Grade-IV inferior glenohumeral mobilization does not immediately alter shoulder and scapular muscle activity: a repeated-measures study in asymptomatic individuals

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ABSTRACT

Objectives: To assess: (1) the presence of any carry-over effect between interventions; (2) the immediate effects of inferior shoulder mobilization on shoulder and scapular muscle activity; and (3) to compare muscle activity response between the control and mobilization conditions. Repeated measures, cross-over, pre-post intervention study with sample of convenience.

Methods: Twenty-two asymptomatic individuals performed 10 repetitions of shoulder abduction before and after the control and mobilization, with a dosage of three sets of 30-s duration, with grade-IV. The order of intervention was randomized. Surface electromyography was used for recording activity of upper and lower trapezius; anterior, middle and posterior deltoids; supraspinatus; infraspinatus; and serratus anterior. Repeated measures mixed-model analysis of variance was used to assess immediate changes in muscle activity levels following inferior shoulder mobilization. Statistical parametric mapping (SPM) was used for comparing muscle activity waveforms between control and mobilization conditions throughout the range of motion.

Results: No systematic changes in muscle activity levels were found between: (1) baseline and follow-up for each condition, at the concentric and eccentric phases of shoulder abduction; (2) control and mobilization conditions during the concentric and eccentric phases of shoulder abduction. SPM results suggested no differences in muscle activity pattern between conditions.

Conclusions: Inferior shoulder mobilization did not produce immediate effects on shoulder and scapular muscle activity. It is possible that the dose used was insufficient to generate an immediate neuromuscular response to the mobilization.

KEYWORDS

Biomechanics; manual therapy; electromyography; manual therapies

Introduction

Patients with shoulder disorders present with altered scapular and shoulder muscle recruitment pattern [1–4]. Examples of altered muscle recruitment include lower activity of middle deltoid muscle in patients with rotator cuff tear compared to healthy controls [5]; and lower activity of lower trapezius muscle and higher activity for upper trapezius muscle activity in patients with shoulder impingement syndrome compared to healthy controls [6]. Therefore, management of shoulder disorders include restoring shoulder and scapular movement pattern [1,2,7–9].

Manual therapy is part of shoulder rehabilitation programme, and joint mobilizations may impact on the mobility of glenohumeral joint and muscle recruitment pattern [10–12]. The inferior gleno-humeral joint mobilization is commonly used for patients with limited shoulder abduction [13], and was found to improve passive mobility of the shoulder [10]. It is proposed that inferior joint

mobilizations: increase the flexibility of non-contractile tissue (i.e. capsule and ligaments); and stimulate mechanoreceptors, reducing the inhibitory stimuli from mechanoreceptors to agonist muscles (in this case the abductor muscles) [11]. Such neuromuscular effect might facilitate recruitment of shoulder abductors muscles and the synergists scapular muscles. Therefore, considering the synergistic activity of scapular and abductor muscles, it is reasonable to expect changes in activity levels of these muscles following inferior glenohumeral mobilizations.

Limited research has explored the effects of mobilization on shoulder and scapular muscle activity levels. One previous study reported increased strength in lower trapezius muscle following spinal mobilization in asymptomatic individuals [14]. Another study reported reduced shoulder muscle activity during shoulder elevation with sustained postero-lateral glide [15]. The effect of inferior glenohumeral mobilization on scapular and shoulder muscle activity remains unclear.

The presence of shoulder disorder and pain may impact on scapular and shoulder muscle activity levels [3]. Prior to assessing the effect of shoulder mobilization in symptomatic individuals, and to exclude shoulder disorders and pain as confounders, we deemed critical to describe what a normal muscular response to shoulder joint mobilization is in a group of asymptomatic individuals. This study aimed to: (1) the presence of any carry-over effect between interventions; (2) assess the immediate effects of shoulder passive accessory mobilization on shoulder and scapular muscle activity; (3) compare shoulder and scapular muscle activity response between mobilization and control conditions. Due to lack of information about the effects of shoulder accessory mobilization on muscle activity levels, we opted for non-directional experimental hypothesis that shoulder and scapular muscle activity would change following inferior shoulder mobilization [16,17].

