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Differences between clinician- and self-administered shoulder sustained mobilization on scapular and shoulder muscle activity during shoulder abduction: a repeated-measures study on asymptomatic individuals

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1 INTRODUCTION

Patients with shoulder pain often present with suboptimal muscle recruitment and joint movement pattern [36,37]. Supraspinatus, infraspinatus [29], lower trapezius and serratus anterior muscles [37] are likely to be inhibited; while upper trapezius muscles are activated to a greater extent in patients with shoulder pain compared to controls [21]. Persistent abnormal muscle recruitment patterns may contribute towards pain [16].

Patients with shoulder pain often demonstrate increased anterior translation of the humeral head in the glenoid [22]. Repeated overarm activities may lead to anterior hypermobility or tightness of the posterior shoulder structures [20]. It is suggested that altered shoulder muscle recruitment is partly responsible for anterior translation of the humerus [10,22] and the associated pain [38].

Mobilization with movement (MWM) is one manual technique used by physiotherapists to treat shoulder pain, and consists of applying a sustained glide to the joint, while the patient performs an active movement that is limited by pain [42]. MWM on the shoulder has immediate [40,41] and short lasting effects [40], improving pain and increasing range of motion in these patients. This technique can either be performed by a clinician or by the patient using an inflexible belt to apply pressure to their own shoulder joint [14]. Self-administered mobilization is commonly prescribed as home-based exercise for patients, and can improve self-efficacy (a common barrier for adherence to exercise) [17].

The different direction of glide between self- and clinician-administered techniques [14] suggests that each technique may induce a different neuromuscular responses. Our previous research showed that clinician-administered sustained postero-lateral glide at the glenohumeral joint reduced muscle activity levels for supraspinatus, infraspinatus, middle and posterior deltoid muscle [31]. This reduction in the muscle activity may be due to changed joint mechanics and/or afferent sensory input when applying the glide. It is unclear whether clinician- and self-administered glides have similar impact on scapular and shoulder muscle activation patterns.

The primary aim of this study was to compare the immediate effect of clinician-administered sustained postero-lateral glide with self-administered sustained glide on scapular and shoulder muscle activity. The secondary aim was to assess whether these two shoulder mobilization techniques lead to changes that last beyond its period of application. To exclude the potentially confounding effects of pain and shoulder disorder on muscle activity [36,38], we examined asymptomatic individuals to identify the effect of each glide technique on muscle recruitment patterns in a healthy neuromotor system.

2 METHODS

2.1 Study design

This is a laboratory-based, cross-over, repeated measures design.

Prior to assessing the effects of sustained glides in patients with shoulder disorders, it is crucial to have a clear understanding of the neuro-mechanical-physiological responses to these techniques. The interaction between pain and neuromuscular control is complex, with neuromuscular adaptations occurring at different stages after 'injury' [16]. Pain may mediate the effect of the sustained glide on muscle activity levels. To exclude the potentially confounding effects of pain and shoulder disorder on muscle activity [32,34,36,38], we examined individuals without shoulder pain to identify the effect of each glide technique on muscle recruitment patterns in a healthy neuromotor system.

2.2 Sample size

Based on pilot data collected within our laboratory, changes in supraspinatus muscle activity represented the smallest effect size among the shoulder muscles, when comparing shoulder abduction with and without manual joint mobilization. Based on our previous study, and assuming a mean difference of 2.47% of the maximal voluntary isometric contraction (MVIC) and a standard deviation of the difference equal to 3.9% MVIC, 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.

2.3 Participants

Twenty-two participants, aged from 18 to 65 years were included. Participants were screened for shoulder and cervical spine disorders. Screening included full cervical active range of motion with overpressure, active shoulder abduction with overpressure, and

maximum voluntary isometric internal and external rotation strength testing [27]. Participants were excluded if they presented with current shoulder injury or any current shoulder symptoms. This study was approved by the University Human Ethics Committee (H15/020). Participants gave written informed consent prior to taking part in the experiment.

2.4 Equipment

Muscle activity was recorded using a 16 channel wireless electromyographic (EMG) system (TeleMyo 2400TG2, Noraxon USA Inc., Arizona, USA) (sampling frequency: 3000 Hz; gain: 500). Movement of the arm was recorded using a 3D motion analysis system (Motion Analysis Corporation™, Santa Rosa, CA) (sampling frequency: 120 Hz). The 3D motion analysis and EMG data were time synchronised using an analogue channel (frequency sample: 2400 Hz).

Surface EMG electrodes (Product SP-00-S/50, Ambu, DK-2750 Ballerup, Denmark) were placed on the following muscles: upper and lower trapezius, supraspinatus, infraspinatus, middle and posterior deltoid, and serratus anterior (Table 1). Surface electrodes were placed 2 cm apart in parallel with muscle fibre alignment, in accordance with the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines [13]. The ground electrode was placed over the spinous process of the seventh cervical vertebrae [13]. Prior to electrode placement, the skin was shaved and

cleaned with an alcohol swab, then skin impedance was measured with a multimeter, to ensure that the impedance at the site was less than 5 KΩ [12].

