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Anamaria Siriani de Oliveira
University of São Paulo

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Original article

Instruction and feedback for conscious contraction of the abdominal muscles increases the scapular muscles activation during shoulder exercises

Angie Stephanie Vega Toro [a], Ann M.J. Cools [b], Anamaria Siriani de Oliveira [a, *]

[a] University of São Paulo, Ribeirão Preto Medical School, Ribeirão Preto, Brazil
[b] Ghent University, Department of Rehabilitation Sciences and Physiotherapy, Ghent, Belgium

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A B S T R A C T

Purpose: The study aimed to investigate the effect of the instruction for conscious contraction of the abdominal muscles on the scapulothoracic muscles activation during shoulder exercises.
Design: Repeated measures design in a single group, pre-post instruction.
Methods: Sixty healthy male and female subjects (mean age 23.5 ± 3 years) volunteered for this study. Two isometric and three dynamic exercises for the scapulothoracic muscles, focusing on the serratus anterior muscle were assessed before and after familiarization training, standardized verbal, and tactile feedback applied to encourage abdominal muscle contraction. Repeated measures ANOVA and Bonferroni post-hoc test were used to compare normalized EMG amplitudes.
Results: Instruction increased EMG amplitude only for serratus anterior muscle during isometric exercises (Inferior Glide and Isometric Low Row). Conscious contraction of the abdominal muscles resulted in significant increase ($p < 0.05$) in the serratus anterior, upper, middle and lower trapezius EMG amplitude, during dynamic exercises (Wall Slide, Wall Press, and Knee Push-Up).
Conclusion: Conscious contraction of the abdominal muscle increased the activation of the serratus anterior e the three parts of the trapezius during dynamic shoulder exercises with moderate to minimal levels of EMG activation. In the other hand, abdominal muscles contraction was effective to increase the activation of the serratus anterior during isometric exercises but did not increase the trapezius activation. So, Inferior Glide and Isometric Low Row performed along with encouraged abdominal muscle contraction are compatible to initial phases of the serratus anterior strengthening with low levels of upper trapezius muscle activation.

1. Introduction

Activation of the scapulothoracic muscles is considered a significant aspect of shoulder complex rehabilitation (Kibler et al., 2008; Kibler and Sciascia, 2010). Exercises minimizing the upper trapezius (UT) muscle activation in relation to the serratus anterior (SA) are recommended to improve scapular stabilization by promoting selective SA strengthening (Martins et al., 2008). Strengthening and facilitation of the abdominal muscles are also recommended as requisite for the restoration of the scapular muscle force couples (Kibler and Sciascia, 2010).

From a mechanical point of view, trunk and pelvis stability are required to transmit force and energy to the upper limbs during function or sports activities (Hirashima et al., 2002; Kibler et al., 2006; Jang et al., 2015). Scapulothoracic joints and its muscles are an anatomofunctional linkage between the trunk and the upper extremities (Kibler and Sciascia, 2010).

Previous studies suggest muscle synergy between the oblique external (OE) muscle and SA during knee push up plus with ipsilateral leg extension (Maenhout et al., 2010; Kim et al., 2011). As a result of the leg extension and gluteus maximus activity, the thoracolumbar fascia is tightened and the lumbar spine extended. Compensatory ipsilateral OE muscle tension is created and transferred to the proximal tendon of the SA, leading to greater muscle fiber recruitment in the scapulothoracic muscle (Maenhout et al., 2010; Kim et al., 2011).

* Corresponding author. Av. Bandeirantes, 3900, Prédio Central, Monte Alegre, Ribeirão Preto, São Paulo, CEP 14090-900, Brazil.
E-mail address: siriani@fmrp.usp.br (A.S. de Oliveira).

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The influence of adding pelvic and thoracic supports on the surface electromyographic (EMG) activity of the scapulothoracic (UT, SA, and lower trapezius – LT) and middle deltoid muscles was already tested (Jang et al., 2015). Trunk stabilization was provided by an external support consisting of pads and belts to the pelvic and the thoracic regions. Participants performed isometric contractions at 45° of shoulder abduction in the scapular plane with pelvic support, with pelvic and trunk support and with no external support. Adding support to the trunk and pelvic regions did not significantly increase the SA and LT activations, but increased the middle deltoid and decreased UT EMG. However, the decrease in UT activation did no significantly decreased the UT/SA ratio which ranged from 0.9 (without stabilization) to 0.94 (both stabilizations) (Jang et al., 2015).

Thus, the influence of trunk stabilization created by conscious contraction of the abdominal muscles on the scapulothoracic muscles activity during shoulder exercises with low UT/SA ratios has not yet been studied. Therefore, the purpose of this study was to investigate the effect of the instruction for conscious activation of the abdominal muscles, encouraged by verbal and tactile feedback, on the EMG activity of the scapular muscles during shoulder exercises commonly used in rehabilitation protocols. Our hypothesis is that adding active abdominal muscle contraction during exercises for the shoulder complex increases the EMG activity of the scapulothoracic muscles.