Methods

Design

This is a repeated measures, cross-over, pre-post intervention study with sample of convenience. Participants were blinded to group allocation. Researchers delivering the intervention and processing the data were not blinded. The intervention consisted of two conditions: shoulder passive accessory mobilization and control. A 5-min interval was set between the two conditions. Participants were requested to perform 10 repetitions of shoulder abduction before (pre) and after (post) each intervention. Surface electromyography (sEMG) was used for recording muscle activity of upper and lower trapezius; anterior, middle and posterior deltoids; supraspinatus; infraspinatus; and serratus anterior. Previous research has shown that sEMG overestimates supraspinatus muscle activity, but in a repeatable manner [18]. Because the present study assessed within-muscle changes, the use of sEMG was considered appropriate for monitoring the supraspinatus muscle.

Sample size estimation

Based on previous research, the posterior deltoid presented the smallest effect size among the monitored muscles, when comparing active shoulder abduction with shoulder abduction performed with a sustained mobilization, in asymptomatic individuals [15]. Thus, assuming a mean difference of 2.1% of the maximal voluntary isometric contraction and a standard deviation of the difference equal to 3.2% of maximal voluntary isometric contraction, we calculated the sample size for a two-tailed paired *t*-test, with alpha set at 0.05, and power at 80%. The estimated sample size was 22 participants.

Participants

Twenty-two asymptomatic (18–40 years old) individuals were recruited from the local community. Prior to taking part in the study, participants signed an informed consent form. Participants were excluded if they presented any pain or discomfort during screening tests for the shoulder and cervical spine. The screening examination included full cervical active range of motion with overpressure, active shoulder elevation with overpressure, and maximum voluntary isometric shoulder internal and external rotation strength testing [19].

Equipment

A 16 channel wireless Noraxon TeleMyo 2400T G2 (Noraxon USA Inc., Arizona, USA) with 3000 Hz sampling frequency, and gain of 500 was used for recording muscle activity. Raw sEMG signals were sent wirelessly from the transmitter to a Noraxon TeleMyo EMG receiver. Disposable, self-adhesive surface Ag/AgCl electrodes (Product SP-00-S/50, Ambu, DK-2750 Ballerup, Denmark) were used for recording shoulder and scapular muscle activity. Electrodes were placed on: upper and lower trapezius; supraspinatus; infraspinatus; anterior, middle and posterior deltoid; and serratus anterior muscles (Figure 1). The Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines were followed for electrode placement for upper and lower

Figure 1. Electrodes placement.

trapezius, anterior, middle and posterior deltoid muscles, and serratus anterior muscles [20]. We followed recommendations and descriptions by Criswell [21] and Waite et al. [22] for electrode placement for supraspinatus and infraspinatus muscles. Surface electrodes were placed parallel with muscle fibres, with a 2 cm inter-electrode distance [20,21]. The spinous process of the seventh cervical vertebrae was used for the reference electrode [20].

Upper limb movements were monitored using a 3D motion analysis system (Motion Analysis Corporation, Santa Rosa, CA), with a frequency sample of 120 Hz. Reflective markers were placed over the acromion, lateral and medial epicondyle. During data processing, upper limb movements were monitored to identify concentric and eccentric phases of movement. The Motion Analysis and Electromyography (EMG) data were synchronized using a trigger system.

Procedures

Before electrode placement, the area on the skin was shaved, abraded with coarse towel and cleansed with alcohol wipes [20]. To reduce EMG baseline noise, this procedure was repeated until skin impedance was verified as $<5 \text{ k}\Omega$ using a standard voltmeter. After electrode placement and prior to data collection, participants performed a maximal isometric voluntary contraction (MIVC) for individually testing each monitored muscle [21,23]. Each contraction was sustained for 5 s. A rest period of 5 min between MIVC and the experimental procedures was adopted.