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Table 1. Surface electrode placement, and maximal isometric voluntary contraction (MVIC) test description.

Muscle	Electrode placement	MVIC test
Upper Trapezius	Electrodes placed at 50% on the line between the acromion and the vertebra C7 (Hermens et al. , 2015).	Shoulder elevated. Neck extended and rotated to the opposite direction of the side being tested. The participants performs an isometric contraction, while pressure pressure against the shoulder and the head in the direction of flexion anterolaterally.
Lower Trapezius	Electrodes placed at 2/3 on the line from the trigonum spinea to the 8th thoracic vertebra, in the direction of a line between T8 and the acromion (Hermens, Merletti, 2015).	Participant in prone. The arm is placed diagonally overhead with the shoulder laterally rotated. Pressure is applied against the forearm in downward direction.
Serratus Anterior	Below the axillary area, at the level of the inferior angle of the scapula, between the latissimus dorsi and pectoralis major (Criswell, 2010).	Subject sitting upright, with no back support. Shoulder abducted to 125^0 in the scapular plane. Resistance applied above the elbow and at the inferior angle of the scapula (leading to downward rotation of the scapula)(Ekstrom et al. , 2005).
Supraspinatus	Electrodes placed over the suprascapular fossa (Criswell, 2010).	Shoulder abducted at neutral, and elbow flexed at 90 degrees. The cervical spine is positioned into ipsilateral side flexion, contralateral rotation, and extension. The participant performs an isometric contraction of shoulder abduction (Kendall et al. , 2005).
Infraspinatus	Electrodes placed over the infrascapular fossa of the scapula, laterally, but not over the posterior deltoid muscle, 4 cm below the spine of the scapula (Criswell, 2010).	Shoulder externally rotated, and abducted at 90 degrees, and elbow flexed at 90 degrees. The participant performs an isometric contraction of shoulder external rotators (Kendall, McCreary, 2005).
Middle Deltoid	Electrodes placed over the muscle bulk, aligned with muscle fibres, 3 cm below the acromion (Hermens, Merletti, 2015).	Shoulder abducted at 90 degrees, and elbow flexed at 90 degrees. The shoulder is kept at neutral rotation (i.e. forearm horizontally aligned). The participant performs an isometric contraction of shoulder abductors (Hermens, Merletti, 2015, Kendall, McCreary, 2005).
Posterior deltoid	Electrodes placed parallel to muscle fibre direction, with an oblique orientation, 2 cm below the lateral border of the scapula (Hermens, Merletti, 2015).	Participant is sitting, shoulder abducted at 90 degrees, and elbow flexed at 90 degrees. The shoulder is kept at 30 degrees of internal rotation (i.e. forearm pointing downwards). The participant performs an isometric contraction of shoulder extension

	(Hermens, Merletti, 2015, Kendall, McCreary, 2005).

Reflective markers (B&L Engineering, Santa Ana, CA, USA) with 12.7mm diameter, were used for tracking trunk and upper limb movements. Individual reflective markers were placed at the manubrium, and the spinous processes of C7 and T8 for monitoring trunk movement [45]. Custom reflective marker clusters with a neoprene wrap were placed in the mid-third of the arm and forearm for monitoring upper limb movement. Marker cluster at the arm allowed the identification of concentric and eccentric phases of shoulder abduction.

2.5 Experimental protocol

First, participants performed two MVIC repetitions, for each muscle, for familiarization with the testing. After, participants performed one MVIC for each muscle, against manual resistance offered by the researcher. To ensure each muscle was maximally activated during the MVIC testing, we followed the recommendations for participant positioning and manual resistance by Kendall et al. [19]. Each MVIC was sustained for 5 seconds [31,32,35]. We used the peak (during a 50 ms window of the 5 s contraction) to normalize EMG data.

As part of the familiarisation process, participants also performed 3 repetitions of shoulder abduction with the addition of the clinician-administered sustained glide. We