2. Methods

2.1. Participants

Healthy participants were recruited by verbal invitation and explanatory flyers distributed in campus facilities. Sixty-five healthy, right-handed, male (n = 27) and female (n = 38) subjects (mean age 23.52 ± 3.61 years and mean body mass 23.2 ± 2.34 kg/m^2) participated in the study protocol. All subjects volunteering signed a consent form according to the national regulation and approved by the institutional review board of the university hospital. Subjects were not included if they had previous trauma, neurological or musculoskeletal conditions in the shoulder complex, upper limb, spine or pelvic girdle; limited or painful range of motion in the shoulder complex, upper limb, spine or pelvic girdle; visually detectable spine misalignment, or reported intake of skeletal muscle relaxant drugs.

2.2. Instrumentation

The EMG signals were collected using the Trigno Wireless System (16-bit A/D converter resolution) and processed by EMG Works Acquisition (both from Delsys Inc. Boston, MA, USA). Data were acquired at 2 kHz of sampling rate per channel.

Trigno sensors (Delsys Inc. Boston, MA, USA) are built on a base for four parallel bars (99.9% Ag, 5 × 1 mm contact area and fixed inter-electrode distance of 10 mm), representing two active electrodes and two stabilizing references, eliminating the use of an external reference electrode. Trigno sensor's amplifier has a band pass filter of 20–450 Hz, the baseline noise of <750 nV RMS, with a full dynamic range of ±5 V and a common mode rejection ratio of 80 dB.

Before sensor placement, the skin was shaved, gently abraded and cleaned using alcohol wipes to reduce skin impedance (Hermens et al., 2000). Sensors were fixed using double sided adhesive tape. EMG signals were collected bilaterally from the SA, UT, middle trapezius (MT), LT, EO, internal oblique (IO) and rectus abdominis (RA).

The SA sensor was placed with bars aligned parallel to the length of the muscle fibers, below the axilla, to the lower level angle of the scapula, anterior to the latissimus dorsi muscle and posterior to the pectoralis major muscle (Maenhout et al., 2010). The UT muscle sensor was placed midway on a line between the acromion and the spinous process of the C7 vertebra (Maenhout et al., 2010). The MT sensor was placed at 50% of the horizontal distance between the medial border of the scapula and the spinous process of the T3 vertebra. The LT sensor was placed at 2/3 of the line between the trigonum spinae scapula and the spinous process of the T8 vertebra (Hermens et al., 1999). The OE muscle sensor was placed 15 cm lateral to the umbilicus with bars parallel-oriented to the muscle fiber's direction, just below the convexity of the 10th rib (Juker et al., 1998). The OI sensor was placed below the external oblique electrodes and just superior to the inguinal ligament (Juker et al., 1998). The RA muscle sensor was placed 3 cm lateral to the umbilicus (Juker et al., 1998).

2.3. Procedure

After sensor placement, the EMG signals were recorded bilaterally from maximal isometric voluntary contractions (MIVC) for all muscles investigated in a random sequence (muscle and side) defined by the drawing lot.

The MIVC task of each muscle was registered during five seconds of sustained effort. Each MIVC task was repeated three times. Participants rested at least 30 s between MIVC of the same muscle and two minutes between different MIVC tasks (Maenhout et al., 2010; De Araújo et al., 2011).

For the SA, the subject was seated with the shoulder in 130° forward flexion. The examiner applied manual resistance against further shoulder elevation (Maenhout et al., 2010). UT MIVC was acquired with the subject seated and shoulder abducted at 90°. The examiner applied manual resistance against further shoulder abduction (Maenhout et al., 2010). MT MIVC was recorded with the subject in prone position, 90° shoulder abduction, and humeral external rotation. The resistance was applied against horizontal abduction (Maenhout et al., 2010). LT muscle MIVC was also recorded with the subject in prone position; the shoulder was abducted to be aligned with the LT fiber's muscle direction. The resistance was applied against retraction and depression (De Mey et al., 2013).

EO and IO (contralateral) MIVC were recorded with the subject in supine position, arms crossed over the chest, 45° of hip flexion and 90° of knee flexion. The examiner applied resistance against the contraction of trunk flexion and rotation to the opposite side. RA MIVC was recorded in the supine sit-up exercise. Subjects performed trunk flexion with their arms crossed over the chest, 45° of hip flexion and 90° of knee flexion. The examiner applied manual resistance against the trunk flexion (Monfort, 2009).

After a resting period of 15 min, the subjects performed one trial of five repetitions of each of the five exercises. Participants rested 5 s between repetitions and two minutes between exercise's trials (Maenhout et al., 2010; De Mey et al., 2013).

The exercises (Table 1) were selected based on literature for being recommended for muscle strengthening with UT/SA ratio <1, or for scapular motor control improvement. Two exercises were performed as sustained contractions (isometric exercises): "Inferior Glide" and "Isometric Low Row" (Fig. 1) (Cricchio and Frazer, 2011; Kibler et al., 2008). Three exercises were performed dynamically: "Wall Slide", "Wall Press" and "Knee Push-Up" (Ludewig et al., 2004; Uhl et al., 2010; Maenhout et al., 2010; Cricchio and Frazer, 2011) (Fig. 2).

