Volitional Preemptive Abdominal Contraction and Upper Extremity Muscle Latencies During D1 Flexion and Scaption Shoulder Exercises

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Context: The abdominal-bracing maneuver, a volitional preemptive abdominal contraction (VPAC) strategy, is commonly used during resisted shoulder exercises. How VPAC affects shoulder-muscle function during resisted shoulder exercise is unknown.

Objective: To identify the effects of VPAC on selected parascapular and glenohumeral muscles during specific shoulder exercises with or without resistance.

Design: Cross-sectional study.

Setting: Clinical biomechanics research laboratory.

Patients or Other Participants: Twenty-two asymptomatic volunteers between 18 and 40 years of age.

Intervention(s): Participants performed arm elevation in scaption and D1 shoulder-flexion (D1F) patterns with and without resistance and VPAC.

Main Outcome Measure(s): Electromyography was used to test the muscle-contraction amplitudes and onset timing of the anterior deltoid, posterior deltoid, upper trapezius, lower trapezius, and serratus anterior. Muscle-response amplitudes were quantified using root mean square electromyography. Shoulder-muscle relative-onset timing was quantified in reference to kinematic elbow-movement initiation.

Results: The VPAC increased serratus anterior amplitude during D1F (P < .001) and scaption (P < .001) and upper trapezius amplitude (P < .001) in scaption. All muscle amplitudes increased with resistance. The VPAC decreased muscle-onset latencies for the anterior deltoid (P < .001), posterior deltoid (P = .008), upper trapezius (P = .001), lower trapezius (P = .006), and serratus anterior (P = .001) during D1F. In addition, the VPAC decreased muscle-onset latencies for the anterior deltoid (P < .001), posterior deltoid (P < .001), posterior deltoid (P < .001), lower trapezius (P = .007), upper trapezius (P < .001), lower trapezius (P < .001), lower trapezius (P < .001), and serratus anterior (P < .001), and serratus anterior (P < .001), during scaption.

Conclusions: The VPAC affected only the parascapular muscles that had the greatest scapular-stabilizing roles during the specific open chain movement we tested. It decreased latencies in all muscles. These neuromuscular changes may enhance the stability of the shoulder during D1F and scaption exercises.

Key Words: abdominal bracing maneuver, electromyography, trapezius, serratus anterior

Key Points

- The effects of volitional preemptive abdominal contraction (VPAC) may be more apparent in muscles that have the greatest roles in scapular stabilization.
- The VPAC affected muscle latencies during D1 shoulder flexion and scaption.
- Individuals can incorporate VPAC during D1 shoulder-flexion and scaption movements without significant negative consequences on the parascapular muscles.

Inicians often attempt to incorporate multiple strategies in their upper extremity strength and conditioning protocols that enhance the effects of commonly used clinical approaches. A frequently used strategy involves asking the patient to perform upper extremity exercises on a stable trunk. This approach incorporates dynamic neuromuscular scapular control and trunk stabilization to create more coordinated movements and reduce any challenges from changing movement parameters.¹

A specific exercise in this strategy asks the patient to contract the abdominal muscles while performing an upper extremity exercise.² Therefore, it can be helpful for clinicians to understand how volitional preemptive abdominal contraction (VPAC) during shoulder exercise affects shoulder neuromuscular function and control. The use of VPAC is particularly prevalent in shoulder-exercise protocols, but research supporting this practice is limited. Miyake et al³ examined the effects of core training on later skilled upper extremity movement and found that the training improved fine motor skills in healthy participants and in an individual with cerebellar ataxia. Supporting this notion, it appears that the quality of shoulder-muscle contraction decreases when the abdominal muscles are fatigued. Rosemeyer et al⁴ reported a significant decrease in shoulder maximum volitional isometric contraction in the frontal and transverse planes after core muscle fatigue. These 2 studies^{3,4} suggest that trunk-muscle training, or the lack thereof, can influence upper extremity movement outcomes.

