Int. J. Morphol.,
39(5):1316-1322, 2021.

Effect of Adduction During Glenohumeral External Rotation Exercises in the Scapulohumeral Muscles

Efecto de la Adducción Durante Ejercicios de Rotación Externa Glenohumeral en los Músculos Escapulohumerales

Claudio Bascour-Sandoval[1,2]; Rubén Gajardo-Burgos[3]; Germán Gálvez-García[4,5] & Mauricio Barramuño-Medina[2]

BASCOUR-SANDOVAL, C.; GAJARDO-BURGOS, R.; GÁLVEZ-GARCÍA, R. & BARRAMUÑO-MEDINA, M. Effect of adduction during glenohumeral external rotation exercises in the scapulohumeral muscles. *Int. J. Morphol., 39(5)*:1316-1322, 2021.

SUMMARY: The effect of adduction during glenohumeral external rotation (ER) exercises on the scapulohumeral muscles is controversial. The aim of this study was to evaluate the effect of carrying out adduction during external rotation exercises in low and high shoulder positions on the electromyographic (EMG) activity of the infraspinatus (IS), middle deltoid (MD), and posterior deltoid (PD) muscles. EMG activity of the IS, MD, and PD muscles of 20 healthy participants was evaluated. Subjects performed 6 ER exercises that combined two factors: i) different adduction pressures according to biofeedback unit (0, 5 and 10 mmHg), and ii) low and high shoulder position. The pressure was controlled using a biofeedback unit. The low and high shoulder positions were 20° and 90° of abduction. In the low shoulder position, the activity of the IS muscle increased as the pressure on the biofeedback unit increased and the MD and PD muscles presented the highest activity at 10 mmHg. In the high shoulder position, the activity of the IS muscle was higher at 0 and 10 mmHg, the MD muscle presented higher activity at 5 mmHg, and PD muscle activity did not vary with the pressure. The addition of adduction at a pressure of 5 mmHg in the low shoulder position promotes is activity. Likewise, adduction at a pressure of 10 mmHg will promote activity of the IS, MD, and PD.

KEY WORDS: Electromyography; Shoulder; Exercises; External rotation; Rotator Cuff; physical therapy/rehabilitation

INTRODUCTION

External rotation (ER) exercises of the shoulder are widely used in the physical rehabilitation of individuals with shoulder pain (Greenberg, 2014; Klintberg *et al*., 2015; Doiron-Cadrin *et al*., 2020). One of the most commonly used exercises is standing on both feet with a wedge (generally a towel) between the thorax and the distal zone of the humerus (Camargo *et al*., 2015) in order to generate a slight abduction of approximately 10°-20°. The use of the wedge requires contraction of the adductor muscles to keep it in position (Kolber *et al*., 2008). This contraction activates a reciprocal inhibition mechanism. This mechanism affects muscle activity, improving the coordination between the infraspinatus muscle (IS, the agonist of ER) and the adductor muscles pectoralis major (PM), latissimus dorsi (LD), and teres major (Reinold *et al*., 2009). Furthermore, as the latter are powerful adductors (Kian *et al*., 2019), their contraction may diminish the activity of the deltoids.

Nevertheless, the effect of the wedge on muscle activity when carrying out ER is controversial. Discussing activity of the IS, Reinold *et al*. (2004), reported that the use of a wedge during a resistance exercise with a dumbell (7.1 ± 2.7 kg) showed an increase of 25 % in the electromyographic (EMG) signal of the IS. Sakita *et al*. (2015), on the other hand, found no difference in IS activity concerning the use of a wedge when carrying out resisted ER with a green elastic band. Bitter *et al*. (2007), compared the activity of the IS in isometric ER with and without a pressure biofeedback unit (wedge), which had to be

[1] Departamento de Medicina Interna, Universidad de La Frontera, Temuco, Chile.
[2] Carrera de Kinesiología, Facultad de las Ciencias de la Salud, Universidad Autónoma de Chile, Temuco, Chile.
[3] Instituto de Aparato Locomotor y Rehabilitación, Facultad de Medicina, Universidad Austral de Chile, Valdivia, Chile.
[4] Departamento de Psicología, Universidad de La Frontera, Temuco, Chile.
[5] Département de Psychologie Cognitive, Sciences Cognitives et Neuropsychologie, Institut de Psychologie, Laboratoired'Étude des Mécanismes Cognitifs, Université Lyon 2, Lyon, France.
FUNDING: This study was financed by Universidad de La Frontera grant DI20-0046.

compressed at up to 40 mmHg. Activation of the adductor muscles was ensured by EMG evaluation. No differences were found in IS activity.

