° shoulder internal rotation is 1.6 cm.⁵¹ These numbers may tell that the infraspinatus is more effective as a humeral abductor when the humerus is internally rotated.^{51, 59}

For the teres minor, the other actions are humeral adduction because of its lower attachments to the scapula and to the humerus^{48, 50, 51}; and humeral horizontal abduction.^{25, 50, 59} The teres minor acts as a weak adductor of the humerus due to the small moment arm.^{48, 50, 51} Its humeral adduction moment arm does not change regardless of the shoulder rotation angle⁵¹ or shoulder abduction angle.⁵⁰

In addition, the infraspinatus and teres minor act as dynamic stabilizers.¹¹ They actively stabilize the glenohumeral joint by resisting both humeral superior translation and humeral anterior translation during shoulder motion.^{8, 11, 12, 56, 57} EMG studies^{53, 58} showed that infraspinatus and teres minor were active through the range of shoulder abduction as they resist the superior translation of the humeral head.

Deltoid. The deltoid originates from the lateral clavicle (an anterior part), the acromion (a middle part), and the scapular spine (a posterior part).¹¹ It inserts onto the deltoid tubercle on the humerus.¹¹ The middle deltoid primarily abducts the humerus.^{11, 48, 50, 51, 61} The actions of the anterior deltoid are flexion, abduction, horizontal adduction, and internal rotation of the humerus.^{11, 48, 50, 51, 62} The anterior deltoid is a better humeral abductor at higher angle of shoulder abduction than at lower angle of shoulder abduction.^{11, 48, 50, 51} The actions of the posterior deltoid are extension, adduction, abduction, horizontal abduction, and external rotation of the humerus.^{11, 25, 48, 50, 51} Interestingly, the posterior deltoid acts as a humeral adductor from 0° to about 80° shoulder abduction and becomes a humeral abductor after passing about 90° shoulder abduction.^{11, 48, 51} Besides, it compresses the humeral head into the glenoid fossa.^{47, 56} All three parts of the deltoid together produce 35% and 80% of total shoulder abduction strength at 30° and 150° shoulder abduction, respectively.⁶¹ The anterior and middle deltoid is more effective as a humeral abductor when the angle of shoulder abduction increases^{47, 50-52}; because their humeral abduction moment arms increase as the arm abducts higher.⁴⁷ In addition, their humeral abduction moment arms exceed that of the supraspinatus at 60° shoulder abduction. Otis et al⁵¹ stated that the humeral abduction moment arm of the middle deltoid might be greater at 40° shoulder abduction than that of the supraspinatus.

The force vector of the anterior and middle deltoid is superiorly directed to the acromion in the early range of shoulder abduction.^{56, 60} In a cadaveric study, the middle deltoid created the highest superior translation of the humeral head at 30° shoulder abduction followed by the posterior deltoid.⁶³ More so at the lower shoulder abduction angle, contraction of the anterior and middle deltoid causes more superior translation of the humeral head.^{47, 56} However, an inferior force produced by the infraspinatus, teres minor, and subscapularis opposes the superior force during shoulder abduction in order to minimize the chance of subacromial impingement.^{12, 61} Myers et al⁶⁴ found that subacromial impingement patients had increased activity of the middle deltoid between 0° and 30° shoulder abduction, where the tendency for superior translation of the humeral head was high.^{47, 56, 63}

Teres Major. The teres major originates from the posterior-inferior angle of the scapula and inserts on the medial margin of the intertubercular groove of the humerus.^{11, 31} It acts as humeral adductor, extensor, and internal rotator.^{11, 31, 48, 50} It not only has large humeral adduction moment arm (4.7 cm and 4.8 cm, respectively) in the coronal and scapular planes, but also has large humeral extension moment arm (4.6 cm).⁵⁰

Biceps Brachii. The long head of the biceps brachii tendon originates from the supraglenoid tubercle and superior glenoid labrum of the scapula.^{11, 31} The tendon of the short head originates from the coracoid process of the scapula.^{11, 31} Both heads insert onto the radial tuberosity of the radius and the aponeurosis on medial side of the ulna.^{11, 31, 65} Actions of the biceps brachii on the shoulder are humeral flexion with neutral rotation of the humerus and humeral abduction with external rotation of the humerus.⁶⁵ The long head of the biceps brachii decreases anterior-posterior translation and superior-inferior translation of the humeral head on

the glenoid fossa.⁶⁶ The short head of the biceps brachii is an inferior stabilizer of the humeral head.⁶³

Triceps Brachii. The triceps brachii originates from three parts: medial, long, and lateral heads.^{11,31} The medial head originates from posterior surface of the humerus, inferior to the radial groove; the long head of the triceps brachii originates from the infraglenoid tubercle and inferior labrum of the scapula; and the lateral head originates from the superior-lateral margin of the humerus.^{11,31,65} They all insert onto the olecranon process of the ulna.^{11,31} Only the long head of triceps brachii extends and adducts the humerus because it crosses the glenohumeral joint.^{11,31,65}

Coracobrachialis. The coracoid process of the scapula is the origin of the coracobrachialis, and the anterior-medial side of the middle humerus is its insertion.^{11,31} Its actions are flexion and adduction of the humerus.^{11,31,65} Increased force of the coracobrachialis helps to stabilize the humerus against inferior translation of the humeral head.⁶³

Pectoralis Major. The pectoralis major originates from medial one-half of the clavicle (upper part); anterior-lateral area of the sternum and the second through fourth ribs (middle part); and the costal cartilages of the fifth and sixth ribs and the external oblique muscle fascia (lower part).^{11,31,65} All of the parts insert onto the greater tuberosity and lateral margin of intertubercular groove of the humerus.^{31,65} Actions of the pectoralis major are adduction, abduction, flexion, horizontal adduction, and internal rotation of the humerus.^{48,50,65} The upper pectoralis major adducts the humerus in the early range of shoulder abduction, but it becomes a humeral abductor from about 40° shoulder abduction.⁴⁸ The pectoralis major is a more effective humeral adductor when the humerus is in the coronal plane, as compared to the scapular plane.^{48,}

⁵⁰ Furthermore, it is a more effective humeral internal rotator when the humerus is at a lower shoulder abduction angle.⁶⁷⁻⁶⁹

Pectoralis Minor. The pectoralis minor originates from the anterior-superior surface of the third through fifth ribs and inserts onto the coracoid process of the scapula.^{11, 31, 65} Its actions are anterior tilt⁶⁵, downward rotation, internal rotation, and depression of the scapular.^{11, 31}

Subclavius. The subclavius origin is the medial part of the first rib and insertion is the subclavian groove of the clavicle.^{11, 31} It stabilizes the sternoclavicular joint by pulling the clavicle to the sternum.¹¹ It indirectly depresses and internally rotates the scapula via the acromoclavicular joint.³¹