"Inferior Glide" and "Isometric Low Row" were performed in five repetitions maintained by five seconds. "Wall Slide", "Wall Press"

Table 1
The five exercises tested in the study.

Exercises	Description
Inferior Glide	Participant sitting with 90° of shoulder abduction, elbow fully extended and, wrist in a neutral position, closed fist with thumb upwards; participant performs shoulder adduction against an unstable base of support (a small ball) while adducting and depressing the scapula relative to the spine.
Isometric Low Row	Participant standing in front of a fixed horizontal surface as a table, with the hand palm touching the edge of this surface; participant performs an isometric contraction of shoulder extension against the edge while adducting and depressing the scapula relative to the spine.
Wall Slide	Participant standing in front of wall with feet away from it as much as necessary to tilt the trunk while forearms rested against the wall, with 90° of elbow and shoulder flexion; participants slides up and downward the forearms ulnar face against the wall, from the initial position to a mark corresponding to 150° of shoulder flexion.
Wall Press	Participant standing in front of a wall with feet away from it as much as necessary to keep elbows extended, 90° of shoulder flexion and scapular retraction; participants presses the palmar face of hand against the wall while fully protracting the scapula.
Knee Push-Up	Participant in four-point-kneeling position on a stable surface, the elbows extended and hands shoulder width apart; participants pushes the palmar face of the hand against the floor while fully protracting (plus phase) the scapula.

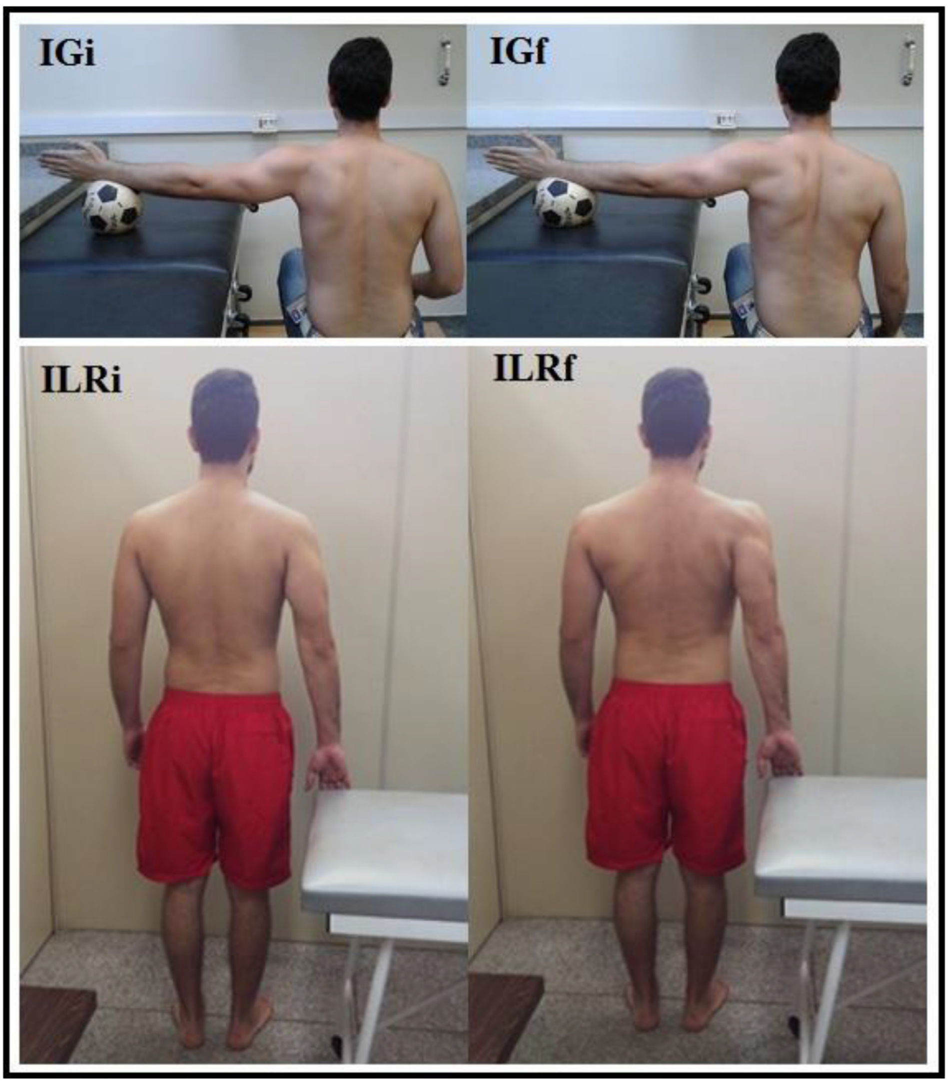

Fig. 1. Isometric exercises. “Inferior Glide” (IGi) initial and (IGf) final position. “Isometric Low Row” (ILRi) initial and (ILRf) final position.

and “Knee Push-Up” were performed in five repetitions with each concentric and eccentric phase lasting three seconds (six seconds total) pace marked by a metronome. Exercises were registered in a random sequence definite by the drawing lots.