The abdominal-bracing maneuver (ABM) is 1 form of VPAC that produces activity in both the abdominal and dorsal-spine muscles.⁵ Performance of the ABM improves

when participants use imagery to initiate the muscle activity, such as mentally preparing their trunk for being punched in the stomach or imagining that they use their trunk muscles to laterally widen their trunk. This approach can result in a more global trunk-muscle response than other commonly used strategies.⁶

The ABM can serve as a protective measure during extremity movement. The ABM selectively induces higher deep–abdominal-muscle activity, which works to stabilize the spine.⁷ This stabilization strategy can help prevent back injury or, in the event of existing low back pain, can contribute to rehabilitation.⁶ In response, Hooper et al⁸ examined the effects of ABM on trunk and lower extremity muscle activity during a vertical drop landing. During the ABM condition, external-oblique activity, knee flexion, and knee-energy absorption all increased, whereas knee-adduction moment decreased, potentially reducing the knee-injury risk while protecting the lumbar spine.⁸

The effects of ABM on scapular control have not been thoroughly examined. Normal arm elevation is accompanied by scapular upward rotation, posterior tilt, and external rotation, motions that are principally controlled by the serratus anterior (SA), upper trapezius (UT), and lower trapezius (LT).⁹ The influence of VPAC on these neuromuscular and movement responses should be examined to identify its ability to enhance shoulder-muscle function during elevation.

The purpose of our study was to evaluate how VPAC performance during upper extremity movement affected the electromyographic (EMG) amplitudes and latencies of the parascapular and deltoid muscles when participants without shoulder pain or dysfunction performed commonly used upper extremity movements, both with and without added resistance. First, because VPAC has been shown to increase the amplitudes of lower extremity muscle activation, we hypothesized that incorporating VPAC during shoulder movements would increase the muscle-activation amplitudes of the parascapular muscles (UT, LT, and SA) and deltoid muscles (anterior deltoid [AD] and posterior deltoid [PD]). Second, we hypothesized that adding resistance to the shoulder movements would further increase parascapular and deltoid muscle-activation amplitudes beyond those already produced by VPAC use.

This study could provide insight into the effect of VPAC on parascapular muscle-contraction-timing responses. These timing responses could affect the role of the parascapular muscles (scapular upward rotation, posterior tilting, and external rotation) during upper extremity movement. Therefore, our third hypothesis was that incorporating VPAC during shoulder movements would change the onset timing of various muscles of the shoulder complex. Our findings could provide a foundation for measuring the clinical consequences of using VPAC during shoulder exercises and activities.

METHODS

Participants

A total of 22 participants were recruited from a convenience sample for this study. The sample size needed to approach 80% statistical power for differences between conditions was estimated from the literature,¹⁰ resulting in an effect-size index of f = 0.25. With a desired power of

80% $(1 - \beta = 0.80)$ and desired $\alpha = .05$, this effect-size index estimated a minimum sample size of 21 participants (G*Power Software version 3.1.9.2; Heinrich Heine University, Düsseldorf, Germany).

Participants were included if they were (1) between 18 and 40 years of age, (2) able to tighten the trunk while performing shoulder exercises, (3) able to stand independently for at least 60 minutes, and (4) cognitively able to follow instructions. Participants were excluded if they presented with (1) existing low back pain or upper extremity pain; (2) shoulder, neck, or low back pain within the previous 6 months that required attention from a health care provider; (3) a history of shoulder injury or shoulder surgery; (4) a body mass index of greater than 30; (5) any diagnosed and presently active abdominal, respiratory, or gastrointestinal condition; (6) pregnancy by participant self-report; (7) significant spinal deformity or condition, including scoliosis, spina bifida, diagnosed spinal injury, tumor, present fracture, or rheumatologic disorder; (8) known neurologic or joint disease affecting the trunk; (9) current urinary tract infection; or (10) a cognitive disorder that would prevent the understanding of simple directions.

The local health science center's institutional review board approved the study. Participants signed a written informed consent before completing the demographic and medical history questionnaires and viewing a video demonstrating the experimental procedures.

Procedures

The participants' heights and weights were measured and their dominant arms were identified. They were then trained to perform, and allowed to practice, the ABM and shoulder exercises for the study. For the ABM, individuals were asked to place each hand's first web space above the respective iliac crest and then tighten the stomach muscles to widen the hands. For the shoulder movements, each person was asked to elevate the arm past the horizontal plane in 2 directions: (1) the proprioceptive neuromuscular facilitation upper extremity movement D1 shoulder flexion (D1F) and (2) scaption.