Latissimus Dorsi. The latissimus dorsi has a broad origin, which is the spinous process of sixth through twelfth thoracic spines, the lumbar vertebrae via lumbodorsal fascia, and the iliac crest.⁶⁵ Its tendon crosses the medial side of the humerus and inserts onto the intertubercular groove of the humerus.⁶⁵ In addition, it usually attaches to the inferior angle of the scapula.¹¹ Its actions are adduction, extension, and internal rotation of the humerus.^{11, 48, 50} Its humeral adduction moment arm is large (3.7 cm and 4 cm, respectively) in both coronal and scapular planes.⁵⁰ Its humeral extension moment arm of is consistently large (4.7 cm) between 0° and 80° shoulder flexion.⁵⁰ It depresses and adducts the scapula.^{11, 65} Another role of this muscle is a compressor of the humeral head into the glenoid fossa.⁴⁷

Trapezius. The trapezius consists of three parts: upper, middle, and lower.⁶⁵ The upper trapezius originates from the external occipital protuberance, the ligamentum nuchae, and the spinous process of the seventh cervical spine to insert onto lateral one third of the clavicle, the acromion process, and the scapular spine.⁶⁵ Its actions are elevation, adduction, and upward rotation of the scapula.^{11, 65} When the shoulder abduction angle increases, the upper trapezius

produces greater muscle activity.^{45, 52, 70} The middle trapezius originates from the spinous processes of the seventh cervix and the first through fifth thoraces to insert onto the acromion process and the lateral scapular spine.⁶⁵ Its action is adduction of the scapula.^{11, 65} The middle trapezius produces low muscle activity from 0° to 100° shoulder abduction, but the activity increases from 100° shoulder abduction to the maximal shoulder abduction angle.⁷⁰ The lower trapezius originates from the spinous processes and supraspinal ligaments of the eighth through twelfth thoraces to insert onto the medial scapular spine.⁶⁵ Its actions are depression, adduction, and upward rotation of the scapula.⁶⁵ Like the middle trapezius, it has low muscle activity from 0° to 90° shoulder abduction.⁷⁰ Its muscle activity rapidly increases when the shoulder is abducted from about 90° to the maximal angle.^{45, 70}

Serratus Anterior. The serratus anterior consists of three parts: superior, middle, and inferior.¹¹ It originates from the anterior aspects of the first through the ninth ribs and inserts onto the anterior surface of the superior angle, the vertebral border, and the inferior angle of the scapula.^{11, 65} Its primary function is fixation of the vertebral border of the scapula onto the thorax.^{11, 65} The other actions are elevation, depression, abduction, and upward rotation of the scapula.¹¹ The superior part elevates the scapula and the inferior part upwardly rotates and depresses the scapula.^{11, 65} The three parts of serratus anterior activity increase as the angle of shoulder abduction increases.^{45, 52} The high activity of the serratus anterior is important because upward rotation of the scapula through the range of motion in shoulder abduction helps increasing the subacromial space to reduce the chance of subacromial impingement.⁷¹ Diederichsen et al⁵² found that the decreased activity of the serratus anterior throughout the range of shoulder abduction with subacromial impingement patients. Winging scapula caused by trauma to the serratus anterior or to the long thoracic nerve, which innervates the serratus

anterior, also reduces the motion of shoulder flexion and abduction due to an inability to upwardly rotate the scapula successfully.^{43, 44, 72}

Rhomboids. The rhomboids divide into major and minor parts. The rhomboid major originates from the spinous processes of the first thoracic through fourth thoracic and inserts onto the vertebral border of the scapula from the scapular spine to the inferior angle of the scapula.^{11,}
³¹ The rhomboid minor originates from the spinous processes of the sixth and seventh cervices and inserts onto the vertebral border of the scapula, superior of the scapular spine.¹¹ Their actions are adduction, elevation, and downward rotation of the scapula.^{11, 31}

Levator Scapulae. The levator scapulae originates from the transverse processes of the first through fourth cervices and inserts onto the vertebral border of the scapula near the superior angle of the scapula.^{11, 31} Its actions are elevation³¹ and downward rotation of the scapula.¹¹

Scapulohumeral Rhythm

For the arm to achieve its maximal arc of motion, the glenohumeral and scapulothoracic joints must combine their range of motions together.⁶⁵ The ratio between the glenohumeral abduction and the scapular upward rotation throughout a full range of shoulder abduction is described as scapulohumeral rhythm.^{37, 73} The total range of shoulder abduction is about 160° to 170°, and the range of glenohumeral abduction and scapular upward rotation is approximately 110° and 60°, respectively.^{74, 75} An average ratio of the scapulohumeral rhythm used to be reported about 2:1.^{39, 74} However, not only the ratio of their motions are inconsistent throughout the total range of motion⁶⁵, but also the scapulohumeral rhythm changes in passive and active shoulder abduction.⁷⁶ In an initial shoulder abduction phase (about 0° to 30°), passive and active scapulohumeral rhythm ratios are 7.9:1 and 3.2:1, respectively; in a middle shoulder abduction

phase (about 65° to 95°), the ratios are 5.3:1 and 3.6:1; and in a last shoulder abduction phase (about 130° to 160°), the ratios are 3:1 and 4.3:1.⁷⁶ With heavy resistance, scapulohumeral rhythm in the initial range of shoulder abduction is lower (1.9:1) and in the last range of shoulder abduction is higher (4.5:1).⁷⁶

There are a few reasons why greater scapular upward rotation is crucial in the mid-range of shoulder abduction: (1) the subacromial space is the narrowest in the mid-range of motion⁷⁷; and (2) additional reduction of the subacromial space, caused by increased scapulohumeral rhythm, may increase the chance of subacromial impingement.^{42, 73, 78, 79} Ebaugh et al⁴⁵ explained that greater contractions of the serratus anterior and the upper and lower trapezius in the initial and middle shoulder abduction phases helped to gain greater scapular upward rotation and posterior tilt during active shoulder abduction in order to lower the scapulohumeral rhythm. Therefore, increased upward rotation of the scapula during shoulder abduction, which lowers the scapulohumeral rhythm, is essential to gain a full range of shoulder abduction.^{45, 65}

Rotator Cuff Injuries

Muscles of the rotator cuff are among the most frequent muscles involved in shoulder injury.⁸⁰ The repetitive microtraumatic stresses placed on the athlete's shoulder complex during the overhead motion cause muscle fatigue, weakness, or imbalance, which lead to injury.⁸⁰ Common rotator cuff injuries are partial- or full-thickness tears,⁸¹ tendinitis,⁸² and subacromial or internal impingement.^{37, 52, 83}

Overhead activities, such as baseball, tennis, and swimming, require high rotator cuff activity concentrically and eccentrically.³³ During the acceleration phase of baseball pitching, for example, both high shoulder internal rotation speed produced by the subscapularis and maximum

shoulder external rotation angle generated by the external rotator cuff and posterior deltoid are important in order to maximize the arm speed from 0°/s at the beginning of acceleration to 7500°/s by the end of acceleration.⁸⁴ During the follow-through phase, the supraspinatus, infraspinatus, and teres minor must be eccentrically activated to decelerate the arm after ball release and work against the distraction force occurring at the shoulder.³³ Yanagisawa et al⁸⁵ found that the rotator cuff was damaged by eccentric contraction during baseball pitching.