Regarding deltoid activity, Reinold *et al*. (2004), observed no differences in the activity of the middle deltoids (MD) and posterior deltoids (PD) with or without the use of a wedge during a resistance exercise, but did not evaluate the activity of adductor muscles or the force applied to the wedge. Bitter *et al*., found less activity of the MD during isometric ER at 10 % of maximum isometric force with a wedge. Similarly, Forbush *et al*. (2018) reported lower activity of the PD when maximum isometric ER was carried out with adduction greater than 80 % of the maximum adduction force versus an adduction force of less than 60 %. Sakita *et al*., found a significant increase in the activity of the PD, but found no significant differences in the activity of the PM when the patient executed ER with or without a wedge. The latter investigation indicates that the mere inclusion of a wedge did not ensure a significant increase in the activity of the adductor muscles.

Thus, although it is supported theoretically, the evidence of deltoid inhibition during adduction is controversial (Bitter *et al*.; Reed *et al*., 2010; Sakita *et al*.). This may be explained by the amount of pressure exercised against the wedge when adduction is carried out, however, the studies that have evaluated this used pressures that are not applicable to rehabilitation scenarios. There is a need to evaluate the effect of different pressures on the activity of IS, MD, and PD, replicating exercises used in rehabilitation, i.e. isotonic ER exercises with low resistance. Another much used exercise is external rotation in high position (90° abduction; Tardo *et al*., 2013) since it is a progression towards more functional tasks like reaching and throwing. This change would also modify the amount of EMG activity of the IS and deltoids (Myers *et al*., 2005) and could alter the effect of adduction on the activity of the IS and deltoid muscles. Therefore, the object of the present study was to evaluate the effect of carrying out adduction during ER exercises in low and high position on the EMG activity of the IS, MD, and PD muscles. The knowledge gained in this investigation will affect clinical decision-making when prescribing exercises to patients with shoulder pathologies.

SUBJECTS AND METHODS

Participants: Twenty male individuals with no current or previous shoulder lesion or instability and no pain in the last 12 months were recruited. The participants had to present a full range of glenohumeral movement and no pain in an isometric resistance test of external rotation. Mean age, height, and weight (±SD) were 22.78±3.45 years, 1.73±0.06 m, and 75.08±7.80 kg respectively. In order to reduce the crosstalk effect that may exist between the DM and PD muscles in smaller subjects, it was decided to include only male subjects. This research was approved by the Scientific Ethics Committee of Universidad de La Frontera (062_20; World Medical Association, 2013). Before evaluation, all the participants signed an informed consent.

Instrumentation and data collection: Surface electromyography (EMG) was carried out with the BTS-FEREEMG1000 wireless system, adjusted to a sample frequency of 1000 Hz per channel and resolution of 16 bits, with the SMART Capture acquisition software (BTS Bioengineering, Milan, Italy). The skin was shaved and cleaned with alcohol to minimize impedance. Miniaturized wireless probes with adhesive active bipolar hydrogel electrodes (Ag/AgCl) were fixed to the skin. Following the recommendations of SENIAM (Hermens *et al*., 2000), the electrodes were oriented in the direction of the muscle fibers, avoiding motor points and with a distance of 2 cm between electrodes. The muscles evaluated were the IS, MD and, PD. The LD and PM muscles were recorded as a control of glenohumeral adduction.