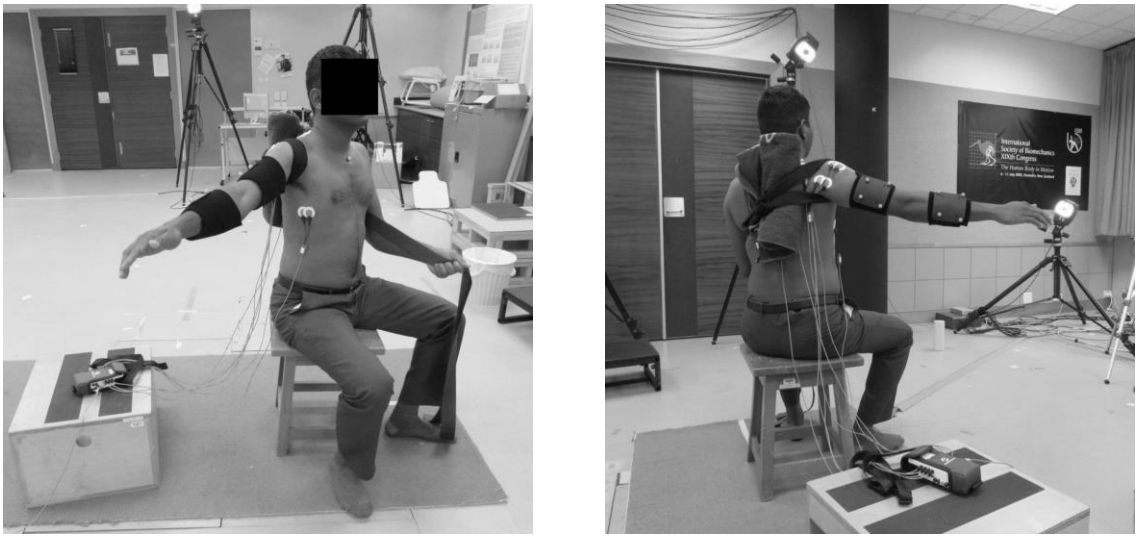
explained to participants that, during the testing, they would also be asked to reproduce a sustained glide with the belt.

Participants performed 10 repetitions of a shoulder abduction movement with their nominated dominant arm before (baseline), during (intervention) and after (follow-up) applications of each of the glenohumeral glide techniques (clinician-administered and self-administered). To minimize the risk of fatigue, the interval between each time point (i.e. baseline, intervention and follow-up) was 1 minute. We recorded shoulder muscle activity levels at baseline, intervention and follow-up time points. Participants performed shoulder abduction movements from neutral (i.e. anatomical position) to the maximal range available (approximately 180 degrees), and were requested to abduct their shoulder following a metronome set at 30 beats/min, resulting in movements 2 seconds duration for the concentric and eccentric phases of shoulder abduction. Participants were also requested to maintain a comfortable, and neutral sitting posture during all the experimental testing.

The experimental conditions consisted of shoulder abduction performed with: (a) self-administered shoulder mobilization (performed with the use of a belt); (Figure 1), and (b) with mobilization administered by a clinical researcher (Figure 2). Self-administered mobilization involved a belt being placed around the shoulder to be mobilised, passed over a rolled towel on the back, under the opposite arm and into the hand. Participants were asked to mobilise the shoulder by extending their opposite arm, creating tension on

the belt. Clinician-administered mobilization involved the clinician stabilising the scapula with one hand while applying a postero-lateral force to the shoulder. In each case, the applied mobilisation lasted only as long as it took for the participant to complete the requisite 10 abduction movements.

The order of intervention (i.e., self-administered mobilization followed by clinician-administered mobilization; or clinician-administered mobilization followed by self-administered mobilization) was randomized using a computer-generated number list [11]. Due to lack of information in the literature regarding the post-mobilization effect on shoulder muscle activity, an arbitrary interval of 5 minutes between the two experimental conditions was used to prevent any carry-over effect.



a) Anterolateral view b) Posterolateral view

Figure 1. Self-administered mobilization with a belt.

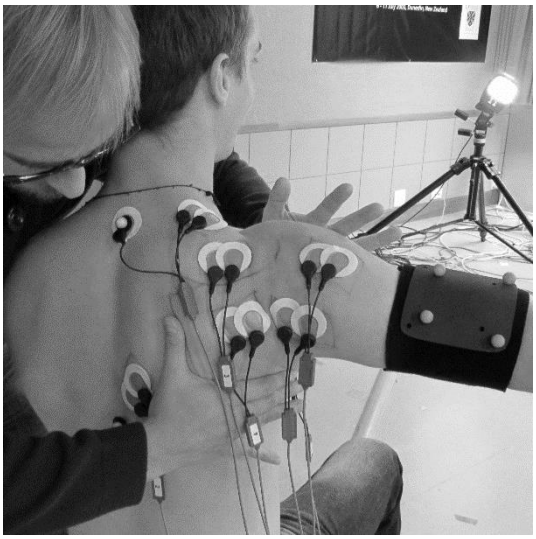


Figure 2. Clinician-administered mobilization.

2.6 Data processing and analysis

Electromyographic recordings were full-wave rectified, and root mean square (RMS) smoothed (50-millisecond average window). Each muscle EMG recording was normalized by its peak EMG RMS value recorded during the MVIC. Kinematic data from reflective markers placed on the arm were used for determining the concentric and eccentric phase of shoulder abduction for each of the ten trials. We used the maximum and minimum values on the vertical axis to identify the start and end of concentric and eccentric phases of shoulder abduction, respectively. The mean muscle activity over the concentric and eccentric phase of each movement was calculated for each muscle using MATLAB 7.12 (Mathworks Inc., USA). The grand mean of the ten trials was calculated for each muscle for each phase of shoulder abduction.

2.7 Primary outcome measures

Muscle activity during each movement was expressed as % of the peak activity level during the maximal voluntary isometric contraction for the same muscle.