Subacromial impingement often impinges the tendons of the supraspinatus and infraspinatus between the humeral head and acromion process.³⁷ Tears of the rotator cuff are usually near their insertion on the greater tuberosity. The tears can be either partial- or full-thickness tears.³⁷ Diederichsen et al⁵² found that subacromial impingement patients had significantly less infraspinatus activity during shoulder external rotation than healthy subjects. Humeral external rotation produced by the external rotator cuff and posterior deltoid during shoulder abduction clears the greater tuberosity of the humerus from the acromion process, so as to gain a further range of shoulder abduction.^{38,39} In addition, the subacromial impingement patients showed significantly decreased activity of the infraspinatus and subscapularis during the early arcs of shoulder abduction (30°-60°).⁵³ Decreased inferior force (from the infraspinatus and subscapularis) on the humeral head in the early shoulder abduction⁵³ may reduce the subacromial space since the superior force (from the deltoid) on the humeral head in the early shoulder abduction translates the humeral head into the acromion.^{47, 56, 60, 63}

Rotator Cuff Exercises

To regain normal shoulder function following shoulder injuries or surgery, a clinician must concentrate on strengthening the rotator cuff.³⁷ In the early phase of rotator cuff

rehabilitation after rotator cuff surgery or injury, the patient needs to avoid exercises that generate high rotator cuff activity so as not to stress the healing tissue.⁵⁹ During an advanced or late phase of rotator cuff rehabilitation, exercises that generate moderate to high activity of the rotator cuff may be appropriate.⁵⁹ In this section, different rotator cuff exercises for each rotator cuff will be discussed and then, the effects of different rotator cuff strengthening programs will be discussed.

Several electromyographic studies^{13, 20, 21, 23-25, 52, 55, 67-69, 86-91} have been done using rotator cuff exercises on shoulder complex muscles. One of the traditional rotator cuff exercises to strengthen the supraspinatus is the 'empty can' exercise, also known as the Jobe exercise.⁸⁹ A patient abducts the shoulder from 0° to 90° in the scapular plane (30°-40° anterior to the coronal plane) with rotating the humerus internally so that his/her thumb is pointing down.⁸⁹ Jobe and Moynes⁸⁹ claimed that the 'empty can' exercise could isolate the activity of the supraspinatus from the activity of the other shoulder muscles. However, they reported only traces of raw EMG signal from all the rotator cuff in a single subject.⁸⁹ Boettcher et al^{86, 87} showed that maximal isometric contraction with the arm at 90° shoulder scaption during the exercise highly activated all the anterior, middle, and posterior deltoid (about 90% MVIC) as well as the supraspinatus (about 90% MVIC). Townsend et al⁹¹ also found that there were similar activity levels of the supraspinatus, and anterior and middle deltoid (74%, 72%, and 83%, respectively) during the exercise with isotonic contraction. Reinold et al⁹⁰ reported that the activity of the supraspinatus (63% MVIC) was not significantly different from the activity of the middle deltoid (77% MVIC) during the exercise with isotonic contraction at 10 repetition maximum (RM). The peak EMG amplitude of the supraspinatus and anterior and middle deltoid was seen between 90° and 120° arc range of shoulder abduction.⁹¹ Thigpen et al⁹², however, stated that the 'empty can' exercise

might increase the chance of subacromial impingement, because the arm position of the exercise would create anterior tilt and internal rotation of the scapula, which theoretically decreases the subacromial space.

The modified ‘empty-can’ exercise is called the ‘full can’ exercise. It has the same excursion of shoulder movement but the humerus is rotated externally, so that the patient’s thumb points up.^{68, 86, 87} The externally rotated position of the humerus during shoulder abduction minimizes the chance of subacromial impingement by clearing the greater tuberosity of the humerus from the coracoacromial arch.^{59, 60} The ‘full can’ exercise may provoke less pain for a subacromial impingement patient who is in his/her early rehabilitation program.⁶⁸ Both Boettcher et al^{86, 87} and Reinold et al⁹⁰ found that ‘full can’ exercise produced significantly less middle and posterior deltoid activity than the ‘empty can’ exercise. Boettcher et al^{86, 87} showed similar activity levels of the supraspinatus (about 90% MVIC), and anterior and middle deltoid (85% and 80% MVIC, respectively) during the ‘full can’ exercise. Reinold et al⁹⁰ and Takeda et al⁹³ also supported that the activity of the supraspinatus and middle deltoid was not significantly different during the ‘full can’ exercise. The activity of the supraspinatus during the ‘full can’ exercise is not significantly different from the ‘empty can’ exercise, either.^{68, 86, 87, 90} Besides, a magnetic resonance imaging study⁹³ with both exercises showed that the supraspinatus had the same amount of T2 relaxation time, which correlates to the level of muscle activity. As a result, the ‘empty can’ and ‘full can’ exercises do not selectively activate the supraspinatus. On the other hand, both exercises highly activate the supraspinatus and deltoid, so that they can be effective exercises for these muscles.

Military press and shoulder flexion can strengthen the supraspinatus effectively because of the high muscle activity level (80% and 67% MVIC, respectively) during these exercises.⁹¹ As

well as the supraspinatus, the anterior and middle deltoid has high activity with the military press (62% and 72% MVIC, respectively) and shoulder flexion (69% and 73% MVIC).⁹¹ Peak EMG signal of the supraspinatus is seen between 0° and 30° arc range during the military press and between 90° and 120° arc range during shoulder flexion.⁹¹

Performing standing internal rotation exercise activates the subscapularis.^{20, 23, 55, 67, 68, 89,}
⁹¹ Like standing external rotation exercise, the standing internal rotation exercise is executed by placing the arm at various angles (0°-90°) of shoulder abduction with 90° elbow flexion.⁸⁹ Decker et al⁶⁷ studied the upper and lower subscapularis EMG activity during internal rotation at 0°, 45°, and 90° shoulder abduction with an elastic band. The upper subscapularis is moderately active (50%, 53%, and 58% MVIC, respectively), and the lower subscapularis is minimally to moderately active (40% and 26%, < 20% MVIC) at 0°, 45°, and 90° shoulder abduction.⁶⁷ Internal rotation at 0° shoulder abduction significantly produces greater lower subscapularis activity than internal rotation at 90° shoulder abduction.⁶⁷ Despite having the similar methodology with the Decker study, Kadaba et al⁵⁵ found that internal rotation at 90° shoulder abduction with an isokinetic machine had greater lower subscapularis activity than internal rotation at 0° shoulder abduction. However, both studies^{55, 67} agreed that performing internal rotation at 0° shoulder abduction produced similar amounts of upper and lower subscapularis activity. A reason for the differences in the lower subscapularis activity between the two studies might be due to the arm-support of the isokinetic machine during internal rotation at 90° shoulder abduction. Kelly et al⁶⁸ reported that internal rotation at 90° shoulder abduction produced the highest EMG activity of the subscapularis compared with the other shoulder abduction angles. However, they⁶⁸ did not report whether the electrode was inserted on the upper or lower subscapularis.