Participants were asked to perform 10 repetitions of shoulder elevation in the coronal plane, prior to and after the first intervention. Participants were asked to elevate their arm until the end of the available active range of motion, and without any compensatory movements. Currently, there is no information available regarding the effect of inferior mobilization on shoulder muscle activity levels. Therefore, we selected an interval of 5 min to be used as a 'wash-out' period. After that, participants repeated 10 repetitions of shoulder abduction prior to and after the second intervention. Using 10 trials leads to smaller absolute error estimates during shoulder elevation task [24]. The order of intervention conditions (i.e. control followed by mobilization; or mobilization followed by control) was randomized using a computer-generated number list [25]. To standardize movement velocity, a metronome was used and set at 30 beats/min.

During both interventions, participants were positioned in supine, with their shoulder maintained at 90° of shoulder abduction, and neutral rotation (Figure 2). The *mobilization condition* consisted of grade-IV inferior glenohumeral mobilization performed by a physiotherapist with 14 years of experience in musculoskeletal rehabilitation. Three sets of thirty seconds of mobilization were performed, at a rate of 2 Hz, with a 30 s interval between

Figure 2. Illustration of patient positioning and shoulder passive accessory movement technique used for the mobilization and the control conditions.

each set of mobilization [26]. This dosage (grade-IV, 2 Hz, three sets of thirty seconds, with 30-s interval between sets) is commonly used in the clinical setting, and is presumed to load the inferior glenohumeral capsule and ligaments [19,26]. In the clinical setting, this technique is used when the inferior gleno-humeral glide reproduces patient's symptoms [13], and the technique generates an inferior glide of the humerus with regards to the glenoid cavity [27]. For the *control condition*, participants were positioned and the clinician's hands placement was the same way as in the mobilization intervention, however, no inferior glenohumeral mobilization was performed. Three sets of thirty seconds were performed, with 30 s interval between each set.

Data processing

The MyoResearch XP, Master Edition software was used for processing sEMG data. Initially, sEMG electrocardiogram artefact spikes were removed, then the signal was smoothed using root mean square with a 50 ms average window. The MVIC peak of muscle activity (during a 50 ms window of the 5 s contraction) was used to normalize sEMG data during shoulder abduction trials.

EMG data are complex, and formed by waveform time-series describing muscle activity during specific tasks [28]. Scalar analysis is commonly used for analyzing EMG data, but it is more susceptible to Type II error, as a point in time or the overall mean is used for the statistical analysis, ignoring significant between-group differences that may be present at specific time points [29]. Statistical parametric mapping (SPM) [30] is an alternative approach to analyze multi-muscle EMG signals [29]. The advantage of SPM vector-field analysis is that it considers the inter-muscle and time dependence

of EMG waveforms, while maintaining a constant alpha level [29]. The use of SPM vector-field analysis can provide insightful information about changes in shoulder and scapular muscle activity patterns following shoulder joint mobilizations.

A customized code written in MATLAB 7.12 (Mathworks Inc., USA) was used to process the sEMG and kinematic data and to conduct SPM analysis. Kinematic data were resampled based on EMG data. The midpoint from lateral and medial epicondyle reflective markers was calculated and used to identify the concentric and eccentric phases of shoulder movement. The maximum and minimum values on the vertical axis of the midpoint were used to determine the start and end of concentric and eccentric phases, respectively. The normalized mean muscle activity was calculated for each phase of abduction, of each trial, for each participant. Then, the grand mean over the 10 trials was calculated for each individual.

Primary outcome measures

Mean muscle activity over the 10 trials and its standard deviation was calculated for all monitored scapular and shoulder muscles. Muscle activity was expressed as % of the muscle-specific MIVC magnitudes.

Mean time-series EMG waveforms were calculated over the 10 trials, for each monitored muscle, for each individual during each condition (i.e. control and mobilization).