Procedure. The participants were evaluated in one session in the Movement Analysis Laboratory of the Universidad Autónoma de Chile. The session started with an interview, evaluation of joint range and strength of the dominant upper limb, and measurement of weight and height. Then, the EMG evaluation was carried out. In order to normalise the EMG signals, the maximum voluntary isometric contraction (MVIC) of each muscle was recorded following the protocol for manual muscle tests (Kendall *et al*., 1993). Each test consisted of 5 seconds of contraction, with 3 repetitions and a pause of 1 minute between them. The mean maximum value obtained was used as the reference maximum value of each muscle studied.

Afterward, the participants carried out 5 test repetitions of the 6 exercises, with a pause of 1 minute between them. All the exercises were carried out in the sitting position with the elbow in 90° flexion. The exercises consisted of an ER from a position of 0° glenohumeral rotation. The resistance was applied by means of a red elastic band (Thera-band®), with one end fixed and the other held in the participant's hand, with an initial tension of 25 % of its length.

Execution of the exercises included two factors: position and pressure. The position factor included 2 variants: low and high. The low position consisted of an abduction of approximately 20° maintained by the pressure biofeedback unit (Stabilizer, Chattanooga Group Inc, Hixson, TN, USA) inflated to 80 mmHg and placed between the thorax and the distal third of the humerus. In the high position (90° abduction), the participant's arm was supported on a stable surface and the pressure biofeedback unit was placed between the distal third of the humerus and the surface. With the arm placed on the pressure unit, the pressure was adjusted to 80 mmHg again. The pressure factor included 3 variants: 0, 5 and 10 mmHg. At 0 mmHg, participants had to keep the pressure unit at 80 mmHg during the execution of the exercise. At 5 and 10 mmHg, participants had to exert an adduction force to increase the pressure of the unit from 80 to 85 and 90 mmHg respectively. The pressure dial and the screen of the force meter were placed where both subject and investigator could see them, in order to control the adduction force.

Half of the participants carried out the exercises with the upper limb in low position and pressure from 0 to 10 mmHg, followed by the exercises in high position and pressure from 0 to 10 mmHg. The other half carried out the exercises in the reverse order, to try to avoid a bias of order. The exercises are illustrated in Figure 1. The participants were evaluated during the execution of a single repetition of each exercise, with a pause of 1 minute between each exercise.

Exercise 1. External rotation in low position with 0 mmHg pressure.
Exercise 2. External rotation in low position with 5 mmHg pressure.
Exercise 3. External rotation in low position with 10 mmHg pressure.
Exercise 4. External rotation in high position with 0 mmHg pressure.
Exercise 5. External rotation in high position with 5 mmHg pressure.
Exercise 6. External rotation in high position with 10 mmHg pressure.