2.8 Secondary outcome measures

Maximum arm range of movement during each trial was expressed as centimetres, and measured in the vertical axis.

2.9 Statistical analysis

All statistical analyses were performed using R software [28]. We used two mixed-effect models for repeated measures analysis of variance (ANOVA) for assessing: the presence of carry-over effect, comparing muscle activity within-conditions and between-conditions. This was done using the *lme()* function in R. The mean activity of each monitored muscle was used as the dependent variable. Period 1 refers to the time when the first intervention was delivered (either self-administered or clinician-administered mobilization); Period 2 refers to the time the second intervention was delivered (either self-administered or clinician-administered mobilization). The order of intervention refers to the sequence in which the interventions were delivered: "self-administered followed by clinician-administered mobilization" or "clinician-administered followed by self-administered mobilization" [32]. When running the mixed-effect models for repeated measures ANOVA, the Period was considered as a fixed-effect, while the order of interventions was considered as a random-effect [26]. When conducting between-condition

comparisons, muscle activity at baseline was used as a covariate in the model. For all comparisons, alpha was set at 0.05, and adjusted for multiple comparisons [7].

2.9.1 Range of movement

For assessing differences in maximum arm range of movement, a mixed-effect model was used, with the two experimental conditions (i.e., self-administered and clinician-administered), Period of intervention (1 and 2) and time point (i.e. baseline, intervention, and follow-up) considered as fixed factors; while participants and the order of intervention as random factors. The interaction 'condition x time point' was included in the model. In the case of significant interactions effects, planned paired-t-tests were conducted to compare maximum arm range of movement within and between-conditions.

2.9.2 Carry-over effects

For assessing carry-over effects in muscle activity levels between experimental conditions, a mixed-effect model was used, with the two conditions (self-administered and clinician-administered), and three time points considered as fixed factors; while participants and order of intervention were considered as random factors.

To assess for carry-over effects, the interaction "Condition x Period x Time point" was included in the model [26]. We used planned paired-t-tests contrasts for comparing muscle activity at baseline between Period 1 and 2, for each experimental condition [26].

2.9.3 Between-condition comparisons

For assessing between-condition differences in muscle activity levels, a different mixed-effect model was used, with the two experimental conditions, Period of intervention (1 and 2) and time point (i.e. intervention, and follow-up) considered as fixed factors; while participants and the order of intervention as random factors. For this model, baseline measurements were included as a covariate and each muscle was analysed separately.

The interaction 'condition x time point' was included in the model. In the case of significant interactions effects, planned paired-t-tests were conducted to compare muscle activity levels between conditions at each time point (i.e. intervention and follow-up).

2.9.4 Within-condition comparisons

For within-condition comparisons, a mixed-effect model was used, with Period of intervention (1 and 2), and time points considered as fixed factors; while participants and the order of intervention as random factors. This model was used for analysing each condition separately. Planned contrasts were used for comparing muscle activity levels between the three levels of time points. This model was used for analysing each condition and each muscle separately.

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3 RESULTS

The participant group was entirely right-handed and largely homogeneous with respect to age and body mass index. Participants' anthropometric data is presented in Table 2.

Table 2. Participants' age and anthropometric characteristics.

Variable	Mean (SD)
Dominant arm (right/left)	22/0
Gender (male/female)	16/8
Age (years)	29.4 (4.2)
Height(cm)	171.8 (10.1)
Weight(kg)	68.3 (13.0)
Body mass index (kg/m^2)	23.0 (2.8)

SD = Standard deviation; cm = centimetres, kg = kilogram; m = meters.

3.1 Range of movement

No significant interactions [$\chi^2(15)=10.25$, $p=0.17$] were found between time point and condition, suggesting no differences in maximum arm range of movement existed within and between-conditions. The mean peak range of movement for each condition at each time point is presented at Table 3.

Table 3. Mean peak of arm movement (expressed in centimetres) and standard deviation (in brackets).

Condition	Baseline	Intervention	Follow-up
Clinician-administered	127.6 (4.6)	126.2 (4.8)	128.3 (5.4)
Self-administered	126.8 (3.8)	126.3 (3.9)	127.6 (3.7)

3.2 Carry-over effects

We found no carry-over effect between experimental conditions for any of the monitored muscles: upper trapezius [$\chi^2(15)=5.9$, $p=0.65$]; lower trapezius [$\chi^2(15)=9.5$, $p=0.30$];

supraspinatus [$\chi^2(15)=13.7$, $p=0.09$]; infraspinatus [$\chi^2(15)=14.4$, $p=0.07$]; middle deltoid [$\chi^2(15)=12.0$, $p=0.15$]; posterior deltoid [$\chi^2(15)=8.7$, $p=0.36$]; serratus anterior [$\chi^2(15)=5.9$, $p=0.55$].

3.3 Between-conditions comparisons

The upper trapezius was the only muscle for which a main significant effect for condition on activity levels was found [$\chi^2(61)=9.9$, $p=0.007$], which indicates that, overall, during the clinician-administered condition, upper trapezius muscle activity was 9.9% MVIC lower than during the self-administered condition.