Statistical analysis

All statistical analyses were performed using R software [31].

Within-session reliability of muscle activity measurements

We used EMG data from the control condition (as no change in muscle activity was expected to occur in this condition) to assess the within-session reliability of muscle activity measurements between baseline and follow-up. The within-session reliability was assessed by means of the intraclass correlation coefficient (two-way mixed model, consistency definition, ICC(3,10)). The mean values of the 10 repetitions of baseline and follow-up measurements for each muscle, during the control condition, were used as input data for this model, assuming the clinical researcher as the single rater. The standard error of measurement (SEM) was also calculated, and reflects the difference between the two measurements (baseline and follow-up) [32].

Changes in muscle activity levels

Two repeated measures mixed-model analysis of variance (ANOVA) were used for assessing: (1) presence of

carry-over effects and the immediate effects of inferior shoulder mobilization on muscle activity (i.e. within-condition comparison); (2) differences between conditions (i.e. control and mobilization). For both analyses, muscle activity for each monitored muscle (upper and lower trapezius; anterior, middle and posterior deltoids; supraspinatus; infraspinatus; and serratus anterior) was considered as the dependent variable. Significant ANOVA results were followed-up with Tukey *post hoc* test, with alpha adjusted for multiple comparisons [33]. These analyses allowed to assess whether inferior shoulder mobilization lead to systematic changes in shoulder and scapular muscle activity levels.

To assess changes in muscle activity waveforms, SPM vector-field analysis was used for comparing shoulder and scapular muscle activity between control and mobilization conditions throughout the range of motion. Below, we present a detailed description of the two repeated measures mixed-model ANOVA used, and the SPM approach.

Carry-over effects and immediate effect of shoulder passive accessory mobilization

To assess the presence of carry-over effect, the interaction between 'Condition x Period x Time Point' was included in the model [34]. If the interaction was significant, then planned contrasts were conducted for comparing muscle activity at baseline between period 1 and 2, for each condition [34]. Period 1 refers to the time the first intervention was delivered (either control or mobilization), while Period 2 refers to the time the second intervention was delivered (either control or mobilization).

To assess the immediate effect of shoulder passive accessory mobilization on individual muscle activity during concentric and eccentric phase of shoulder abduction, a repeated measures mixed-model ANOVA was used, with condition, Period of intervention (1 and 2), and time point (baseline and follow-up) as fixed factors, and participants and the order of intervention (i.e. control followed by mobilization; or mobilization followed by control) as random factors.

Within-condition comparisons between baseline and follow-up were performed by including in the model the interaction 'Condition x Time Point'. If the interaction was significant, planned contrasts were conducted for comparing muscle activity between baseline and follow-up, for each condition.

Differences between control and mobilization conditions

To assess differences in individual muscle activity between the two conditions, during concentric and eccentric phase of shoulder abduction, a repeated measures mixed-model ANOVA was used. Condition, period of intervention (1 and 2) and follow-up were considered as

fixed factors; and participants and the order of intervention (i.e. control followed by mobilization; or mobilization followed by control) as random factors. Baseline measurements was used as a covariate. To compare shoulder and scapular muscle activity response between conditions, planned contrasts were conducted for comparing muscle activity levels at follow-up.

Statistical parametric mapping

The SPM was implemented using Matlab®. We used a paired *t*-test waveform-level Hotelling's T2 multivariate test to examine the complete EMG time-series, and a detailed description and discussion of this method can be found elsewhere [29].

The processed EMG signal was normalized into 1000 points for the concentric and eccentric phases of shoulder abduction. Then, differences between baseline and follow-up measurements were calculated at each point in time for both conditions, for each participant, for each of the ten trials. The average of difference between baseline and follow-up was calculated for the ten trials, for each condition (control and mobilization), for each muscle, and each participant. The EMG time-series data, used as input data for the SPM, represented the difference between baseline and follow-up, for each condition, for each muscle. The EMG time-series data consisted of an 8-component vector-field ($I = 8$), as 8 muscles were analyzed; 22 participants ($J = 22$); and a total of 2000 points ($Q = 2000$), with the first 1000 points referring to the concentric phase, and the last 1000 points referring to the eccentric phase [29].