We chose the D1F, which is composed of glenohumeral flexion, adduction, and external rotation,¹⁰ because it reestablishes the synergistic muscle coactivation during shoulder movement and resembles normal shoulder movements during activity across the body's midline.^{1,11} Scaption was chosen because of its effectiveness in producing substantial shoulder-complex muscle activity.¹²

The participants practiced the ABM and each shoulder movement using the dominant arm for 10 repetitions without resistance. Then they stood on one end of a resistance band of standardized length using the foot ipsilateral to the dominant arm. To standardize the length of the elastic resistance for each individual, the length from the end on which the participant stood to the end that he or she held needed to equal his or her height minus 5 in (12.7 cm).¹³ The participant practiced both shoulder movements with the dominant arm for 5 repetitions, using the bluelevel resistance band that provides a midrange of resistance as a standard for most people.^{11,14} Clinicians often add resistance to shoulder exercises, which can aid in regaining muscle function during shoulder movements.



Figure 1. Anterior view of electrode and marker placement.

Electromyography

Self-adhesive Ag-AgCl bipolar differential surface electrodes (model 272; Noraxon USA Inc, Scottsdale, AZ) with a 2-cm interelectrode distance (1-cm diameter) were used to record EMG signals from the AD, PD, UT, LT, and SA, as well as the dominant-side and nondominant-side external obliques (EO1 and EO2, respectively) and nondominantside internal oblique (IO). The reference electrode was placed on the sternum.¹⁵ All surface EMG raw data were hardware filtered to a bandwidth of 20 to 500 Hz. Sampling frequency was 1000 Hz. Electrode placement sites were cleaned, abraded, and lightly shaved when needed. The EMG electrodes were placed along the primary fiber directions for each of the tested muscles as described by previous investigators¹⁶ (Figures 1 and 2).

Kinematics

Kinematic data for shoulder and elbow movements were collected at a 100-Hz sampling rate using an 8-camera system (Vicon Motion Systems, Centennial, CO), and these data were synchronized with EMG recordings in Vicon. Reflective markers were attached to the bony landmarks according to a previously established model of upper body reflective-marker placement.^{17,18} Shoulder-movement data were used to represent shoulder positions throughout each trial sequence. Elbow-movement data were used as a reference for quantifying EMG latencies.



Figure 2. Posterior view of electrode and marker placement.

Functional Maximum Contraction

The EMG electrode placements were confirmed by asking the participants to perform each muscle's intended action. Afterward, 2 functional maximum contractions (FMCs) were performed for each muscle using specific position techniques,^{16,19} with manual resistance applied against the segment's movement direction. For the FMCs, the participants were asked to push against the examiner's resistance applied in a break-test fashion, resulting in an isometric contraction.¹⁹ The participants were instructed to gradually increase their push toward maximum force and then encouraged to sustain the FMC for 5 seconds, followed by gradually releasing the force.²⁰ Between FMC trials, each person was allowed 5 seconds of rest.

Shoulder Movements

Each participant performed D1F and scaption with and without ABM, as well as with and without resistance, for a total of 4 conditions: (1) no ABM, no resistance; (2) no ABM, resistance; (3) yes ABM, no resistance; and (4) yes ABM, resistance. Each ABM-resistance combination was performed a total of 3 times throughout the experiment in each movement direction, resulting in 24 trials performed in a random sequence. The participant ceased movement through the specific pattern when the upper arm touched the chin (for D1F) or when the elbow reached the participant's eye level (for scaption). Participants were asked to keep their eyes looking forward during all trials.



Figure 3. Means of muscle latencies across conditions during D1 shoulder flexion. Error bars = 95% confidence intervals. Abbreviations: AD, anterior deltoid; LT, lower trapezius; NBNR, no brace, no resistance; NBYR, no brace, yes resistance; PD, posterior deltoid; SA, serratus anterior; UT, upper trapezius; YBNR, yes brace, no resistance; YBYR, yes brace, yes resistance.