Following the sEMG data collection of all exercises, a 15-min of familiarization and training for the conscious contraction of the abdominal muscles was performed. Subjects were instructed to perform abdominal bracing and hollowing abdominal exercises (Maeo et al., 2013; Koh et al., 2014). Both exercises are focused on the co-activation of the OE and OI muscles. While performing each exercise, the instructor asked the subject to contract his/her abdomen leading it toward his/her back, during the expiratory phase of breathing. Abdominal contractions were verbally encouraged by commands as: “tighten the abdomen”, “focus your effort on the abdomen”, “embrace the low back spine with your abdomen” (Vezina and Kozey, 2000; Souza et al., 2001; Urquharta

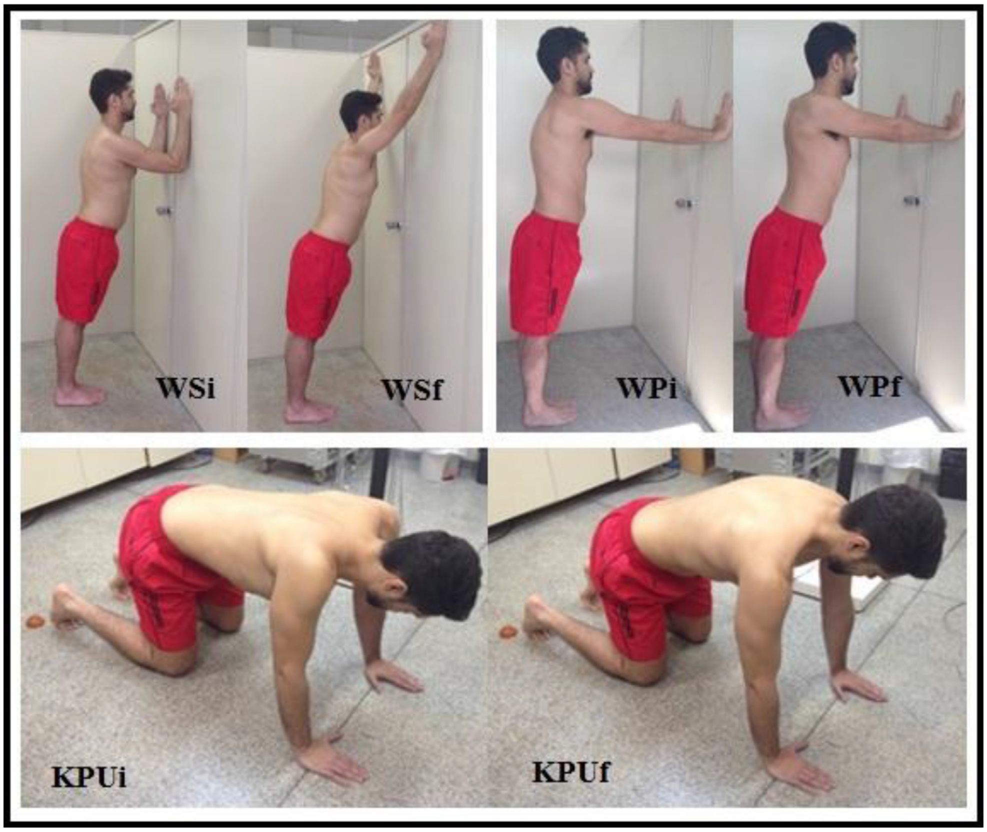

Fig. 2. Dynamic exercises. "Wall Slide" (WSi) initial and (WSf) final position. "Wall Press" (WPi) initial and (WPf) final position. "Knee Push Up" (KPUi) initial and (KPUf) final position.

et al., 2005; Kibler et al., 2006). Additional tip-of-fingers light pressure and slight tapping were applied in the longitudinal direction of the abdominal muscles fibers, in a relative low-frequency of two stimuli per second, as tactile feedback (Mottram et al., 2009; Worsley et al., 2013), without touching sensors in those muscles.

Finally, subjects repeated the whole procedure of EMG data collection, immediately after familiarization. The five studied exercises were again randomized and now performed with additional verbal commands and tactile feedback delivered by the same examiner who did familiarization. Verbal and tactile feedback was given only during the expiratory phase of breathing to avoid precocious fatigue of abdominal muscles.

2.4. Signal processing and statistics

All raw EMG signals were digitally band-pass filtered at 10–500 Hz (fourth-order Butterworth filter).

EMG amplitudes of the isometric contractions (MVIC and isometric exercises) were calculated using a standard root-mean-square (RMS) function applied to a 3-s window, corresponding to the second, third and fourth seconds of the signal (Maenhout et al., 2010). For each muscle, the RMS values of the middle 3 of 5 repetitions (De Araújo et al., 2011; Nagai et al., 2013) of the isometric exercises were averaged. Also, the mean RMS of three repetitions of MVIC contractions was calculated. Mean RMS value of each muscle during isometric exercises was normalized and subsequently expressed as a percentage of the mean MVIC RMS values.