No significant interactions were found between time point and condition, suggesting no differences between self-administered and clinician-administered mobilizations at intervention and follow-up during both concentric and eccentric phases of shoulder abduction (Table 4).

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Table 4. Estimated marginal mean amplitudes (95% confidence intervals) of muscle activity during the self-administered mobilization and clinician-administered mobilization during intervention and follow-up for each muscle, and the between-condition mean differences (95% confidence intervals). All values have been adjusted based upon between-subject variability in baseline measures.

	Self-administered mobilization	**Clinician-administered mobilization**	**Self-administered vs Clinician-administered mobilization €**
Concentric			
Upper trapezius			
Intervention	50.1 (44.6 to 55.6)	44.6 (39.1 to 50.1)	-5.5 (-12.8 to 1.6)
Follow-up	55.5 (50.0 to 61.0)	52.4 (46.9 to 57.9)	-3.1 (-10.3 to 4.1)
Lower trapezius			
Intervention	31.3 (24.4 to 38.1)	28.1 (21.2 to 34.9)	-3.2 (-12.9 to 6.5)
Follow-up	39.9 (33.1 to 46.8)	40.6 (33.8 to 47.5)	0.7 (-9.05 to 10.4)
Supraspinatus			
Intervention	43.6 (38.7 48.5)	46.1 (41.2 to 51.0)	2.5 (-4.5 to 9.5)
Follow-up	54.0 (49.1 to 58.9)	54.0 (49.1 to 58.9)	0.0 (-7.0 to 7.0)
Infraspinatus			
Intervention	22.6 (19.6 to 25.7)	16.7 (13.6 to 19.7)	-5.9 (-10.3 to -1.7)
Follow-up	20.9 (17.9 to 23.9)	19.3 (16.2 to 22.3)	-1.7 (-5.6 to 2.6)
Middle Deltoid			
Intervention	40.2 (36.6 to 43.8)	35.9 (32.3 to 39.5)	-4.2 (-8.6 to 0.2)
Follow-up	43.1 (39.5 to 46.7)	40.4 (33.8 to 43.9)	-2.7 (-7.2 to 1.7)
Posterior Deltoid			
Intervention	12.9 (11.8 to 13.9)	11.0 (9.9 to 12.0)	-1.9 (-3.3 to -0.5)#
Follow-up	14.2 (13.1 to 15.2)	12.4 (11.3 to 13.5)	-1.7 (-3.2 to -0.3)#
Serratus anterior			
Intervention	52.0 (45.6 to 58.4)	52.5 (46.1 to 58.9)	0.5 (-7.9 to 8.9)
Follow-up	57.4 (51.0 to 63.8)	60.0 (53.6 to 66.4)	2.6 (-5.8 to 11.1)
Ecentric			
Upper trapezius			
Intervention	23.4 (20.3 to 26.6)	21.7 (18.5 to 24.8)	-1.7 (-5.9 to 2.5)
Follow-up	24.5 (21.4 to 27.7)	21.4 (18.25 to 24.5)	-3.1 (-7.4 to 1.1)
Lower trapezius			
Intervention	13.7 (9.9 to 14.5)	12.9 (9.2 to 16.7)	-0.7 (-5.9 to 4.4)
Follow-up	18.2 (14.4 to 21.9)	19.7 (15.9 to 23.4)	1.5 (-3.6 to 6.6)
Supraspinatus			
Intervention	21.8 (19.0 to 24.6)	24.8 (22.1 to 27.6)	3.0 (-0.6 to 6.7)
Follow-up	25.5 (22.7 to 28.3)	26.2 (23.4 to 28.9)	0.6 (-2.3 to 4.3)

Infraspinatus			
Intervention	12.6 (11.1 to 14.1)	9.6 (8.11 to 11.2)	-2.9 (-4.9 to -1.0)
Follow-up	11.4 (9.9 to 12.9)	11.2 (9.7 to 12.8)	-0.2 (-2.2 to 1.8)
Middle Deltoid			
Intervention	16.7 (14.8 to 18.5)	13.2 (11.4 to 15.0)	-3.5 (-5.8 to -1.1)#
Follow-up	20.0 (18.2 to 21.9)	19.0 (17.2 to 20.8)	-1.0 (-3.4 to 1.3)
Posterior Deltoid			
Intervention	5.7 (5.2 to 6.3)	4.8 (4.2 to 5.3)	-0.9 (-1.8 to -0.2)#
Follow-up	6.8 (6.2 to 7.4)	6.5 (5.9 to 7.1)	-0.3 (-1.1 to 0.5)
Serratus anterior			
Intervention	22.2 (17.3 to 27.2)	26.6 (21.6 to 31.5)	4.3 (-1.9 to 10.6)
Follow-up	22.2 (17.3 to 27.2)	28.5 (23.5 to 33.5)	6.2 (-0.1 to 12.5)

Interaction effect not significant. €: negative values indicate clinician-administered mobilization was lower during follow-up.