Isolation of the subscapularis from the pectoralis major during standing internal rotation exercise increases as the shoulder abduction angle increases.^{67, 68} In contrast, isolation of the subscapularis from the latissimus dorsi during standing internal rotation exercise decreases as the shoulder abduction angle increases.⁶⁸ During internal rotation at 0° shoulder abduction with low, medium, and high intensities, the activity levels of the subscapularis and pectoralis major are not significantly different.^{20, 67, 68} With high intensity, the activity of the latissimus dorsi during internal rotation at 0° shoulder abduction has one half of the activity of the subscapularis.^{20, 68} With low and medium intensities, however, the activity levels of both muscles are similar.^{20, 68}

One of the most optimal exercises for isolation and activation of the subscapularis is the ‘Gerber life-off’ exercise^{68, 69, 88}, which is performed by lifting the dorsum of the hand off the mid-lumber spine against resistance by concurrently extending and internally rotating the humerus. The exercise produces high subscapularis and latissimus dorsi activity, but the other muscles (the pectoralis major, supraspinatus, infraspinatus, and three parts of deltoid) have significantly lower activity.⁶⁹ With maximal isometric contraction, the activity of the subscapularis was about 2.5 times and 3 times higher than the activity of the latissimus dorsi and pectoralis major, respectively.⁶⁸ When the hand is at the buttocks level during the exercise, upper and lower subscapularis activity decreases about 30%, as compared to the hand at the mid-lumber spine level.⁸⁸

The other exercises that highly activate the subscapularis are push-up, dynamic hug, and diagonal exercises.⁶⁷ MVICs of the upper subscapularis activity during the push-up, dynamic hug, and diagonal exercises are 122%, 58%, and 60%, respectively; the lower subscapularis are 46%, 38%, and 39%; and the pectoralis major are 94%, 46%, and 76%.⁶⁷ These data show similar activity levels of the upper subscapularis and pectoralis major during these exercises.⁶⁷

Townsend et al⁹¹ claimed that the push-up had less than 50% MVIC of the subscapularis activity and produced 64% MVIC of the pectoralis major activity. However, their study did not report whether the upper or lower subscapularis was measured.

A common rotator cuff exercise for strengthening the infraspinatus and teres minor is the standing external rotation exercise, which is performed with the elbow flexed at 90° and the arm fixed at various angles of shoulder abduction.^{13, 20, 23-25, 52, 87} When the arm is next to the side of the body (0° shoulder abduction) during the exercise with a dumbbell, the recruitment pattern of the infraspinatus rapidly increases from 80° shoulder internal rotation to the neutral (0° shoulder internal rotation) position of the humerus; and then, the activity slowly decreases from the neutral position of the humerus to 80° shoulder external rotation.⁵² Also, using an elastic band with standing external rotation exercise (from 80° to 0° shoulder internal rotation) at 0° shoulder abduction produces the similar recruitment pattern of the infraspinatus, as compared to using a dumbbell.²³

Although the standing external rotation exercise at 0°, 45°, and 90° shoulder abduction produces similar activity level of the infraspinatus (40%, 53%, and 50% MVIC, respectively)²⁵, external rotation at 0° shoulder abduction is probably the most favorable position to isolate the infraspinatus from the other shoulder muscles.^{21, 25, 68} The external rotation at 0° shoulder abduction produces the lowest activity of the middle and posterior deltoid, compared with external rotation at 45° or 90° shoulder abduction.^{21, 25} Boettcher et al⁸⁷, Hintermeister et al²³, and McCann et al²⁴ found that the infraspinatus during external rotation at 0° shoulder abduction with an elastic band had greater muscle activity than the supraspinatus and all parts of the deltoid. On the other hand, the activity levels of the supraspinatus and middle and posterior deltoid during external rotation at 90° shoulder abduction are similar to the activity levels of the infraspinatus

and teres minor.^{21, 25} Also, the isolation of the infraspinatus from the middle and posterior deltoid becomes greater as intensity of the exercise decreases.¹³ Dark et al²⁰ studied the muscle activity patterns of the infraspinatus, supraspinatus, and posterior deltoid during external rotation at 0° shoulder abduction with different intensities (low, medium, and high). The activity ratio of the infraspinatus, supraspinatus, and posterior deltoid is 6.7:2.5:1 with the low intensity (10-20% of maximal strength), respectively; 3.8:2.3:1 with the medium intensity (45-55% of maximal strength); 2.3:1.7:1 with the high intensity (60-70% of maximal strength).²⁰ Both Boettcher et al⁸⁷ and Reinold et al²⁵ also supported that the infraspinatus activity during the external rotation exercise at 0° shoulder abduction with high intensity was about twice as high as the posterior deltoid activity. These results may be explained by eliminating compensatory shoulder movement, such as shoulder abduction. McCann et al²⁴ showed that the activity of all parts of the deltoid was decreased with the elbow fixed at the side during external rotation compared with the elbow non-fixed at the side, although reduction of the muscle activity was not significant.

An alternating way to do the same exercise is sidelying or prone. Sidelying external rotation exercise is performed while lying on the non-exercised shoulder side, flexing the elbow to 90°, and adducting the arm to the side.²⁵ Prone external rotation exercise is performed in the prone position, 90° elbow flexion, and 90° shoulder abduction.²⁵ Both exercises not only produce greater activity of the infraspinatus and teres minor, but also increase the activity of the middle and posterior deltoid and supraspinatus, as compared to the standing external rotation at 0° shoulder abduction.^{21, 25} The prone external rotation exercise produces greater activity of the posterior deltoid and supraspinatus than the activity of the infraspinatus and teres minor.^{21, 25} The activity level of the middle deltoid during the prone external rotation exercise is the same as the activity level of the infraspinatus and teres minor.^{21, 25}