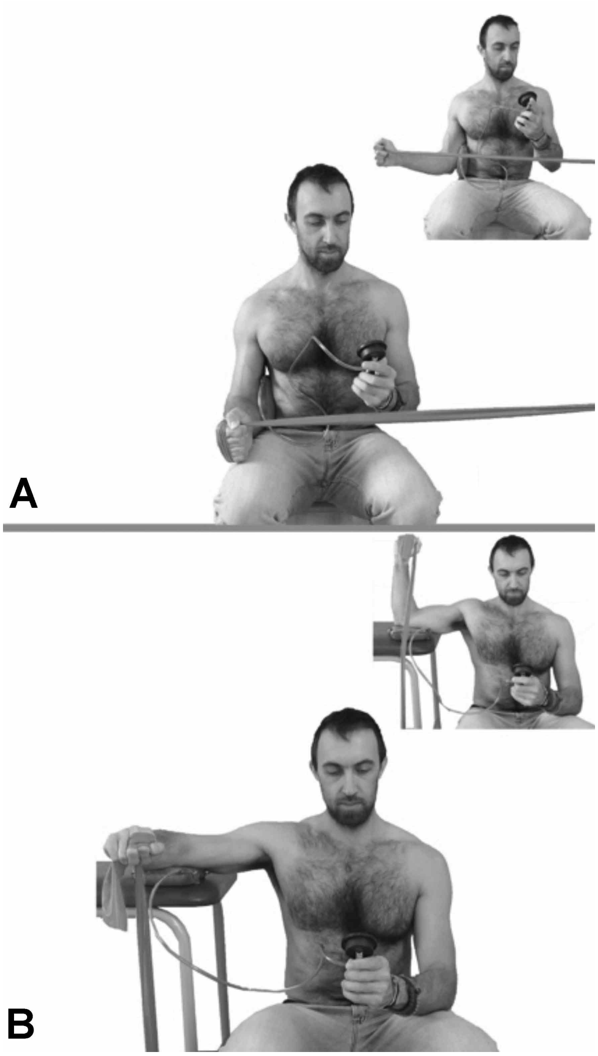

Fig. 1. Initial and final positions of exercises. A: Low position; B: High position.

Data processing. The signal was processed digitally by an algorithm in the MatlabR2016a software (MathWorks Inc., USA.). Initially, the signal was centered on zero by excluding the mean of the wave; fourth-order low pass and high pass Butterworth filters were applied, with cut-off frequencies of 10 and 450 Hz respectively. Then, the root mean square (RMS) of the signal was calculated by a sliding window method with a width of 20 samples and a jump of 1. The amplitude was normalized in accordance with the maximum voluntary isometric contraction (%MVIC) and each burst of EMG was isolated to calculate the mean amplitude (hereafter mean EMG; Konrad, 2005) of the signal of each muscle in each exercise.

Ethics approval: This research was approved by the Scientific Ethics Committee of the Universidad de La Frontera (062_20). Before evaluation, all the participants signed an informed consent.

Statistical analysis. The statistical program used for data analysis was SPSS version 23.0. The dependent variables were the mean EMG values of IS, MD, and PD. The Shapiro-Wilk normality test was applied to these data. As the assumption of normality was met for the analysis of the mean EMG of the IS, MD, and PD, a series of factorial repeated measures ANOVAs were carried out for these variables. Two intra-subject factors were considered: i) position (high vs. low); and ii) pressure (0 mmHg, 5 mmHg, and 10 mmHg). Using the same factors, two factorial repeated measures ANOVAs were carried out to evaluate the mean EMG of the PM and LD. The significance threshold set for all cases was $P < 0.05$. The interactive effects between position and pressure were of primary interest. Bonferroni's test was used for the post hoc analysis. The mean EMG of the IS was divided by the mean EMG of the MD and the mean EMG of the PD to calculate the mean EMG IS/MD and IS/PD ratios.

RESULTS

Descriptive statistics of the normalized EMG activity of each muscle in each exercise studied are shown in Table I. The mean EMG IS/MD and IS/PD ratios are shown in Table II.

Infraspinatus muscle. For the mean EMG of the IS, the principal effect of position was significant (P = 0.002), with greater activation in the low position than in the high position. The principal effect of pressure was significant (P < 0.001). The activity of the IS presented significant differences between the 3 pressures, with the greatest activity at 10 mmHg and the least at 0 mmHg. The interaction between position and pressure was significant (P < 0.001). It was observed that, with pressures of 5 and 10 mmHg, the muscle activity of the IS was greater in the low position than in the high position. At 0 mmHg, the muscle activity did not vary between the high and low positions. In the low position, the muscle activity of the IS varied significantly between the 3 pressures, being greatest with 10 mmHg and least with 0 mmHg. The IS in high position presented greater activity at 0 mmHg than at 5 mmHg, and at 10 mmHg than at 5 mmHg.

Middle deltoids muscle. For the mean EMG of the MD, the principal effect of position was significant (P = 0.001), with greater activation in the high position than in the low position. The principal effect of pressure was not significant (P = 0.067). The interaction between position and pressure was significant (P = 0.015). Muscle activity of the MD was greater in the high position than in the low position for all pressures. In the low position, the muscle activity of the MD was significantly greater with 10 mmHg than with 5 mmHg. In the high position, muscle activity was significantly greater with 5 mmHg than with 10 mmHg.