3.4 Within-condition comparisons

3.4.1 Self-administered mobilization

Self-administered mobilization induced significant reductions in supraspinatus muscle activity within the *concentric* phase of movements performed during the intervention when compared to baseline or follow-up measurements. The activity levels of the lower trapezius and middle deltoid muscles were significantly lower (compared to baseline levels) within the *eccentric* phase of shoulder abduction during the intervention, and such reductions were maintained at follow-up. The posterior deltoid muscle was less active during the intervention when compared to follow-up. The infraspinatus muscle was significantly more active during the intervention period compared to baseline, during the concentric and eccentric phases of shoulder abduction.

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Table 5. Within-condition comparisons for MVC-normalised EMG amplitudes (estimated marginal mean differences and 95% confidence intervals) between different time point (baseline, intervention and follow-up), during **self-administered mobilization**.

Muscle	Baseline - Intervention[#]	Follow-up - Intervention[≈]	Baseline - Follow-up[€]
Concentric phase			
Upper trapezius	3.4 (-5.9 to 12.7)	5.3 (-3.9 to 14.6)	-1.9 (-11.3 to 7.3)
Lower trapezius	9.3 (-1.1 to 19.8)	8.7 (-1.8 to 19.2)	0.7 (-9.8 to 11.1)
Supraspinatus	8.6 (1.5 to 15.7)*	10.4 (3.3 to 17.4)*	-1.7 (-8.8 to 5.3)
Infraspinatus	-3.4 (-6.1 to -0.8)*	-1.7 (-4.4 to 0.9)	-1.7 (-4.4 to 0.9)
Middle deltoid	1.0 (-3.4 to 5.5)	2.9 (-1.5 to 7.4)	-1.9 (-6.3 to 2.5)
Posterior deltoid	-0.1 (-1.4 to 1.3)	1.2 (-0.1 to 2.6)	-1.3 (-2.6 to 0.1)
Serratus anterior	7.7 (-0.5 to 16.0)	5.4 (-2.9 to 13.7)	2.3 (-5.9 to 10.6)
Eccentric phase			
Upper trapezius	1.6 (-3.7 to 6.9)	1.1 (-4.2 to 6.4)	0.5 (-4.8 to 5.8)
Lower trapezius	5.5 (1.6 to 9.5)*	4.5 (0.5 to 8.4)*	1.1 (-2.8 to 5.1)
Supraspinatus	3.6 (0.0 to 7.3)	3.7 (0.0 to 7.3)	0.0 (-3.7 to 3.6)
Infraspinatus	-1.4 (-2.6 to -0.2)*	-1.1 (-2.4 to 0.1)	-0.3 (-1.5 to 1.0)
Middle deltoid	2.4 (0.3 to 4.5)*	3.3 (1.2 to 5.5)*	-0.9 (-3.1 to 1.2)
Posterior deltoid	0.6 (-0.3 to 1.5)	1.1 (0.1 to 1.99)*	-0.4 (-1.3 to 0.5)
Serratus anterior	1.1 (-2.7 to 4.9)	0.0 (-3.8 to 3.8)	1.1 (-2.7 to 4.9)

* = statistically significant difference. [#]: negative values indicate muscle activity level was lower during intervention. [≈]: negative values indicate muscle activity level was lower during intervention. [€]: negative values indicate muscle activity level was lower during follow-up.

3.4.2 Clinician-administered mobilization

All monitored muscles, with the exception of the infraspinatus muscle, demonstrated significant reductions in muscle activity levels at intervention compared to baseline during the clinician-administered mobilization, within the *concentric* phase of shoulder abduction. These changes were maintained at follow-up for upper and lower trapezius, supraspinatus, middle and posterior deltoid (Table 6). During the *eccentric* phase of the movement, the lower trapezius, middle and posterior deltoid muscles demonstrated reductions in muscle activity levels during the intervention, compared to baseline and follow-up.

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Table 6. Within-condition comparisons of MVC-normalised EMG amplitudes (estimated marginal mean differences and 95% confidence intervals) between different time point (baseline, intervention and follow-up), during **clinician-administered mobilization**.