Data Analysis

All raw EMG and kinematic data were converted to numeric text files and managed using a custom analysis program written in MATLAB (version 7.10.0; The Math-Works, Inc, Natick, MA). The EMG amplitudes and muscle latencies were determined for the AD, PD, UT, LT, and SA muscles of the dominant upper limb. The EMG amplitudes were determined for the EO1, EO2, and IO muscles as well. Before we calculated EMG amplitudes (root mean squares [RMSs]), all raw EMG data were high-pass filtered using a fourth-order, no-phase-shift Butterworth filter with a highpass cutoff set to 30 Hz to minimize cardiac myoelectrical interference.²¹ Filtered EMG data were then normalized using the greater of the 2 FMCs for each muscle during the experimental conditions. This provided a reference standard for each muscle's myoelectrical activity during the experimental trials, in which all EMG data from the trials were reported as a percentage of the FMC value. After normalization, RMS EMG values were calculated using the following formula:

$$RMS = \sqrt{(mean(x^2))},$$

where x is the amplitude datum for a particular condition. Then, the mean RMS EMG values were established for each muscle across the participant's 3 trials of the same condition. For muscle latencies, the *initial activation onset* of each muscle was defined by the signal-inflection point according to Dedrick et al.²² The muscle-onset times were analyzed relative to the initial elbow movement. Therefore, latencies were calculated as the difference (in milliseconds) between the initial elbow-movement time and each muscle-onset time during movement initiation. Negative latencies represented muscle activation before elbow movement, whereas positive latencies represented muscle activation after elbow movement. Each muscle-onset event was determined using a custom algorithm and was visually inspected by an investigator to ensure onset-timing face validity.

Statistical Analysis

Central tendency and dispersion values were computed for all descriptive amplitude and muscle-onset data. A Shapiro-Wilk test was used to assess violations of normality. An assessment of parametric assumptions revealed that the amplitude and latency variables were not normally distributed and, therefore, the data were analyzed with nonparametric tests.

To indicate that participants were sufficiently bracing during the VPAC conditions, we conducted Wilcoxon signed-rank tests on the EO1, EO2, and IO muscle amplitudes during the no-VPAC versus VPAC conditions. To investigate the effects of VPAC and resistance on muscle amplitudes, we calculated Wilcoxon signed-rank

Table 1. Average Electromyographic Amplitude Activity for All Participants (N = 22) by Condition for D1 Shoulder Flexion (D1F) and Scaption^a

Movement	Muscle	Condition, Mean ± SD			
		NBNR	NBYR	YBNR	YBYR
Movement D1F Scaption	AD	26.9 ± 19.1	32.4 ± 23.8	24 ± 20.2	38.5 ± 23.7
	PD	919.3 ± 3446.8	1096 ± 4107.5	1014.3 ± 3889.2	1036.4 \pm 3831.9
	UT	$\textbf{38.8} \pm \textbf{43.1}$	61.5 ± 66	38.2 ± 45.3	61 ± 75
	LT	23.8 ± 41.6	$39.5~\pm~70.3$	25 ± 40.4	38.5 ± 23.8
	SA	8.5 ± 7	21.4 ± 13.1	11.2 ± 7.6	31± 23.8
Scaption	AD	15.9 ± 12.9	31.6 ± 20.1	15.2 ± 14.8	31 ± 20.2
	PD	931.3 ± 3683	1446.7 ± 5678	1216.5 ± 4968.3	1667.3 ± 6650.80
	UT	52.3 ± 63.6	$88.6~\pm~90.3$	65.9 ± 84.5	113.7 ± 133.1
	LT	14.3 ± 25.9	29.1 ± 45.1	10.2 ± 13.2	28.5 ± 38.7
	SA	26 ± 20.2	52.7 ± 34.7	40.8 ± 28.5	71.6 ± 51.8

Abbreviations: AD, anterior deltoid muscle; LT, lower trapezius muscle; NBNR, no brace, no resistance; NBYR, no brace, yes resistance; PD, posterior deltoid muscle; SA, serratus anterior muscle; UT, upper trapezius muscle; YBNR, yes brace, no resistance; YBYR, yes brace, yes resistance.

^a All electromyographic amplitude data are reported as a percentage of the functional maximum contraction value.

tests to identify significant differences between the no-VPAC and VPAC conditions and between the no-resistance and resistance conditions for each tested muscle (AD, PD, UT, LT, and SA) during each movement direction (D1F and scaption; $\alpha = .01$). The familywise α level adjustment, $\alpha = .01$, allowed the type I error rate to remain at .05 across all 5 tests.