Posterior deltoids muscle. For the mean EMG of the PD, the principal effect of position was significant (P = 0.001), with greater activation in the high position than in the low position. The principal effect of pressure was not significant (P = 0.579). The interaction between position and pressure was significant (P = 0.036). The muscle activity of the PD was greater in the high position with all three pressures. In the low position, the muscle activity of the PD was significantly greater with 10 mmHg than with 5 mmHg. In the high position, muscle activity did not vary significantly with the pressure.

Pectoralis major and Latissimus dorsi muscles. For the mean EMG of the PM and LD, the principal effect of position was not significant (P = 0.214 and P = 0.188). The principal effect of pressure was significant in both muscles (P < 0.001).
The muscle activity with 10 mmHg was greater than with both 5 mmHg and 0 mmHg. The interaction between position and pressure was significant for both muscles (P < 0.001).

Table I. Mean values and standard deviation of the mean EMG activity by muscle studied.

	Low position			High position			^{b}p value					
Muscle	0 mmHg	5 mmHg	10 mmHg	0 mmHg	5 mmHg	10 mmHg	Pairwise Comparisons					
IS	9.56±4.03	10.88±4.59	12.54±5.17	8.92±2.40	7.53±1.91	8.49±2.15	LP0/LP5	*p* = 0.019	LP5/LP10	*p* = 0.001	HP0/HP5	*p* = 0.044
							LP0/LP10	*p* < 0.001	LP5/HP5	*p* = 0.001	HP0/HP10	*p* = 0.964
							LP0/HP0	*p* = 0.437	LP10/HP10	*p* = 0.001	HP5/HP10	p = 0.041
MD	1.56±1.18	1.55±0.86	1.82±0.98	7.44±6.91	8.04±6.57	6.14±6.65	LP0/LP5	*p* = 1.000	LP5/LP10	*p* < 0.001	HP0/HP5	*p* = 1.000
							LP0/LP10	*p* = 0.320	LP5/HP5	*p* < 0.001	HP0/HP10	*p* = 0.112
							LP0/HP0	*p* = 0.001	LP10/HP10	*p* = 0.007	HP5/HP10	p = 0.038
PD	2.96±2.11	3.10±2.44	3.77±3.05	6.27±3.25	5.90±3.32	5.76±2.93	LP0/LP5	*p* = 1.000	LP5/LP10	*p* = 0.006	HP0/HP5	*p* = 1.000
							LP0/LP10	*p* = 0.063	LP5/HP5	*p* < 0.001	HP0/HP10	p = 0.664
							LP0/HP0	*p* < 0.001	LP10/HP10	*p* = 0.004	HP5/HP10	p = 1.000
PM	1.38±0.74	1.9±0.86	3.11±1.64	1.89±1.05	1.73±0.98	1.94±1.05	LP0/LP5	*p* = 0.004	LP5/LP10	*p* < 0.001	HP0/HP5	*p* = 0.182
							LP0/LP10	*p* < 0.001	LP5/HP5	*p* = 0.385	HP0/HP10	*p* = 1.000
							LP0/HP0	*p* = 0.007	LP10/HP10	*p* = 0.007	HP5/HP10	*p* = 0.041
LD	1.93±1.32	2.59±1.79	4.16±3.11	2.21±0.87	2.05±1.01	2.45±0.77	LP0/LP5	*p* = 0.016	LP5/LP10	*p* = 0.001	HP0/HP5	*p* = 0.595
							LP0/LP10	*p* = 0.001	LP5/HP5	*p* = 0.250	HP0/HP10	*p* = 0.266
							LP0/HP0	*p* = 0.421	LP10/HP10	*p* = 0.028	HP5/HP10	*p* = 0.028

Values are expressed in mean EMG ± SD. EMG, electromyography; IS, infraspinatus; MD, middle deltoid; PD, posterior deltoid; PM, pectoralis major; LD, latissimus dorsi; MVIC, maximum voluntary isometric contraction; LP, low position; HP, high position; 0, 0 mmHg; 5, 5 mmHg; 10, 10 mmHg. P < .05 indicates statistical significanc.

Table II. Ratios of activity IS/MD and IS/PD.