Muscle	Baseline - Intervention[#]	Follow-up - Intervention[≈]	Baseline - Follow-up[€]
Concentric phase			
Upper trapezius	6.3 (2.1 to 10.6)*	7.8 (3.6 to 12.1)*	-1.5 (-5.7 to 2.8)
Lower trapezius	15.5 (3.8 to 27.2) *	12.6 (0.8 to 24.3)*	2.9 (-8.8 to 14.6)
Supraspinatus	7.2 (0.4 to 13.9)*	7.8 (1.1 to 14.6)*	-0.7 (-7.4 to 6.0)
Infraspinatus	3.2 (-2.2 to 8.0)	2.6 (-2.8 to 8.0)	0.6 (-4.8 to 6.0)
Middle deltoid	5.0 (1.0 to 9.1)*	4.4 (0.4 to 8.5)*	0.6 (-3.4 to 4.6)
Posterior deltoid	1.8 (0.6 to 3.1)*	1.4 (0.1 to 2.7)*	0.4 (-1.0 to 1.7)
Serratus anterior	9.9 (2.3 to 17.5)*	7.5 (-0.1 to 15.2)	2.4 (-5.2 to 10)
Eccentric phase			
Upper trapezius	1.2 (-1.8 to 4.2)	-0.3 (-3.3 to 2.7)	1.5 (-1.5 to 4.5)
Lower trapezius	7.8 (1.1 to 14.5)*	6.7 (0.1 to 13.4)*	1.0 (-5.6 to 7.7)
Supraspinatus	1.3 (-2.6 to 5.2)	1.3 (-2.6 to 5.2)	-0.0 (-3.9 to 3.9)
Infraspinatus	1.9 (-0.8 to 4.6)	1.6 (-1.1 to 4.3)	0.3 (-2.5 to 3.0)
Middle deltoid	5.4 (2.4 to 8.3)*	5.8 (2.9 to 8.8)*	-0.4 (-3.4 to 2.5)
Posterior deltoid	1.6 (0.9 to 2.2)*	1.7 (1.1 to 2.4)*	-0.2 (-0.8 to 0.4)
Serratus anterior	0.8 (-1.8 to 3.4)	1.9 (-0.7 to 4.5)	-1.1 (-3.7 to 1.5)

* = statistically significant difference. [#]: positive values indicate muscle activity level was lower during intervention. [≈]: positive values indicate muscle activity level was lower during intervention. [€]: negative values indicate muscle activity level was lower during follow-up.

4 DISCUSSION

Both conditions led to changes in activity levels for some scapular and shoulder muscles at intervention (when compared to baseline or follow-up). The clinician-administered mobilization led to reductions in most monitored muscles at intervention during the concentric phase of shoulder abduction movements. We found no differences between conditions with respect to the changes in muscle activity each induced.

The upper trapezius muscle was less active before, during and after clinician-administered mobilization than self-administered mobilization. This difference in activation between conditions was an unexpected finding, and it is unclear why this

occurred. The fact that the difference is consistent at the three different time points suggests this is not related to the effect of the tested interventions. Such difference may reflect a different posture adopted by participants during each intervention, despite the best efforts to ensure participants adopted the same sitting posture during the testing.

The lower trapezius and serratus anterior muscles showed lower activity levels when a sustained glide was applied by the clinician, when compared to baseline; activation of the lower trapezius muscle returned close to baseline levels by the follow-up measurement. Both lower trapezius and serratus anterior muscles are considered to have a critical role in optimising scapula movement and position during upper limb tasks [23,24]. Cutaneous stimuli can inhibit motor neurons linked to the lower trapezius muscle [1], and the hand of the clinician or the belt might serve as the stimulus for this inhibition of motor neuron excitability. When applying the sustained mobilization, the clinician placed one hand at the scapula, to stabilize it against the thorax [14]. The external mechanical support provided by the clinician's hand might have contributed to scapular positioning, removing the demand for this function from the lower trapezius and serratus anterior muscles.

The supraspinatus muscle is a prime agonist for shoulder abduction [30], stabilizes the glenohumeral joint [4] and prevents superior translation of the humerus during shoulder abduction [39]. The present findings are consistent with those of our previous study [31] in that sustained glides leads to reduced activity of the supraspinatus during shoulder

abduction and elevation. Another study reported that sustained mobilization at the glenohumeral joint led to inferior translation of the humerus in cadavers [15]. If the sustained mobilization in this study led to inferior translation of the humerus then, given the role of the supraspinatus in generating this translation, it is reasonable to expect the supraspinatus muscle to present reduced activity during the intervention period. If a perturbation of humeral position was responsible for the reduction in supraspinatus activity, activation levels would be expected to return to baseline levels following the intervention, which is what we have observed.

During self-administered mobilization, the infraspinatus muscle demonstrated increased activity (compared to baseline), while no changes were observed during clinician-administered mobilization. Increased activity levels of infraspinatus muscle suggests a larger contribution for generating shoulder abduction torque, stabilizing the humerus, and preventing excessive superior translation of the humeral head [25]. These findings are intriguing and may be explained by differences in force direction between the two conditions. Previously [31], we reported significant, but small, reductions (2.1%MVIC, 95%CI=1.0,3.2%) in infraspinatus muscle activity while a sustained mobilization was applied during shoulder abduction and elevation in asymptomatic individuals. For the present study, we analysed the concentric and eccentric phases separately, while our previous study [31] compared the overall activity during ten trials of shoulder elevation. The subdivision of the shoulder abduction movement into eccentric and concentric

phases appears to enhance the sensitivity to detect asymmetric changes in activity between the two interventions [31].