An intraclass correlation coefficient (3,1) was used to assess the investigator's reliability in identifying the muscle onsets. To assess the effects of VPAC on muscle latencies, we conducted Wilcoxon signed-rank tests to identify significant differences between the no-VPAC and VPAC conditions during each movement direction (D1F and scaption; $\alpha = .05$).

RESULTS

Data were collected from 22 participants (10 women, 12 men). The mean age of participants was 24.6 ± 2.8 years and mean height and weight were 172.1 ± 12.8 cm and 71.7 ± 16.7 kg, respectively.

The participants' ability to adequately perform the ABM was represented by the Wilcoxon signed-rank test results, which showed increased EMG amplitudes in EO2 and IO

Table 2. Wilcoxon Signed-Rank Tests for Amplitudes During D1 Shoulder Flexion (D1F) and Scaption, No-Brace Versus Braced Conditions

Movement	Muscle	T Value	P Value	r Value ^a
D1F	AD	483.0	.496	0.10
	PD	432.5	.466	-0.11
	UT	293.0	.047	-0.30
	LT	619.5	.146	0.22
	SA	756.0	<.001 ^b	0.57
Scaption	AD	280.0	.566	-0.09
	PD	645.0	.080	0.26
	UT	758.0	<.001 ^b	0.51
	LT	378.5	.254	-0.17
	SA	930.0	<.001 ^b	0.77

Abbreviations: AD, anterior deltoid muscle; LT, lower trapezius muscle; PD, posterior deltoid muscle; SA, serratus anterior muscle; UT, upper trapezius muscle.

^a r = effect size.

^b Significant result at $\alpha = .01$.

in the ABM conditions during the D1F movement, with and without resistance. Similarly, increased EMG amplitudes occurred in EO2 and IO in the ABM conditions during scaption, with and without resistance. Moreover, the VPAC condition produced increased EO1 EMG amplitudes during scaption without resistance but not with resistance.

With respect to hypotheses 1 and 2, the effects of VPAC and resistance on each muscle during both the D1F and scaption trials were tested. For D1F, the VPAC versus no-VPAC data revealed higher amplitudes for the SA during the VPAC condition (Tables 1 and 2). For scaption, the VPAC versus no-VPAC data demonstrated higher amplitudes for both the UT and the SA during the VPAC condition (Tables 1 and 2). Data analysis of the noresistance versus resistance conditions showed higher amplitudes during the latter in all muscles (AD, PD, UT, LT, SA) in both D1F and scaption (Tables 1 and 3). For further analysis, parametric tests were conducted. Results of the parametric and nonparametric tests were identical for the effects of VPAC, with no interaction between VPAC and resistance in the parametric assessment.

Reliability analysis of EMG onset detection showed that the investigator was highly reliable in selecting muscleonset timing for the latency calculations (intraclass

Table 3. Wilcoxon Signed-Rank Tests for Amplitudes During D1 Shoulder Flexion (D1F) and Scaption, No-Resistance Versus Resistance Conditions

Movement	Muscle	T Value	P Value	r Value
D1F	AD	742.0	<.001 ^b	0.61
	PD	774.0	.001 ^b	0.49
	UT	868.0	<.001 ^b	0.80
	LT	990.0	<.001 ^b	0.87
	SA	980.0	<.001 ^b	0.84
Scaption	AD	735.0	<.001 ^b	0.80
	PD	990.0	<.001 ^b	0.87
	UT	902.0	<.001 ^b	0.85
	LT	990.0	<.001 ^b	0.87
	SA	980.0	<.001 ^b	0.85

Abbreviations: AD, anterior deltoid muscle; LT, lower trapezius muscle; PD, posterior deltoid muscle; SA, serratus anterior muscle; UT, upper trapezius muscle.

^a r = effect size.

^b Significant result at $\alpha = .01$.