The SPM approach calculates the scalar output statistic for each instant of time, and that is referred to as SPM {T2}. The SPM {T2} is a vector-field analysis, and represents the difference between the two conditions over the whole range of movement. For that analysis, alpha was set at 0.05. If the SPM {T2} exceeded the critical threshold, then *post hoc* scalar field SPM analysis were conducted for individual muscles, for comparing EMG time-series between the experimental and control conditions [29].

Results

Twenty-two participants (11 male/11 female) took part in the study. Participants' anthropometric characteristics were as follow: 21 participants were right hand dominant; mean age: 23.5 ± 4.8 years; mean height: 1.7 ± 0.08 metres; mean weight: 69.2 ± 12.6 kg; body mass index: 23.7 ± 3.3 kg/m².

Within-session reliability of muscle activity measurements

The reliability of EMG measurements between baseline and follow-up was excellent with ICC values ranging from

0.88 to 0.99; and with small SEM values, ranging from 0.8% MVIC to 5.6% MVIC (Table 1).

Carry-over effects

We found no significant interaction for 'Condition x Period x Time Point', suggesting there was no carry-over effects (Table 2).

Immediate effects of shoulder passive accessory mobilization on shoulder and scapular muscle activity

We found no significant within-condition differences in muscle activity levels between baseline and follow-up for each of the monitored muscles, at the concentric and eccentric phases of shoulder abduction (Table 3).

Table 1. Within-session reliability of muscle activity measurements between baseline and follow-up.

Muscles	Concentric ICC	SEM (%MVIC)	Eccentric ICC	SEM (%MVIC)
Upper trapezius	0.99	5.6	0.96	4.1
Lower trapezius	0.98	3.6	0.94	3.5
Supraspinatus	0.97	4.9	0.95	3.3
Infraspinatus	0.97	0.9	0.94	0.8
Anterior deltoid	0.96	3.7	0.91	3.1
Middle deltoid	0.97	2.6	0.92	1.5
Posterior deltoid	0.99	1.8	0.99	0.8
Serratus anterior	0.98	7.8	0.88	8.8

Notes: ICC = intraclass correlation coefficient; SEM = standard error of measurement; MVIC = maximal voluntary isometric contraction.

Table 2. 'Condition x Period x Time Point' interaction for assessing the presence of carry-over effect.

Muscle and phase of movement	Likelihood ratio	Degrees of freedom	p-value
<i>Concentric phase</i>			
Upper trapezius	1.78	5	0.77
Lower trapezius	6.72	5	0.15
Supraspinatus	5.16	5	0.27
Infraspinatus	2.86	5	0.58
Anterior deltoid	3.68	5	0.44
Middle deltoid	2.08	5	0.72
Posterior deltoid	5.14	5	0.27
Serratus anterior	4.33	5	0.36
<i>Eccentric phase</i>			
Upper trapezius	7.88	5	0.09
Lower trapezius	7.38	5	0.11
Supraspinatus	6.15	5	0.18
Infraspinatus	3.17	5	0.52
Anterior deltoid	7.28	5	0.12
Middle deltoid	7.07	5	0.13
Posterior deltoid	5.00	5	0.28
Serratus anterior	7.76	5	0.10

Table 3. Within-condition mean differences (95% CI) between baseline and follow-up for control and mobilization conditions, during concentric and eccentric phase.