Another exercise for strengthening of the infraspinatus and teres minor is prone horizontal abduction or the prone ‘empty can’ exercise, performed by horizontally abducting the arm with 90° or 100° shoulder abduction, full humeral external rotation, and full elbow extension.^{19, 21, 25, 90, 91, 93} Several studies^{25, 87, 90, 93} found that the posterior deltoid had greater activity during the exercise than the infraspinatus, supraspinatus, and middle deltoid. During the prone ‘empty can’ exercise with low intensity, the activity of the infraspinatus is greater than 80% MVIC; the teres minor is about 70% MVIC; the supraspinatus is about 80% MVIC; the middle deltoid is about 80% MVIC; and the posterior deltoid is 90% MVIC.^{19, 91} Takeda et al⁹³ also found the posterior deltoid and infraspinatus had greater activity during the exercise with low intensity than the middle deltoid and supraspinatus. The activity of the middle and posterior deltoid and supraspinatus (about 80% MVIC) during the exercise with high intensity is twice as high as the activity of the infraspinatus and teres minor (about 40% MVIC).²⁵ Fleisig et al²¹ showed a similar result that the activity of the middle and posterior deltoid and supraspinatus (> 90% MVIC) had about twice as high activity of the infraspinatus and teres minor (50% MVIC) , but intensity of the exercise was not reported. As a result, lower intensity of the prone ‘empty can’ exercise may be able to activate and strengthen the infraspinatus and teres minor effectively. Besides, the prone ‘empty can’ exercise can be used to strengthen the supraspinatus, middle, and posterior deltoid at any intensities.

Effects of a Towel Roll during External Rotation Exercise

Even though shoulder external rotation at 0° shoulder abduction produces greater infraspinatus activity than at higher shoulder abduction angles, the 0° shoulder abduction position may create negative effects, such as avascularity³⁰ and increased tension²⁹, on the

supraspinatus and infraspinatus tendons for the patients who have external rotator cuff disorders. The shoulder abduction position created by a towel roll may help to increase the blood supply and decrease the tension to these tendons.²⁶ Anecdotally, many clinicians prefer to use a towel roll between the arm and the side of the body while performing standing or sidelying external rotation exercises because of eliminating the compensatory shoulder abduction movement. In addition, some authors^{26, 27, 32, 94} believe that holding a towel roll between the arm and the side of the body during standing external rotation exercise creates greater isolation of the infraspinatus and teres minor from the middle deltoid than standing external rotation exercise without a towel roll. During standing external rotation exercise, compensatory shoulder abduction movement would activate larger shoulder muscles, such as the middle and posterior deltoid, rather than activating the external rotator cuff.²⁶ One of the hypotheses is that shoulder adduction force produced by holding a towel roll under the arm during the exercise may decrease shoulder abduction force, which is referred to as the adduction strategy.^{13, 25, 26, 28} Thus, reduction in abduction force may stabilize the arm to the side and optimize external rotator cuff activation due to the isolation of the external rotator cuff.^{13, 21, 26}

A few studies^{13, 21, 25} have compared the activity of the external rotator cuff to the activity of the middle and posterior deltoid during standing external rotation exercise with and without shoulder adduction. Bitter et al¹³ compared the relative contributions of the infraspinatus, and middle and posterior deltoid during 10%, 40%, and 70% MVICs of external rotation with and without a pressure cuff (< 10° shoulder abduction) between the arm and the side of the body. The contribution of the infraspinatus is optimized during 40% MVIC of external rotation with and without shoulder adduction.¹³ However, the contribution of the infraspinatus is not significantly different during any tasks. The contribution of the middle deltoid is significantly decreased

during 10% MVIC of external rotation with shoulder adduction and is the highest during 70% MVIC of external rotation alone.¹³ During the three intensities of external rotation with shoulder adduction, the contribution of the middle deltoid is significantly lower than that of the infraspinatus.¹³ During any tasks, the contribution of the posterior deltoid did not significantly change and there are no differences between the contributions of the infraspinatus and posterior deltoid, either.¹³ Reinold et al²⁵ tested the activity of the infraspinatus, teres minor, supraspinatus, and middle and posterior deltoid during standing external rotation exercise with heavy intensity (10 RM) with and without a towel roll (15° shoulder abduction). The activity of the supraspinatus, and middle and posterior deltoid during standing external rotation with and without a towel roll between the arm and the side of the body was not significantly different. The activity of the infraspinatus and teres minor during external rotation with a towel roll was greater than external rotation without a towel roll, but these differences are not significant.²⁵ Fleisig et al²¹ found similar results with the Reinold study. However, they²¹ did not report the intensity of the exercise, the positions of MVIC for normalization, the angle of shoulder abduction with a towel roll, and statistical analysis. Even though there were some methodological differences between these studies, they all^{13, 21, 25} agreed that standing external rotation exercise with shoulder adduction did not significantly increase the activity of the external rotator cuff.

The other hypothesis is that a shoulder abduction position ($> 0^\circ$) may reduce tension of the supraspinatus and superior part of infraspinatus tendons over the humeral head compared with 0° shoulder abduction position.^{26, 29} In a cadaveric study²⁹, tension of these tendons at 30° shoulder abduction is reduced by 34 N compared with tension at 0° shoulder abduction. This load would cause bone-tendon gap formation, which would be 9 mm in 24 hours after rotator cuff repair surgery.²⁹ The gap at the repair region can interfere with the healing restoration of tendon

continuity.²⁹ Additionally, the 30° shoulder abduction position presents a more comfortable position for a patient who has the supraspinatus and/or infraspinatus disorder or is recovering from rotator cuff surgery, as compared to hanging the arm by the side (0° shoulder abduction); and thus, 30° shoulder abduction during external rotation exercise for the patient might ease the tension of these tendons.²⁶

Also, a shoulder abduction position might prevent squeezing out the blood supply of the supraspinatus, superior portion of the infraspinatus, and long head of the biceps tendons.³⁰ At 0° shoulder abduction, the humeral head creates constant pressure to these tendons near their insertion sites.³⁰ The constant pressure makes an avascular zone in these tendons, and then degeneration of these tendons occur.³⁰ This avascular zone may not be ideal for a patient who recovers from rotator cuff injury or surgery. Placing a towel roll between the arm and the side of the body during external rotation exercise might attenuate the avascularity, and these tendons might be able to have adequate blood supply from the suprascapular and subscapular arteries during external rotator exercise.²⁶

Long-term Effects of the Rotator Cuff Exercises

In order to find the long-term effects of rotator cuff exercises, several rotator cuff strength programs have been studied.^{22, 94-96} Moncrief et al⁹⁵ examined five posterior rotator cuff exercises with lightweight dumbbells for four weeks (five times per week) to find whether shoulder external and internal rotation torques would increase. After four weeks, both shoulder external and internal rotation torques were significantly increased approximately 8-9%.⁹⁵ Both males and females had significant increase in external and internal rotation torques, in addition to

significant increased rotation torques in both dominant and non-dominant arms with the strength program.⁹⁵

Page et al⁹⁴ tested eccentric strength of the shoulder complex muscles with using an isokinetic machine before and after 6-weeks of rotator cuff training with a 5 lb dumbbell or an elastic band. The elastic band group had significantly greater eccentric strength at 60°/s compared to the dumbbell group, but at 180°/s there was no significant difference between the two groups.⁹⁴ Even though the study showed greater eccentric strength gains at 60°/s in the elastic band group than the dumbbell group, there were few methodological issues in this study such as specificity of speed and training. During the 6-week training period, the elastic band group had similar shoulder motion as the isokinetic testing motion, and also had similar speed of motion to the isokinetic testing speed (60°/s). These might affect the results of the study.