Table 4. Average Latency Data for All Participants (N = 22) by Condition for D1 Shoulder Flexion (D1F) and Scaption^a

Movement	Muscle	Condition, Mean \pm SD			
		NBNR	NBYR	YBNR	YBYR
D1F	AD	0.02 ± 1.03	0.01 ± 1.01	-0.69 ± 1.08	-0.81 ± 0.97
	PD	-0.23 ± 0.26	-0.38 ± 0.69	-0.64 ± 0.76	-0.64 ± 0.69
	UT	0.14 ± 0.36	-0.14 ± 0.66	-0.56 ± 0.89	-0.53 ± 0.68
	LT	-0.02 ± 0.48	-0.29 ± 0.77	-0.55 ± 1.28	-0.74 ± 1.03
	SA	0.02 ± 0.48	-0.30 ± 0.77	-1.00 ± 1.28	-0.67 ± 1.03
Scaption	AD	0.14 ± 1.01	0.07 ± 0.82	-0.72 ± 1.40	-0.87 ± 1.13
	PD	-0.17 ± 0.14	-0.20 ± 0.39	-0.72 ± 0.80	-0.56 ± 0.70
	UT	-0.04 ± 0.27	0.04 ± 0.39	-0.60 ± 0.83	-0.61 ± 0.71
	LT	-0.17 ± 0.42	-0.15 ± 0.47	-0.67 ± 0.98	-0.72 ± 0.83
	SA	-0.04 ± 0.71	0.04 ± 0.72	-1.08 ± 1.24	-0.86 ± 1.16

Abbreviations: AD, anterior deltoid muscle; LT, lower trapezius muscle; NBNR, no brace, no resistance; NBYR, no brace, yes resistance; PD, posterior deltoid muscle; SA, serratus anterior muscle; UT, upper trapezius muscle; YBNR, yes brace, no resistance; YBYR, yes brace, yes resistance.

^a All electromyographic latencies were calculated as the difference in the time interval (in milliseconds) between initial elbow-movement time and each muscle-onset time during movement initiation.

correlation coefficient [3,1] = 0.96). With respect to hypothesis 3, the effects of VPAC were tested by condition for both the D1F and scaption directions. For D1F and scaption, latencies for the AD, PD, UT, LT, and SA muscles were decreased during selected VPAC conditions (Tables 4 and 5). In addition to decreasing, the muscle latencies clustered closer together during the VPAC conditions (Figures 3 and 4).

Statistical analysis revealed large standard deviations in the data. In most cases, the standard deviations were larger than the differences in conditions. We concluded that this could be the result of including outliers in the analysis. The data sets of the different conditions showed several outliers. Outliers can increase standard deviations; however, in order to keep the data in their original form, we maintained every data point, including the outliers.

DISCUSSION

Contrary to traditional exercise and training approaches, contemporary clinicians may choose to implement VPAC strategies into shoulder-movement activities and exercise protocols in preparation for participating in upper extremity-dominant activities. McMullen and Uhl¹ reported that optimizing lower extremity and trunk activation assisted in

Table 5.Wilcoxon Signed-Rank Tests for Latencies During D1Shoulder Flexion (D1F) and Scaption, No-Brace Versus BracedConditions

Movement	Muscle	T Value	P Value	<i>r</i> Value ^a
D1F	AD	71.0	<.001 ^b	-0.70
	PD	267.0	.008 ^b	-0.40
	UT	208.0	.001 ^b	-0.51
	LT	261.0	.006 ^b	-0.41
	SA	180.0	.001 ^b	-0.52
Scaption	AD	80.5	<.001 ^b	-0.65
	PD	262.0	.007 ^b	-0.41
	UT	164.0	<.001 ^b	-0.58
	LT	168.0	<.001 ^b	-0.58
	SA	37.0	<.001 ^b	-0.81

Abbreviations: AD, anterior deltoid; LT, lower trapezius; PD, posterior deltoid; SA, serratus anterior; UT, upper trapezius.

^a r = effect size.

^b Significant result at $\alpha = .01$.

normalizing upper extremity movement patterns and reducing challenges in learning new movements. However, no authors to date have measured the effects of VPAC on shoulder function in normal, active participants. Our investigation showed that VPAC overall affected muscle amplitudes and latencies differently for each investigated movement direction.

Except for the SA during D1F and the UT and SA during scaption, our findings suggest that VPAC had no other effect on muscle amplitude. Although our first hypothesis was only partially supported, our results indicated that VPAC's effects were apparent on the scapulothoracic muscles (UT and SA) that have the greatest roles in stabilizing the scapula during open chain movements. To our knowledge, no other investigators have examined these effects during open chain upper extremity elevation. Vega Toro et al²³ discovered that conscious abdominal muscle contraction increased SA amplitude during isometric and dynamic closed chain shoulder exercises. Similarly, Ludewig et al²⁴ and Maenhout et al²⁵ demonstrated that abdominal-activation exercises increased EMG SA amplitude while maintaining low UT amplitude. They concluded that closed chain upper extremity activities were beneficial for SA strengthening without overly activating the UT.