Muscle	Control baseline	Follow-up	Mean difference (95% CI)	Mobilization baseline	Follow-up	Mean difference (95% CI)
<i>Concentric phase</i>						
Upper trapezius	90.0 (52.6)	95.4 (66.1)	−5.2 (−18.6 to 8.1)	91.4 (56.1)	91.4 (48.1)	−0.5 (−13.9 to 12.8)
Lower trapezius	48.8 (31.2)	53.2 (32.2)	−4.1 (−10.9 to 2.7)	50.1 (30.1)	47.2 (26.1)	2.3 (−4.5 to 9.2)
Supraspinatus	59.1 (29.1)	74.4 (58.4)	−14.4 (−29.1 to 0.3)	64.2 (33.2)	62.7 (35.4)	1.9 (−12.8 to 16.7)
Infraspinatus	15.7 (5.8)	17.5 (9.4)	−1.7 (−4.1 to 0.6)	15.9 (5.9)	16.5 (5.9)	−0.62 (−3.0 to 1.7)
Anterior deltoid	54.2 (18.9)	69.0 (56.5)	−13.1 (−30.2 to 3.9)	55.3 (18.3)	55.0 (18.9)	0.2 (−16.8 to 17.3)
Middle deltoid	44.3 (15.2)	48.1 (20.2)	−3.7 (−9.3 to 1.9)	44.6 (14.4)	44.9 (14.9)	−0.6 (−6.2 to 5.0)
Posterior deltoid	23.9 (31.0)	28.8 (33.6)	−4.5 (−10.2 to 1.1)	24.8 (30.8)	24.3 (31.7)	0.4 (−5.2 to 6.1)
Serratus Anterior	51.8 (55.1)	65.8 (73.0)	−13.3 (−25.0 to −1.5)*	59.8 (61.5)	63.9 (64.6)	−4.5 (−16.2 to 7.2)
<i>Eccentric phase</i>						
Upper trapezius	41.3 (23.7)	48.6 (36.2)	−6.5 (−18.5 to 5.4)	44.2 (29.8)	42.5 (23.6)	2.1 (−9.8 to 18.4)
Lower trapezius	26.3 (14.9)	26.5 (15.6)	0.1 (−3.8 to 4.1)	27.1 (16.4)	26.8 (18.6)	0.3 (−3.7 to 4.3)
Supraspinatus	32.5 (19.3)	41.6 (43.8)	−8.1 (−22.2 to 6.0)	35.5 (22.9)	36.0 (23.1)	−0.3 (−9.5 to 19.9)
Infraspinatus	10.2 (3.8)	11.0 (7.8)	−0.7 (−2.9 to 1.5)	10.5 (4.2)	10.5 (3.6)	0.0 (−2.2 to 2.3)
Anterior deltoid	22.8 (12.6)	29.5 (25.7)	−5.9 (−16.4 to 4.6)	24.3 (11.7)	22.0 (9.5)	2.6 (−7.9 to 13.1)
Middle deltoid	19.0 (8.5)	21.7 (10.6)	−2.3 (−7.1 to 2.4)	21.1 (8.8)	19.7 (6.8)	1.6 (−3.2 to 6.4)
Posterior deltoid	12.8 (14.4)	15.4 (16.8)	−2.4 (−6.9 to 2.1)	13.5 (14.8)	13.2 (13.6)	0.2 (−4.3 to 4.7)
Serratus Anterior	23.6 (22.7)	30.9 (30.8)	−6.7 (−15.9 to 2.5)	27.6 (26.7)	26.1 (27.3)	1.6 (−5.0 to 14.2)

Notes: Negative values = higher muscle activity levels were observed at follow up. Baseline and follow-up mean activity and standard deviation (in brackets).

All values expressed as % maximal isometric voluntary contraction.

*Adjusted *p*-value not significant.

Differences in shoulder and scapular muscle activity between control and mobilization conditions

We found no significant differences in muscle activity levels between conditions during the concentric and eccentric phases of shoulder abduction (Table 4).

Statistical parametric mapping

The mean difference between baseline and follow-up for each point in time through the shoulder abduction cycle, for both conditions, and for each muscle are presented in Appendix 1.