	Low position			High position		
	0 mmHg	5 mmHg	10 mmHg	0 mmHg	5 mmHg	10 mmHg
IS/MD	7.67±3.59	8.26±3.73	8.04±3.82	1.65±0.76	1.44±1.20	2.33±1.58
IS/PD	4.12±2.22	4.75±3.01	4.55±2.82	1.71±0.75	1.57±0.73	1.79±0.87

IS, infraspinatus muscle; MD, middle deltoid muscle; PD, posterior deltoid muscle.

DISCUSSION

The object of the present study was to evaluate the effect of carrying out an adduction during ER exercises in low and high position on the EMG activity of the IS, MD, and PD muscles. It was shown that the addition of adduction to ER exercises in high and low position modifies the activity of the IS, MD, and PD.

Varying findings were observed in the low position. Firstly, the activity of the IS increased with the pressure on the wedge. This finding could be associated with co-contraction. The PM and LD are powerful internal rotators and glenohumeral adductors (Kian *et al*.). Thus, the increased activity of the PM and LD would generate a moment of internal rotation, promoting the activity of the IS to achieve net ER movement. Another explanation is that the activity of the PM generates anterior slipping of the humeral head; this is counteracted by the action of the IS and the other muscles of the rotator cuff, which limits the slipping (Sharkey & Marder, 1995; Wilk *et al*., 2002).

Secondly, the activity of the MD and PD increased at 10 mmHg. This finding goes against reciprocal inhibition. This is in line with the results of Bitter *et al*. who found no differences in the activity of the MD and PD when comparing the use or absence of a wedge in loads of 40 % and 70 % of the maximum ER force. Nevertheless, they did show a diminution of the activity of the PD at 10 % of the maximum force (Bitter *et al*.). Forbush *et al*. using maximum ER load, also showed a diminution of the activity in the PD. Both these studies used isometric contractions, in contrast to the present study which used isotonic contraction. Thus, the type of contraction must be considered when interpreting and comparing our results.

Thirdly, the IS presented greater activity in the low position than in the high position, while the MD and PD presented less activity in the same scenario, which agrees with another study (Escamilla *et al*., 2009). It should be noted that the IS/MD and IS/PD ratios were best in the low position with 5 mmHg. These findings support the use of low position and adduction of 5 and 10 mmHg in early stages of rehabilitation to increase the activity of the IS, as compared to the deltoids. Exercises with high IS activity, together with the other muscles of the posterior rotator cuff (i.e., supraspinatus and teres minor), and minimal deltoid activity are recommended to ensure glenohumeral stability (Clisby *et al*., 2008). Based on our findings, we can recommend the use of low position with 5 mmHg of adduction.

Finally, the greater the pressure, the greater the activity of the PM and LD. With 0 mmHg, the activity of both adductors was less than 2 %, increasing to more than twice their value with 10 mmHg. In other words, the pressure is related with the muscle activity of the adductors, and a pressure unit is a useful tool for confirming the activation of this muscle group. This was not the case in the high position, where no relation was found between the pressure and the activity of these muscles. A possible explanation for this is that, in the high position, the change from 0 to 5 mmHg is not enough to cause a significant variation in electromyographic activity.

Moreover, in the high position, the activity of the MD and PD is greater and the IS/MD and IS/PD ratios are smaller. Thus, the high position would be indicated to prioritize the activity of the deltoids and improve the coordination between the IS and the deltoids (Bigliani *et al*., 1996), using a more functional angle.

As far as we know, this is the first study to evaluate the effects of different degrees of adduction on muscle activity concerning isotonic ER exercise with low load. The exercise present in this evaluation is easy to apply in clinical practice; it also uses a pressure unit, which allows the force exerted by the individual to be quantified. This pressure unit is a low-cost item and is already present in many rehabilitation centers. Moreover, La Scala Teixeira *et al*. (2019) propose that the complexity of an exercise is a form of progression for the strengthening exercises that is added to the conventional variables (i.e., load, volume, frequency). Thus, performing ER by pressing the wedge with a specific force would be a progression to the typical ER exercise with a wedge since it represents greater complexity by performing a double task during its execution. This would add an interesting clinical tool for rehabilitation and / or strengthening programs. Likewise, to individuals with shoulder pain, performing this exercise—that demands great attention resources (ie, concentration)—could distract them from the pain (ie, distraction task; Bascour-Sandoval *et al*., 2019) and result in performing the exercise with less pain. However, this must be verified by future studies. Therefore, we believe that our findings provide valuable information for decision-making in prescribing exercises.