Treiber et al⁹⁶ studied the effects on tennis serve velocity and shoulder rotation torque after 4-weeks (three times per week) of rotator cuff training with an elastic band and lightweight dumbbell. The elastic band and dumbbell group had significantly increased average and peak velocities (8% and 6%, respectively) of the tennis serve in both men and women.⁹⁶ Additionally, the elastic band and dumbbell group had significant increases in shoulder internal (at 120°/s and 300°/s) and external (only at 300°/s) rotation torque. On the other hand, a non-training group did not increase in either velocity of tennis serve or torques of shoulder internal and external rotation.⁹⁶

Giannakopoulos et al²² compared an open chain rotator cuff strength program to a closed chain rotator cuff strength program over six weeks (three times per week). In addition, strength of shoulder external and internal rotations for the both sides of the shoulder were isokinetically tested before starting the strength program to see which side of the shoulder was stronger or

weaker than the other.²² The open chain exercises were shoulder external and internal rotations with a 2 kg dumbbell; and the closed chain exercises were push-ups, lat pull-downs, reverse pull-ups, and overhead presses.²² Both groups had significant increases in shoulder external and internal rotation strength in the weak side of the shoulder.²² Only the closed chain group had significant increase in shoulder external and internal rotation strength in the strong side of the shoulder.²² They concluded that a rotator cuff training program should change to closed chain exercises once a patient gained his/her normal shoulder strength following rotator cuff injury or surgery.²² However, the number and intensity of the closed chain exercises were greater than the open chain exercises, which might affect on the results of strength gain of shoulder rotations in the strong side of the shoulder.

The Use of Electromyography

Electromyography (EMG) is a tool that can be very valuable in muscle function studies if it is properly used.^{97,98} To use EMG correctly, testers must know different types of electrodes and locations of electrode, have a knowledge of anatomy, and understand its limitations.^{97,98}

Electrodes and Site Selection EMG electrodes are used to record action potentials of muscle fibers.⁹⁷ There are different sizes of electrodes. Electrodes with smaller detection areas allow closer interelectrode spacings and thus a higher level of selectivity.⁹⁹ These electrodes might be 0.5 mm in diameter and placed at an interelectrode distance of 1 cm.⁹⁷ They are usually used for smaller muscles, such as the facial or upper extremity muscles.⁹⁷ For larger muscles, electrodes with larger surface areas are desirable and may be placed farther apart.⁹⁷ They might be 1 cm in diameter and placed with an interelectrode distance of 2 cm.⁹⁷

It is important to keep the skin impedance as low as possible even though some manufactures claim that electrode site preparation requires little attention because of the high input impedance of their EMG amplifiers.⁹⁷ However, it is generally recommended to prepare the skin prior to electrode placement. The skin is prepared by using an alcohol-soaked pad to rub the electrode site with about six vigorous strokes.⁹⁷ The skin must be abraded at least lightly with an emory cloth with or without an abrasive conductive gel.⁹⁷

Knowing where to place the electrodes on the muscles is important because the electrodes are devices that pick up muscle activity.⁹⁷ There are six strategies of electrode placement: (1) keep the minimum amount of tissue between the electrodes and the muscle fibers; (2) place the electrodes parallel to the muscle fibers; (3) avoid placing the electrodes on the motor end plate region; (4) choose sites that are easy to locate in order to facilitate reliable electrode placement; (5) avoid areas that cause problems, such as skin folds or bony obstruction; (6) minimize cross-talk from proximal muscles by choosing the appropriate electrode size and interelectrode spacing.¹⁰⁰

Electrode Placement For the supraspinatus electrode location, a tester palpates the spine of the scapula and electrodes are placed on approximately 1.5 cm superior to the midpoint of the spine of the scapula.¹⁰¹ For the infraspinatus, the location of electrodes is approximately 4 cm inferior to the midpoint of the spine of the scapula, over the infrascapular fossa of the scapula.⁹⁷ The electrodes should be placed parallel to the spine of the scapula to avoid placement over the posterior deltoid.⁹⁷ The electrode site for the teres minor is at a point one third of the way between the acromion and inferior angle of the scapula along the lateral border.¹⁰¹ For the approach to the upper and lower subscapularis, the electrode location is 3 cm (for the upper subscapularis) and 5 cm (for the lower subscapularis) below the midpoint of the spine of the

scapula and anterior to the lateral border.⁵⁵ For the anterior deltoid, electrodes are placed on the anterior aspect of the arm, approximately 4 cm below the clavicle, so that they run parallel to the muscle fibers.⁹⁷ For the middle deltoid, electrodes are placed, parallel to the muscle fibers, on the lateral aspect of the upper arm and approximately 3 cm below the acromion.⁹⁷ For the posterior deltoid, the location of electrodes is 2 cm below the lateral border of the spine of the scapula and angled on an oblique angle toward the arm.⁹⁷ There two electrode locations for the pectoralis major: for clavicular placement, electrodes are placed 2 cm below the clavicle, just medial to the axillary fold, and angled on an oblique angle toward the clavicle; and for the sternal placement, electrodes are placed 2 cm medial to the armpit, horizontally on the chest wall over the muscle mass.⁹⁷

Surface vs Fine Wire Electrodes Testers must know advantages and disadvantages of the use of surface and fine wire electrodes in order to measure the electrical activity from a specific muscle. Surface electrodes provide a safe, easy, and noninvasive method.⁹⁷ They do not need to penetrate the skin, which lessens discomfort to the patient.^{97, 98} However, skin-electrode preparation may create considerable patient discomfort.⁹⁸ Also, surface electrodes are able to receive signals from more than single motor units.⁹⁷

One of the disadvantages for surface electrodes is that the electrodes are not useful to receive signals from small muscles or deeper muscles, which lie under superficial muscles.⁹⁸ The estimated effective recording area of surface electrodes ranges between 10 and 20 mm from the skin surface.¹⁰² Another disadvantage is that muscle will move under the skin, thereby creating different volumes of muscle tissue from which the electrodes are recording.⁹⁸ An additional disadvantage of surface electrodes is the possibility of “cross-talk,” a phenomenon where energy from one muscle travels over into the recording field of another muscle.⁹⁷ It may

make it difficult to isolate the signals from a specific muscle.⁹⁷ In addition, there are only a few published guides to electrode placement and there are reliability issues of the measurement of the same muscle tissue with a repeated measurement.^{97,98} A final disadvantage of surface electrodes is that the electrodes and leads can get in the way of motion or make the patient feel self-conscious about a posture; in other words, the surface electrode signals may not reflect the customary patterns of use for the patient.⁹⁷