No significant differences in muscle activity waveforms were found when comparing the two conditions, as SPM{T2} did not exceed the critical threshold, which was valued at 132.7. Since the SPM{T2} did not exceed the critical threshold, no *post hoc* scalar field SPM analyses were conducted.

Discussion

This is the first study to explore the effects of shoulder passive accessory inferior mobilization on shoulder and scapular muscle activity levels. No carry-over effects were observed, which suggests that the wash-out period was appropriate. Shoulder passive accessory mobilization had no immediate effect on shoulder and scapular muscle activity levels after three sets of inferior shoulder mobilization, and no differences were observed between conditions during shoulder abduction. The SPM analysis suggested no differences in muscle activity patterns through the cycle of shoulder abduction.

Theoretically, passive joint mobilizations generate neurophysiological and neuromechanical responses,

Table 4. Mean differences (95% confidence interval) in muscle activity change following the intervention between control and mobilization conditions for both phases (concentric and eccentric).

Muscle	Concentric phase	Eccentric phase
Upper trapezius	−4.7 (−17.3 to 26.7)	−9.3 (−25.4 to 6.8)
Lower trapezius	−6.2 (−16.1 to 3.6)	−0.2 (−4.6 to 4.3)
Supraspinatus	−17.7 (−52.1 to 16.6)	−11.3 (−37.6 to 15.0)
Infraspinatus	−1.5 (−5.9 to 2.8)	−1.2 (−4.6 to 2.2)
Anterior deltoid	−17.6 (−52.8 to 17.5)	−9.5 (−24.9 to 5.9)
Middle deltoid	−3.1 (−12.1 to 6.0)	−3.4 (−9.2 to 2.4)
Posterior deltoid	−6.4 (−18.5 to 5.6)	−3.4 (−10.9 to 3.6)
Serratus anterior	−9.5 (−27.3 to 8.3)	−8.3 (−18.9 to 2.3)

Note: Negative values = higher muscle activity levels were observed during the control when compared to mobilization condition.

impacting on muscle activity levels [11]. With regards to neurophysiological effects, the literature suggests that passive mobilizations may stimulate muscle spindle receptors [35,36], and golgi tendon organs, especially if performed at the end of range [37]. Such stimuli could explain the reported reductions in muscle activity levels following joint mobilization [16,38–40]. Our findings suggest no change in muscle activity levels following shoulder passive accessory inferior mobilization. It is possible that the dose we used (grade-IV) did not sufficiently stimulate mechanoreceptors such as muscle spindle and golgi tendon organs. That could explain the lack of differences between: (a) baseline and follow-up for the mobilization condition; (b) the control and mobilization conditions.

With regards to neuromechanical responses, shoulder passive accessory mobilization techniques are thought to increase non-contractile tissues mobility (e.g. capsule and ligaments), by exposing it to repetitive loading [41]. In our study, the humerus was inferiorly mobilized for three sets of thirty seconds, grade-IV [26]. Theoretically,

such cyclic loading could increase: (1) the threshold of mechanoreceptors located at the inferior glenohumeral ligament (neurophysiological response); (2) the flexibility of the inferior glenohumeral capsule and ligament (mechanical response) [41]. These neurophysiological and mechanical responses should lead to changes in muscle activity levels, and that was not observed.

Differences in findings between the present and previous studies [16,42,43] could be due to differences in the dosage used (duration, grade, frequency and interval used). Our study adopted a 30 s duration, grade-IV, 2 Hz and 30-s interval. Previous studies adopted longer durations (i.e. 1 or 2 min), with grade-IV and different frequency or interval between sets [16,43]. These studies reported changes in muscle activity levels or muscle strength, suggesting that the duration of mobilization may be a key aspect to elicit changes in muscle activity or muscle strength following mobilization.