Neuromuscular changes induced by mobilizations are related to neurophysiological and mechanical changes that occur during and immediately after the technique is applied at the joint [3]. The mechanisms underlying therapeutically-induced changes in muscle activation are complex, and not yet been understood [3], but they likely include changes in cutaneous and proprioceptive afferent discharge and changes in descending drive to motor neurons [3]. Cutaneous afferents have both inhibitory and excitatory effects on motor neurons located in the spinal cord [18]. Cutaneous receptors influence motor neuron threshold and the recruitment order of motor units [8,9]. This mechanism could partially explain the reductions in muscle activity levels when the sustained mobilization was applied to the shoulder.

The acute changes in muscle activation observed during each intervention could be explained by mechanical changes at the glenohumeral joint that are induced by the sustained mobilization [31,42]. In cadavers, sustained mobilization at the glenohumeral joint resulted in a 7.7mm posterior displacement of the humerus during shoulder abduction [15]. Displacement of the humeral head might change the moment arm of shoulder muscles, impacting on muscle activity levels. With larger moment arm, a muscle would need less muscle force being generated to produce the same moment magnitude [5,33]. It is possible that humerus displacement led to changes in moment arm magnitude, impacting on

muscle activity levels of the supraspinatus, infraspinatus, middle and posterior deltoid muscles.

The mechanical effects of sustained mobilizations might influence the function of sensorimotor circuits of the peripheral and central nervous system [38]. Humerus anterior translation [10] may influence afferent input from mechanoreceptors around the glenohumeral joint. The afferent input may impact on spinal and transcortical reflex circuits that regulate the excitability of motoneurons projecting to muscles crossing the scapula and shoulder joint [38]. It is likely that any posterior humeral displacement caused by sustained mobilization reduces activity in these afferent pathways, as well as those carrying nociceptive signals from the shoulder.

Previous studies have demonstrated inhibitory response in shoulder muscles when receptors at the glenohumeral capsule or ligaments are stimulated [6,43]. Those findings suggest a proprioceptive link between glenohumeral capsular and ligament receptors and shoulder muscles activation and may partially explain reductions in the activation of muscles involved in posterior translation of the humerus [6,43]. This is speculative. Future studies could explore such associations during sustained mobilization at the glenohumeral joint.

It is important to understand how sustained mobilisations influence motor synergies of muscles. Our study includes measurements from multiple muscles as a first step in understanding the nature of interactions between muscles. Future studies may expand these further by specifically identifying the formation of muscle synergies between scapular and glenohumeral muscles, and by exploring whether sustained mobilization alter these synergies. This would help us to better understand the effect of manual therapy techniques on neuromuscular control of scapular and glenohumeral muscles.

4.1 Clinical implications

Our findings help to explain how sustained mobilization techniques might reduce pain and increase shoulder range of motion in patients with shoulder disorders. Combined, the present and our previous study [31] show that, in asymptomatic individuals, the technique reduces the activation of shoulder muscles that are commonly affected in patients with shoulder disorders (e.g. deltoid, supraspinatus, lower trapezius and serratus anterior). Sustained mobilizations might help to restore the activity pattern of shoulder muscles that are commonly impaired, through changing the nociceptive and mechanical inputs to the somatosensory cortex and influencing motor neurons at the spinal cord and motor cortex [38]. Future studies exploring the effect of this technique in patients with shoulder disorders will further clarify the neuromuscular response to this manual technique.

4.2 Limitations

In patients, the presence of pain and restricted range of motion may act like a feedback mechanism, helping and guiding patients to apply the ideal pressure over the shoulder, when sustaining the mobilization with the belt. Due to absence of pain or restricted range of motion, our participants were asked to replicate the pressure they felt when abducting the shoulder while the clinician applied the sustained mobilization (at the familiarization phase). The instructions given to participants replicated recommendations from the literature [14]. It is reasonable to assume that the application of the mobilization is similar to that performed by patients. For the present study, we did not include a sham mobilization, as this would increase the complexity of the trial, impacting on statistical power. It has been shown that sEMG overestimates supraspinatus muscle activity in comparison to indwelling EMG [2] and that the cross-talk between upper trapezius and supraspinatus is minimal [44]. Therefore, when assessing within-muscle changes (as we did in this study), it is reasonable to use sEMG for monitoring the supraspinatus muscle activity [31,32]. To minimize electrodes displacement, especially around the scapula, the physiotherapist's hand and the towel and belt were placed with care around the shoulder. It is reasonable to state that fatigue did not have any effect on scapular and shoulder muscle activity levels, since participants performed shoulder abduction movements with no resistance and, at follow-up, the mean muscle activity values were the same as baseline measurements.

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5 CONCLUSIONS

This study suggests that in young, asymptomatic individuals, self- or clinician-administered sustained mobilizations (that resembles MWM) reduced activity levels of most scapular and shoulder muscles during shoulder abduction. This effect was observed only while the sustained glides were applied to the shoulder. At the immediate follow-up, scapular and shoulder muscle activity levels were similar to baseline measurements. Our novel findings support neuromechanical effects of sustained shoulder glides when performed by a clinician or by the patient. These results contribute to a better understanding of how sustained glenohumeral postero-lateral glides may impact on clinical outcomes.

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