EMG signal of the dynamic contractions was full-wave rectified and low-pass digitally filtered ('linear envelope') with an 8 Hz cutoff (fourth-order Butterworth filter). Integrated EMG (iEMG) was calculated from a 3-s window, from the first to the third seconds of the signal, corresponding to time elapsing the concentric phase of the muscle's contraction. For each muscle, the iEMG values of the middle 3 of 5 repetitions of the dynamic exercises were averaged (De Araújo et al., 2011; Nagai et al., 2013). Also, the mean iEMG of three repetitions of MVIC was calculated to be used as a reference to normalize amplitudes of muscle activation obtained in the dynamic exercises. So, the iEMG amplitude of each muscle is expressed as a percentage of the MVIC iEMG.

Reliability of the EMG amplitude within the three repetitions of MVIC contractions was calculated by Intra-Class Coefficient (2,1) for consistency. When MVIC amplitude was obtained as RMS (reference values for isometric exercises), ICC ranged from 0.9 to 0.95. When MVIC amplitude was obtained as iEMG (reference values for dynamic exercises), ICC ranged from 0.89 to 0.95. Reliability of the 3-repetition MVIC amplitude was almost perfect (Shrout and Fleiss, 1979).

EMG amplitudes were also classified as minimal (<20% MVIC), moderate (21–50% MVIC) or marked (>50% MVIC) (McCann et al., 1992).

EMG amplitudes were presented as means, standard deviation (SD) and, confidence interval (IC) of 95%.

Paired t-test was used to compare normalized EMG amplitudes of the EO, IO, and RA before and after instruction (right side previous vs. right side post and left side previous vs. left side post). Those comparisons were made to confirm if the protocol was effective to increase abdominal muscle's contraction.

Two-way repeated-measures ANOVA was performed to compare the normalized EMG amplitude of each muscle (SA, UT, MT and, LT) with the factors: condition instruction (with and without) and side (right and left). Mauchly's test of sphericity with the Greenhouse-Geisser correction was considered in this analysis.

Exercises were not included as factors in the analysis of variance since comparisons of their amplitudes among muscles would result in differences due to the specific muscle fiber recruitment and biomechanical requirements.

In the case of interaction effects condition × side, Bonferroni posthoc tests were applied to multiple comparisons. In the case of main effects, no posthoc tests were performed, since each variable only had two levels. An alpha level of 0.05 was adopted for all comparisons. All statistical analyzes were performed using SPSS (version 17.0; Chicago, IL, USA).

Since the sample size was estimated based on the pilot study, as a complement to statistical hypothesis testing, the effect size was used to represent the magnitude of the difference among EMG amplitude comparisons and power analyses. The magnitude of difference was classified as small if the value of Cohen's d ranged from 0.2 to 0.5, as moderate if it ranged from 0.5 to 0.8 or, as large if Cohen's d value was greater than 0.8. Moderate and large magnitudes of effect size were considered indicators of appropriate statistical power (Cohen, 1988; Page, 2014).

3. Results

Instruction to conscious abdominal contraction applied during all selected shoulder exercises increased significantly ($p < 0.05$) the EO, IO, and RA normalized EMG amplitudes (Table 2).

Two-way repeated-measures ANOVA applied to SA, UT, MT, and LT normalized EMG amplitudes showed no significant interaction effects condition × side for any muscle and any exercise. There was no significant main effect relative to the body side (right or left) in the statistical analysis for all studied muscles. Significant main effects for the condition were found based as a result of the instruction to conscious contraction of the abdominal muscles.

SA activity increased as result of instruction to conscious contraction of the abdominal muscles in all 5 exercises: “Inferior Glide” ($F = 77.25$, $P < 0.001$) and, “Isometric Low Row” ($F = 112.45$, $P < 0.001$) (Table 3) “Wall Slide” ($F = 113.21$, $P < 0.001$), “Wall Press” ($F = 206.56$, $P < 0.001$) and, “Knee Push-Up” ($F = 206.53$, $P < 0.001$) (Table 4).

The instruction for conscious contraction of the abdominal muscles during the isometric shoulder exercises (Table 3) did not cause a significant increase in the EMG amplitude normalized of the tree parts of the trapezius muscle.

Significant main effects were found for the factor condition only when the three parts of trapezius performed the dynamic exercises. UT activity increased with instruction to contract abdominal muscles in “Wall Slide” ($F = 43.92$, $P < 0.001$), “Wall Press” ($F = 45.97$, $P < 0.001$) and “Knee Push-Up” ($F = 40.61$, $P < 0.001$) (Table 4). MT activity increased as a result of the instruction to conscious contraction of the abdominal muscles in “Wall Slide” ($F = 33.52$, $P < 0.001$), “Wall Press” ($F = 30.94$, $P < 0.001$) and “Knee Push-Up” ($F = 37.04$, $P < 0.001$) (Table 4). Finally, LT activity increased as a result of the instruction to conscious contraction of the abdominal muscles in “Wall Slide” ($F = 76.33$, $P < 0.001$), “Wall Press” ($F = 71.64$, $P < 0.001$) and “Knee Push-Up” ($F = 28.85$, $P < 0.001$) (Table 4).