Within the limitations of the study, the use of a unique load (i.e., only one color elastic band) can be considered. This resistance load would represent different percentages of the maximum external rotation force of each subject. However, the results are presented based on the within-subject differences between the exercises performed. Care must be taken in extrapolating these results to patients with pain, as they may present different patterns of muscle activity, however, they provide a baseline. It must also be considered that the presence of fatigue may produce different muscle behavior to that reported in the present study.

CONCLUSION

Our results indicate that activity of the IS, MD, and PD is associated with the activity of the glenohumeral adductors in the low position. The addition of adduction at a pressure of 5 mmHg in the low position will therefore promote IS activity; adduction at a pressure of 10 mmHg will promote activity of the IS, MD, and PD. On the basis of our findings, we recommend executing ER in the low position using a pressure biofeedback unit and applying adduction during the execution of the exercise, as this favors the activity of the IS. In particular, we recommend the use of 5 mmHg, as this pressure maintains the activity of the MD and PD and increases the activity of the IS.

ACKNOWLEDGEMENTS

We thank the Dirección de Investigación of the Universidad de La Frontera for the translation of the manuscript. In addition, we recognize Rodrigo Montefusco, Tomás Herrera, Lucas Heise, Camilo Klagges, Bastián Saavedra and Constanza Sandoval students for providing support for the assessments.

BASCOUR-SANDOVAL, C.; GAJARDO-BURGOS, R.; GÁLVEZ-GARCÍA, R. & BARRAMUÑO-MEDINA, M. Efecto de la adducción durante ejercicios de rotación externa glenohumeral en los músculos escapulohumerales. *Int. J. Morphol., 39(5)*:1316-1322, 2021.

RESUMEN: El efecto de la aducción durante los ejercicios de rotación externa (RE) glenohumeral sobre los músculos escapulohumerales es controversial. El objetivo de este estudio fue evaluar el efecto de la realización de la aducción durante los ejercicios de rotación externa en posiciones bajas y altas del hombro sobre la actividad electromiográfica (EMG) delos músculos infraespinoso (IS), deltoides medio (DM) y deltoides posterior (DP). Se evaluó la actividad EMG de los músculos IS, MD y PD de 20 participantes sanos. Los sujetos realizaron 6 ejercicios de RE que combinaron dos factores: i) diferentes presiones de aducción de acuerdo con la unidad de biorretroalimentación (0, 5 y 10 mmHg), y ii) posición del hombro baja y alta. La presión se controló mediante una unidad de biorretroalimentación. Las posiciones del hombro baja y alta fueron de 20° y 90° de abducción. En la posición del hombro bajo, la actividad del músculo IS aumentó a medida que aumentaba la presión sobre la unidad de biorretroalimentación y los músculos MD y PD presentaron la actividad más alta a 10 mmHg. En la posición del hombro alto, la actividad del músculo IS fue mayor a 0 y 10 mmHg, el músculo MD presentó mayor actividad a 5 mmHg y la actividad del músculo PD no varió con la presión. La adición de aducción a una presión de 5 mmHg en la posición baja del hombro promueve la actividad del músculo IS. Asimismo, la aducción a una presión de 10 mmHg promoverá la actividad del IS, MD y PD.

PALABRAS CLAVE: Electromiografía; Hombro; Ejercicios; Rotación externa; Manguito rotador; Fisioterapia / rehabilitación.

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Correspondencing author:
Mauricio Barramuño
Universidad Autónoma de Chile
Avenida Alemania 1090
Temuco
CHILE

Email: mauricio.barramuno@uautonoma.cl

Received: 10-06-2021
Accepted: 11-07-2021