Conflicting results exist in the literature regarding neuromuscular response to joint mobilizations [16,42,43]. For example, in asymptomatic individuals, inferior hip joint mobilization (3 sets, 1 min, grade-IV, 30-s interval) led to 17% increase in hip abductor muscle torque [42]. However, two other studies reported reductions in muscle activity levels following mobilizations. One study reported central posteroanterior mobilizations (2 min duration, frequency 1.2 Hz) to reduce by 15% the erector spinae muscle activity in a group of asymptomatic individuals [16]; and another one reported oscillatory distraction mobilization (3 sets, 1 min duration each, grade-IV, 10 s interval) at the temporomandibular joint (TMJ) to reduce masseter muscle activity in patients with TMJ disorders [43]. It is possible that the type of mobilization and area being mobilized (i.e. spinal or peripheral) may influence the neuromuscular effect. Spinal and peripheral joint distraction mobilizations may inhibit muscle contraction; while peripheral mobilization may facilitate muscle contractions. However, this still needs to be further explored.

Passive mobilizations impose a cyclic loading into the capsular and ligament tissues [10]. Repetitive and static flexion loading induced creep in posterior spinal passive tissue, and triggered increased lumbar extensor muscle activity as a compensatory mechanism [44,45]. Similar responses occurred with cyclic loading (10 min) on the anterior cruciate ligament, and quadriceps and hamstrings muscle responses [46]. Our findings do not agree with those reported in the literature. It is possible that the dosage we adopted was not sufficient to elicit neuromuscular changes. However, the magnitude, frequency and duration adopted in the present study were based on the clinical literature [26], and are representative of the dosage used by clinicians.

This study has limitations. We used sEMG for monitoring supraspinatus muscle. One criticism for the use of sEMG is the possible cross-talk between nearby

muscles [47,48], this is potentially problematic for the supraspinatus muscle. The cross-talk between upper trapezius and supraspinatus muscle and trapezius (upper and middle fibres) and infraspinatus was found to be minimal [22]. In fact, sEMG recordings of supraspinatus were found to overestimate fine-wire recording of supraspinatus muscle. Such overestimation seems not to be related to cross-talk [18,22], but caused by different muscle fibre orientation between fibres recorded by sEMG and fine-wire EMG and muscle size and location [18,22]. Overestimation of supraspinatus muscle activity as recorded by sEMG tends to be reduced when this muscle is the primary mover for the movement being analyzed (e.g. shoulder abduction) [18]. Finally, electrodes placement were not changed with regards to the underlying muscle, therefore, if any difference was observed between the control and mobilization conditions that would represent the effect of inferior shoulder mobilization on muscle activity.

We assessed the effect of inferior shoulder mobilization in a group of asymptomatic individuals. We recruited asymptomatic individuals to understand what a normal response to inferior shoulder mobilization is, and to exclude confounding factors such as pain or shoulder structural injuries. It is likely that symptomatic individuals might respond differently to this intervention. We did not monitor shoulder adductor muscles, which are antagonists during active shoulder abduction, so it is unknown whether or not inferior shoulder mobilization had any effect on these muscles. Future studies could explore the effect of shoulder mobilization on antagonist muscles.

Based on our findings, inferior shoulder passive accessory mobilization has no immediate effect on shoulder and scapular muscle activity levels during shoulder abduction in a group of young, asymptomatic individuals. There were no differences in muscle activity levels between the control and mobilization conditions. These findings suggest that inferior glenohumeral joint accessory mobilizations (performed through shoulder mobilization, grade-IV) had no significant effects on shoulder and scapular muscles. Patients with shoulder disorders may respond differently to this intervention. Future research should explore the effect of different treatment dose on muscle activity levels in asymptomatic and symptomatic population.

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No potential conflict of interest was reported by the authors.

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Appendix 1.

Mean difference in muscle activity between baseline and follow-up for control (solid blue line) and mobilization (Mob) (solid black line) conditions, and standard deviation for control (blue shadowed) and mobilization (grey shadowed).

a) Upper trapezius

b) Lower Trapezius

c) Supraspinatus

d) Infraspinatus

e) Anterior deltoid

f) Middle deltoid

g) Posterior deltoid

h) Serratus anterior