The effect sizes were moderate-large in SA EMG comparisons, in all exercises (Tables 3 and 4) and small in comparisons of the activation amplitude of the three parts of trapezius in isometric

Table 2
Mean (±SD) values of normalized electromyographic amplitude of the abdominal muscles with and without instruction for conscious activation of abdominal muscle during exercises: “Inferior Glide”, “Isometric Low Row”, “Wall Slide”, “Wall Press”, and “Knee Push-Up”.

Muscle	Side	No instruction	With instruction	Difference	CI 95%	ES
Inferior Glide						
External oblique	Right	29.46 ± 20.53	53.08 ± 28.63	23.62*	(−30.94; −16.30)	0.95
	Left	34.54 ± 23.13	53.49 ± 31.18	18.94*	(−24.10; −13.79)	0.69
Internal oblique	Right	28.97 ± 23.39	94.63 ± 64.22	65.66*	(−79.75; −51.57)	1.36
	Left	47.77 ± 30.26	148.65 ± 74.71	100.88*	(−117.26; −84.49)	1.77
Rectus abdominis	Right	10.63 ± 7.64	20.26 ± 17.51	9.63*	(−13.97; −5.29)	0.71
	Left	14.15 ± 9.72	25.27 ± 18.85	11.13*	(−15.09; −7.16)	0.74
Isometric Low Row						
External oblique	Right	23.89 ± 15.05	46.90 ± 31.07	23.01*	(−28.71; −17.31)	0.94
	Left	19.23 ± 13.59	37.79 ± 24.29	18.55*	(−22.55; −14.56)	0.94
Internal oblique	Right	57.99 ± 50.58	131.76 ± 85.77	73.77*	(−88.63; −58.90)	1.05
	Left	82.03 ± 42.62	177.42 ± 68.59	95.39*	(−109.07; −81.71)	1.67
Rectus abdominis	Right	19.23 ± 13.66	28.01 ± 23.19	8.78*	(−13.27; −4.29)	0.46
	Left	23.65 ± 19.98	35.08 ± 28.25	11.43*	(−16.88; −5.98)	0.47
Wall Slide						
External oblique	Right	13.38 ± 8.53	36.7 ± 27.10	23.32*	(−29.09; −17.55)	1.16
	Left	13.48 ± 12.06	28.13 ± 19.26	14.65*	(−17.59; −11.71)	0.91
Internal oblique	Right	22 ± 20.44	69.82 ± 61.82	47.81*	(−60.34; −35.29)	1.04
	Left	35.95 ± 35.69	118.92 ± 79.61	82.96*	(−99.57; −66.35)	1.34
Rectus abdominis	Right	9.44 ± 9.34	14.84 ± 12.72	5.4*	(−7.95; −2.85)	0.48
	Left	10.7 ± 10.92	17.73 ± 15.64	7.02*	(−10.39; −3.66)	0.52
Wall Press						
External oblique	Right	7.22 ± 5.49	19.66 ± 12.72	12.45*	(−14.91; −9.99)	1.27
	Left	7.63 ± 8.15	18.54 ± 15.19	10.9*	(−13.12; −8.69)	0.90
Internal oblique	Right	12.31 ± 12.55	67.10 ± 70.78	54.79*	(−70.02; −39.56)	1.08
	Left	23.92 ± 26.91	115.24 ± 79.19	91.32*	(−108.27; −74.37)	1.54
Rectus abdominis	Right	3.39 ± 2.29	5.81 ± 3.96	2.41*	(−3.40; −1.42)	0.75
	Left	4.07 ± 3.06	7.11 ± 5.79	3.04*	(−4.23; −1.84)	0.66
Knee Push-Up						
External oblique	Right	8.74 ± 6.78	21.83 ± 13.31	13.08*	(−15.76; −10.41)	1.24
	Left	8.60 ± 8.07	21.08 ± 21.61	12.47*	(−16.07; −8.88)	0.77
Internal oblique	Right	9.37 ± 11.57	53.27 ± 48.26	43.91*	(−54.83; −32.98)	1.25
	Left	17.15 ± 19.67	100.46 ± 71.62	83.31*	(−99.34; −67.28)	1.59
Rectus abdominis	Right	4.26 ± 3.32	8.33 ± 6.79	4.07*	(−5.79; −2.35)	0.76
	Left	4.96 ± 3.71	9.30 ± 6.86	4.34*	(−5.82; −2.86)	0.79

*Significant difference between conditions ($p < 0.05$). CI 95%: 95% confidence interval. ES: Effect Size.

Table 3
Mean (±SD) values of normalized electromyographic amplitude of the scapulothoracic muscles with and without instruction for conscious activation of abdominal muscle during isometric exercises: "Inferior Glide" and "Isometric Low Row".