Fine wire electrodes can be used for small or deep muscles that surface electrodes cannot measure.⁹⁸ However, locating the electrode in a specific muscle requires sufficient anatomical knowledge and training in the skill of implanting the wire.⁹⁸ Besides, there are discomfort, pain, or bleeding with fine wire electrodes because of the invasive method, and sometimes the patients feel pain even after the experiment.⁹⁸ Same as surface electrodes, reliability of the measurement is problematic for fine wire electrodes.⁹⁸ In addition, the wires may easily fracture during dynamic movement.⁹⁸

Chapter 3

Methods

Design

The experiment is a controlled laboratory study, with one independent variable.

- Independent variable is the application of a towel roll.
 - With and without a towel roll during standing and sidelying external rotation exercises
- Dependent variable is the amplitude of each muscle activation.
 - Amplitude of the middle and posterior deltoid, infraspinatus, and pectoralis major electromyography activity

Subjects

Twenty right dominant hand collegiate male subjects, who have bilateral healthy shoulders, will be selected. The throwing hand defines the dominant hand. The subjects' ages will be between 18 to 30 years old. Each subject will sign an IRB informed consent form and be allowed to withdraw from this study at any time. Also, they will answer the exclusion criteria questionnaires (Appendix A). Exclusion Factors are:

- Current pathology in the cervical region
- A history of shoulder pathology or surgery
- Skin disease or lesion on the shoulder region
- Infection of the shoulder region

Procedures

A tester will instruct all subjects as to what to do before the trial. Subjects will pick days for practice and experiment. The practice day and the experiment day will be separated by at

least one week. The right dominant shoulder of each subject will be used for both practice and experiment.

For the practice day, the subjects will practice four maximal voluntary isometric contractions (MVICs) and four external rotation exercises.

The four MVIC positions will be:

- For the middle deltoid, with the shoulder at 0° abduction, and the subjects will pull a cable laterally in the standing position, in order to create shoulder abduction force (Figure 1).¹⁰³
- For the posterior deltoid, with the shoulder abducted 0° , and the subjects will pull back a cable in the standing position, in order to create shoulder extension force (Figure 2).¹⁰³
- For the infraspinatus, with the shoulder abducted 0° , neutral shoulder rotation, and the elbow flexed 90° , with pulling a cable in the external rotation direction in the standing position, so as to create shoulder internal rotation force (Figure 3).^{103, 104}
- For the pectoralis major, with the shoulder abducted 0° bilaterally with heel of the hands together and the elbows flexed 90° , as the heels of the hands are pushed against each other in the standing position (Figure 4).¹⁰⁴



Figure 1.



Figure 2.

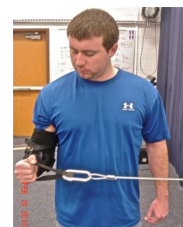


Figure 3.



Figure 4.

The four external rotation exercises will be:

- Standing external rotation alone (the arm at 0° shoulder abduction)



- Standing external rotation with a towel roll (the arm at 30° shoulder abduction)



- Sidelying external rotation alone (the arm at 0° shoulder abduction)



- Sidelying external rotation with a towel roll (the arm at 30° shoulder abduction)



The 30° angle of shoulder abduction will be confirmed by placing an inclinometer (MiE, Medical Research *Ltd*, UK) on the lateral-middle part of the upper arm while the shoulder is adducted against a towel roll. The thickness of the towel roll will be adjusted to each subject, so that 30° shoulder abduction will be maintained for all subjects. The right dominant elbow will be fixed at 90° flexion by using an elbow brace (HEX Elbow Brace, BREG Inc, Vista, CA) set at 90°. The starting position of the shoulder external rotation for all exercises will be at neutral shoulder rotation (0° shoulder external rotation). In the concentric phase, the shoulder will be externally rotated to maximum (80° – 90° shoulder external rotation from the pilot study), and then the shoulder will be internally rotated to the neutral position in the eccentric phase. The speed of the repetitions will be controlled by a metronome, which will be set to one beat per second. Each concentric and eccentric phase will be performed during 1 beat (about 85°/s). For standing external rotation exercise with and without a towel roll, all subjects will use a green colored elastic band (TheraBand, Hygienic Corporation, Akron, OH), which is defined as heavy resistance. Distance (260 cm) between the end of the elastic band and a hand gripper at the starting position will be same for all subjects. For sidelying external rotation, a 4-lb dumbbell will be used as resistance for all subjects. The subjects will be allowed to practice these exercises until they become familiar.

For the experiment day, the subjects will be asked if they have pain or soreness in the shoulder region before the trials. If so, the subjects will reschedule their experiment day. Prior to applying the surface electrodes to the skin, the skin near the surface electrode locations will be cleaned so as to reduce skin impedance. This will include the shaving of hair, scraping the skin smoothly with sandpaper, and wiping the area with an alcohol swab. Disposable pre-gelled Ag-AgCl surface electrodes (BIOPAC Systems, Inc., Goleta, CA) with 2 cm interelectrode distance

will be used to record surface EMG activity. The electrodes will be placed over four muscles: the middle and posterior deltoid, the infraspinatus, and the sternal part of the pectoralis major. The locations of the electrodes will be over the central portion of the muscle bellies.⁹⁷ For the middle deltoid, the electrodes will be positioned 3 cm below the acromion process over the muscle mass on the lateral upper arm. For the posterior deltoid, 2 cm inferior to the lateral border of the scapular spine, and the electrodes will be angled parallel to the muscle fibers. For the infraspinatus, the electrodes will be positioned 4 cm inferior and parallel to the scapular spine on the lateral aspect over the infrascapular fossa. For the sternal part of the pectoralis major, the electrodes will be placed horizontally on the chest wall over the middle part of the pectoralis major, 2 cm from the axillary fold. A ground electrode will be positioned over the acromion process on the same side of shoulder. The same tester will place the electrodes on all subjects in order to maintain consistency (Figure 5).