Muscle	Side	Not instruction	With instruction	Difference	CI 95%	ES
Inferior Glide						
Serratus anterior	Right	52.48 ± 36.86	71.84 ± 49.36	19.36*	(13.63; 25.09)	0.44
	Left	47.80 ± 39.86	64.45 ± 49.59	16.65*	(10.92; 22.38)	0.37
Upper trapezius	Right	15.05 ± 11.23	19.15 ± 19.63	4.1	(0.03; 8.18)	0.26
	Left	21.01 ± 17.23	22.51 ± 21.63	1.5	(−2.57; 5.58)	0.08
Middle trapezius	Right	32.76 ± 23.95	33.43 ± 24.29	0.67	(−4.88; 6.22)	0.03
	Left	37.38 ± 29.67	38.71 ± 37.03	1.33	(−4.22; 6.88)	0.04
Lower trapezius	Right	41.49 ± 27.37	39.86 ± 24.03	−1.63	(−7.21; 3.95)	0.06
	Left	38.49 ± 24.95	41.22 ± 29.01	2.74	(−2.84; 8.32)	0.1
Isometric Low Row						
Serratus anterior	Right	49.64 ± 42.01	73.72 ± 58.39	24.08*	(17.93; 30.22)	0.47
	Left	40.39 ± 33.05	62.90 ± 46.40	22.51*	(16.36; 28.65)	0.56
Upper trapezius	Right	14.35 ± 10.13	19.47 ± 16.19	5.12	(0.88; 9.36)	0.38
	Left	26.93 ± 26.34	27.61 ± 18.82	0.68	(−3.56; 4.92)	0.03
Middle trapezius	Right	53.49 ± 32.66	57.84 ± 34.20	4.35	(−0.29; 9.00)	0.13
	Left	50.58 ± 27.62	52.54 ± 31.24	1.96	(−2.68; 6.61)	0.07
Lower trapezius	Right	45.07 ± 25.65	44.93 ± 29.40	−0.15	(−5.76; 5.47)	0.01
	Left	48.09 ± 24.91	54.27 ± 32.12	6.17	(0.56; 11.78)	0.21

*Significant difference between conditions ($p < 0.05$). CI 95%: 95% confidence interval. ES: Effect Size.

Table 4
Mean (±SD) values of normalized electromyographic amplitude of the scapulothoracic muscles with and without instruction for conscious activation of abdominal muscle during dynamic exercises: "Wall Slide", "Wall Press", and "Knee Push-Up".

Muscle	Side	No instruction	With instruction	Difference	CI 95%	ES
Wall Slide						
Serratus anterior	Right	19.77 ± 12.64	35.88 ± 26.91	16.12*	(12.35; 19.89)	0.77
	Left	20.29 ± 11.11	32.84 ± 19.93	12.55*	(8.78; 16.32)	0.78
Upper trapezius	Right	13.53 ± 10.86	19.64 ± 11.74	6.11*	(3.52; 8.70)	0.54
	Left	14.65 ± 14.80	20.80 ± 14.37	6.15*	(3.56; 8.74)	0.42
Middle trapezius	Right	4.27 ± 3.08	6.41 ± 4.48	2.14*	(0.80; 3.49)	0.56
	Left	4.37 ± 3.33	7.78 ± 7.29	3.42*	(2.07; 4.76)	0.6
Lower trapezius	Right	6.24 ± 5.47	10.85 ± 8.73	4.62*	(3.09; 6.15)	0.63
	Left	6.69 ± 8.76	11.64 ± 11.16	4.95*	(3.41; 6.48)	0.5
Wall Press						
Serratus anterior	Right	14.36 ± 10.96	29.52 ± 16.43	15.15*	(12.14; 18.17)	1.09
	Left	15.13 ± 10.49	30.90 ± 17.07	15.77*	(12.76; 18.78)	1.11
Upper trapezius	Right	13.66 ± 15.07	23.80 ± 21.98	10.14*	(6.19; 14.09)	0.54
	Left	15.66 ± 20.38	24.65 ± 33.59	9.0*	(5.05; 12.95)	0.32
Middle trapezius	Right	8.14 ± 10.72	15.76 ± 24.62	7.62*	(4.15; 11.10)	0.4
	Left	9.14 ± 10.55	15.34 ± 18.70	6.2*	(2.73; 9.68)	0.41
Lower trapezius	Right	11.15 ± 10.07	16.79 ± 13.03	5.64*	(3.51; 7.78)	0.48
	Left	9.21 ± 7.71	16.48 ± 11.36	7.27*	(5.14; 9.40)	0.75
Knee Push-Up						
Serratus anterior	Right	16.07 ± 9.22	31.10 ± 15.42	15.03*	(12.13; 17.94)	1.18
	Left	17.16 ± 10.89	31.99 ± 20.12	14.83*	(11.92; 17.73)	0.92
Upper trapezius	Right	8.23 ± 6.93	15.27 ± 13.94	7.04*	(4.08; 10.00)	0.64
	Left	9.25 ± 10.86	15.70 ± 21.27	6.46*	(3.49; 9.42)	0.38
Middle trapezius	Right	5.27 ± 6.25	8.76 ± 9.33	3.48*	(2.07; 4.90)	0.44
	Left	6.57 ± 7.25	9.24 ± 9.39	2.67*	(1.26; 4.09)	0.32
Lower trapezius	Right	7.74 ± 7.36	11.10 ± 9.64	3.37*	(1.79; 4.95)	0.39
	Left	6.17 ± 5.87	8.87 ± 7.43	2.7*	(1.12; 4.28)	0.4

*Significant difference between conditions ($p < 0.05$). CI 95%: 95% confidence interval. ES: Effect Size.

exercises (Table 3). Effect sizes ranged from moderate to small in UT, MT and LT EMG comparisons in dynamic exercises (Table 4). Small effect sizes indicate low statistical power.

Mean SA activation during exercises performed with instruction to conscious contraction of abdominal muscles varied between 30 and 35% MVIC (moderate activation) in dynamic exercises and 60–65% MVIC (marked activation) in isometric exercises. UT level of activation ranged between 15 and 25% MVIC (minimal to moderate activation) in dynamic exercises and 20–30% MVIC (minimal to moderate activation) in isometric exercises. Level of EMG normalized activation of the MT ranged between 5 and 15% MVIC (minimal activation) in dynamic exercises and 30–60% MVIC (moderate to marked activation) in isometric exercises and, in the LT ranged from 5 to 15% MVIC (minimal activation) in dynamic exercises and from 35 to 55% MVIC (moderate to marked activation) in isometric exercises.

4. Discussion

The purpose of this study was to investigate the influence of conscious activation of the abdominal muscles on the SA, UT, LT and MD EMG activities during shoulder exercises commonly used in rehabilitation protocols. The study hypothesis was partially confirmed. In particular, SA activation increased with conscious contraction of the abdominal muscles in both isometric and dynamic exercises but did not influence the three parts of trapezius muscle activation during isometric exercises.

The synergism between abdominal and scapulothoracic muscles was described during throwing as a strategy of anticipatory postural adjustments reached by increasing muscle activation in a proximal-to-distal sequence (Magarey and Jones, 2003). Increasing SA muscle activation, as a result of mechanical tension transferred from OE to SA tendon, was also already described in studies that created compensatory abdominal muscle contraction to counterbalance extension torque in the lumbar spine caused by one leg extension during knee push-up plus exercise (Maenhout et al., 2010; Kim et al., 2011). Our study was the first to show SA and abdominal muscles synergy by bilateral and encouraged conscious contraction of the abdominal muscles during shoulder exercises.

Trapezius muscle activation increased as a result of conscious abdominal contraction only during the dynamic shoulder exercises, from minimal (>20%MVIC) to minimal and moderate levels of EMG activation (>20–50%MVIC). Previous studies also did not find the clear influence of axial muscles contraction (Maenhout et al., 2010; Kim et al., 2011) and external trunk and pelvis stabilization (Jang et al., 2015) on the trapezius muscle activation. The UT activation was not influenced by raising either ipsi- or contralateral legs (Maenhout et al., 2010), creating unstable bases of support for hands or adding external load in the leg extended (Kim et al., 2011) during three-point knee push-up plus exercises. UT normalized EMG activity decreased in isometric shoulder abduction by adding external stabilization of trunk and pelvis (Maenhout et al., 2010). However, the decrease in UT activation along with trunk and pelvis external stabilization was not enough to chance the SA/UT EMG ratio significantly (Maenhout et al., 2010). LT EMG activity increased in knee push up plus with contralateral leg extension (Maenhout et al., 2010), but its activation did not change with more stabilization of the trunk and pelvis (Jang et al., 2015). As the magnitude of the effect sizes for trapezius activation comparisons in the present study was in majority small, the statistical power of those analyses was considered low, and the effect of instruction on the conscious contraction of abdominal muscles in trapezius remains to be clarified.

From a clinical perspective, the instruction to conscious contraction of the abdominal muscles increases the activation of the SA muscle in both isometric and dynamic shoulder exercises. ‘Isometric Low Row’ and ‘Inferior Glide’ produced moderate to marked levels of muscle activation and conscious contractions of the abdominal muscles did not increase the UT activation, creating a better SA/UT ratio for isometric exercises. So, those two isometric exercises performed along with encouraged abdominal muscle contraction are compatible to initial phases of the SA strengthening training with low levels of UT activation.

This study has some limitations. First, only healthy individuals were evaluated. Subjects with painful shoulder conditions possibly may not show an increase in scapulothoracic muscle activation due to the inhibitory effect of pain on individual muscle activation. Therefore, extrapolation of our results to a patient population should be performed with caution. Second, the research design did not include randomizing the conditions with and without instruction. Therefore, all exercises were performed first without and then with the instruction for conscious abdominal muscle contraction. As a result, some of the increase in scapulothoracic muscles activation might be due to an increase in the neural drive following repeated contractions. However, considering the protocol had a few number of repetitions of the shoulder exercises and resting periods between conditions with and without instruction to abdominal contractions, we believe that the increase in the periscapular muscles EMG after instruction could be rather attributed to the specific intervention on abdominal muscle, rather than a facilitatory effect of the first part of the study's protocol.

5. Conclusion

Conscious contraction of the abdominal muscle increased the activation of the SA e the three parts of the trapezius muscle during dynamic shoulder exercises with moderate to minimal levels of EMG activation. In the other hand, conscious contraction of the abdominal muscles was effective to increase the activation of the SA during isometric exercises but did not increase the trapezius activation. So, Inferior Glide and Isometric Low Row performed along with encouraged abdominal muscle contraction are compatible to initial phases of the SA strengthening with low levels of UT activation.

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