Figure 5. Electrode Placements

After applying the electrodes, a clinician will confirm the electrode signals from each muscle by having the subjects stand and isometrically contract the muscles being tested: for the middle deltoid, the arm will be abducted at 0° shoulder abduction; for the posterior deltoid, the arm will be extended at 0° shoulder extension; for the infraspinatus, the arm will be externally

rotated at 0° internal rotation while the arm is by the side of the body; and for the pectoralis major, the arm will be horizontally adducted at 90° shoulder flexion.¹⁰³

The surface electrodes will be attached to the surface EMG system (MP150, BIOPAC Systems, Inc., Santa Barbara, CA). Signals from the muscles will be amplified (DA100B, BIOPAC System Inc., Santa Barbara, CA) at 1000 Hz. The input impedance of the amplifier will be 1.0 mega-ohm, with a common mode rejection ratio of 90 dB, band-pass filters from 10 to 500 Hz and a signal to noise ratio of 70 dB. Filtered EMG signals will be converted to a root mean square (RMS) signal with a 10 msec moving window.

Prior to starting electromyography (EMG) measurement, the same warm-up procedure will be given to every subject. The following steps will be performed:

1. Pendulum: clockwise & counter clockwise (Figure 6)
2. Shoulder flexion, abduction, extension, horizontal abduction and adduction, and external and internal rotations



Figure 6. Pendulum

For both step 1 and 2, the subjects will hold a 1-lb dumbbell and perform 1 set of 20 repetitions.

Data collection for each subject will begin with three 4-second MVIC for each muscle to normalize the EMG data. The testing position will be same as the MVIC positions for the practice day. Resting time between each set will be at least three minutes so as to reduce the fatigue effect.

The experimental trials will be performed exactly the same as they did in the practice session. One set of 10 repetitions of each exercise will be performed with three minutes resting time and EMG signals will be recorded for 10 seconds for the exercise trial. Recording will be started after the 2nd repetition. The metronome will be set at one beat per second, 20 seconds for

10 repetitions; so the 10-second recording will capture between the 3rd and 7th repetitions. The recorded EMG signals will be normalized by expressing both average and mean-peak EMG values of the subject's 5 repetitions for each muscle for each trial as a percentage of the MVIC of the same muscle. Testing order will be counterbalanced to minimize the fatigue effect. In addition, an accelerometer (Tri-axial Accelerometer 50G, BIOPAC Systems, Inc., Goleta, CA) will be placed on the distal, lateral side of the right forearm during the exercises in order to confirm each concentric and eccentric contraction phase on the surface EMG system.

Statistical Analysis

Paired t-test will be used to compare both average and mean peak activity of each muscle during standing and sidelying external rotation with a towel roll against without a towel roll. Statistical significance will be set at $P < .05$.

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Appendix A – Consent Form

Consent to be a Research Subject

Introduction:

This research is being conducted by Ty Hopkins PhD, associate professor, and Kazuto Sakita, graduate student, of the Human Performance Research Center at Brigham Young University. This study is intended to examine the effects of a towel roll during standing and sidelying shoulder external rotation exercise on shoulder muscle activation. You are invited to participate because you are (1) right dominant hand and have (2) no history of shoulder disorders or surgeries, (3) no current cervical disorders, and (4) no known of shoulder skin disease or infection.

Procedure:

This study will consist of two sessions with 2.5 hours of total time commitment. Today, you will go through the practice session (30 minutes), which includes maximal voluntary isometric contractions and four shoulder external rotation exercises.

At least one week following the practice session, you will report back to the Biomechanics Lab (RB124) for a 2-hour session. You will be asked if there is shoulder pain or soreness. If so, you will have to reschedule your experiment session and be given rest until pain or soreness is gone. If there is no shoulder pain or soreness, skin over your right shoulder will always be shaved, lightly abraded with sandpaper, and cleaned with alcohol prep in order to place nine adhesive surface electrodes (two for each muscle and one for a ground) since we are only interested in the right hand of the right dominant hand subjects. The muscles that we will test are the infraspinatus, middle and posterior deltoid, and pectoralis major. Also, you will be asked to take off your shirt during the experimental session in order to have electrode's cords attached to the surface electrodes during testing.

You will always warm-up your right shoulder with a one-pound dumbbell in the right hand since we are only interested in the right hand of the right dominant hand subjects. You will perform (1) pendulum motion (clockwise and counter clockwise) and (2) shoulder movements in all directions. One set of 20 repetitions will be performed for each shoulder motion.

You will be asked to perform three 4-second maximal voluntary isometric contractions for each muscle (middle and posterior deltoid, infraspinatus, and pectoralis major). The testing positions will include the arm straight out, the arm back, and the arm rotated. Resting time between each set will be at least three minutes. You will be asked to hold a handle and pull the non-elastic cable as hard as possible for the middle and posterior deltoid, and infraspinatus. Also, you will be asked to put the heel of the hands together and push against each other as hard as possible for the pectoralis major.

Next, you will be asked to perform the experimental trials. The experimental trials will be (a) standing rotation without a towel roll, (b) standing rotation with a towel roll, (c) sidelying rotation without a towel roll, (d) sidelying rotation with a towel roll. The testing order will be randomized. There will be only one set of 10 repetitions for each exercise with three minutes rest between exercises.

Risk/discomforts

You may experience mild discomfort with sandpaper and alcohol swab during the process of surface electrode placement. There may be muscle soreness after the initial visit as well as the

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second visit. You may also feel fatigue during the exercises each visit. We will follow up for at least 3 days after experiment if there is muscle soreness or not. If you want to have a treatment, we, as athletic trainer, will give you a stretching program and an ice bag to reduce the muscle soreness.

Benefits:

The benefit associated with this study is knowing how a towel roll between the arm and the side of the body during standing and sidelying shoulder external rotation exercises affects the shoulder muscle activity. These data will lead to further understanding of rehabilitation of the shoulder muscles.

Confidentiality:

All information provided will remain confidential and will only be reported as group data with no identifying information. All data including the questionnaire will be kept secured, and only those involved in the study will have access to this information. Following the investigation, the questionnaires will be destroyed.

Participation:

Participation in this research study is voluntary. You have the right to withdraw at anytime or refuse to participate entirely without jeopardy to your class status, grade, or standing with the university. You may be dropped from the study due to scheduling conflicts or an inability to follow the research protocol.

Questions about the Research:

Do you have any questions (please circle one)? YES No

If yes, then write your question(s) on the back of this sheet and DO NOT sign below until your questions have been answered satisfactorily. You may take as much time as necessary to think this over. If you have any questions or comments regarding this study, you may contact:

Ty Hopkins PhD, ATC Principle Investigator Brigham Young University 120B Richards Building (801) 422-1573 tyhopkins@byu.edu	Kazuto Sakita, ATC, CSCS Graduate Student Brigham Young University 577N 100W APT104 Provo, 84601 (801) 422-9156 kazuto200@hotmail.com
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Questions about your Rights as Research Participants

If you have questions you do not feel comfortable asking the researcher, you may contact the BYU IRB Administrator by phone (801) 422-1461, by email at irb@byu.edu, or in person at A-285 ASB, Provo, UT 84602.

I have read, understood, and received a copy of the above consent and desire of my own free will to participate in this study.

Signature: _____ Date: _____

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