We observed an increase in SA EMG amplitude with VPAC in both movement directions, accompanied by increased UT during scaption (Tables 1 and 2). The UT must elevate the clavicle and upwardly rotate the scapula during open chain scaption.⁹ Similarly, the SA functions to upwardly rotate, protract, depress, and fix the scapula to the thorax. The SA and UT are the main stabilizing muscles of the scapulothoracic joint, serving to secure the scapula against the thoracic wall.²⁶ These muscles act synergistically to allow for the appropriate scapulothoracic rhythm, which is essential to maintain scapulohumeral muscle length-tension relationships and normal shoulder biomechanics during humeral elevation.²⁴ Each muscle must perform its synergistic role in order to optimize scapulothoracic movements.⁹ Our UT findings may be related to the open chain movement and the muscle's requirement to synergistically stabilize the scapula while promoting full clavicular elevation.

Our results demonstrated that resistance did not enhance an increase in amplitude caused by VPAC. As expected, we



Figure 4. Means of muscle latencies across conditions during scaption. Error bars = 95% confidence intervals. Abbreviations: AD, anterior deltoid; LT, lower trapezius; PD, posterior deltoid; NBNR, no brace, no resistance; NBYR, no brace, yes resistance; SA, serratus anterior; UT, upper trapezius; YBNR, yes brace, no resistance; YBYR, yes brace, yes resistance.

observed an increase in the amplitudes of all muscles with resistance during both D1F and scaption (Tables 1 and 3). This finding supports the results of a previous study²⁷ on the influence of resistance on EMG amplitudes during shoulder movements in different populations.

With respect to our third hypothesis, comparisons of different muscles' onset timings are often used to represent neuromotor coordination and control around a joint system when a movement is initiated.²⁸ We noted a difference in onset timings between the 2 VPAC conditions in both D1F and scaption (Tables 4 and 5), demonstrating a decrease in selected onset latencies for every muscle during the VPAC conditions. These tenths-of-millisecond differences led to increased muscle-activation clustering, and muscle-onset times appeared to cluster closer together during the VPAC conditions (Figures 3 and 4). Most important, this may reflect an increase in shoulder-complex stability, whereby decreased muscle latencies and earlier muscle-onset time clusters can improve joint stability during movement.²⁶

Previous investigators demonstrated that ABM had stabilizing effects on the trunk,⁸ increasing antagonist muscle cocontraction in response to a sudden perturbation.²⁹ Muscle cocontraction, or a simultaneous antagonistic muscle activation across a joint, helps to maintain joint stability by augmenting the ligament function, providing resistance to joint rotation, and equalizing articular surface pressure distribution.³⁰ Our findings confirm that VPAC conditions increased abdominal activation, suggesting that

trunk stabilization was increased. Moreover, the VPAC supported a stabilizing effect beyond the immediate trunk locale by increasing the amplitudes and decreasing the latencies of important scapular stabilizing muscles.

In addition to the previous results that pertain to our study purpose, we noted a finding that is worthy of discussion. During the VPAC condition, EO1 EMG amplitudes increased during scaption without resistance but not with resistance. When resistance was added during this movement, the external oblique on the ipsilateral side (EO1) was not able to increase its amplitude. Perhaps the resistance caused this ipsilateral muscle to reach the "ceiling" of its muscular output and no further activity could be appreciated during the VPAC condition.

LIMITATIONS

Although our results could be beneficial to practicing clinicians concerning the use of VPAC during upper extremity movement, we focused only on D1F and scaption. It is not certain that the same results would occur with other upper extremity movements and, therefore, the results can be applied only to performing D1F and scaption.

Rotator cuff EMG data were not collected in the current study and, thus, differences in or consequences on shoulder-complex stability and function in response to VPAC cannot be fully elucidated. Moreover, the scapulothoracic and glenohumeral muscles act differently to elevate and lower the shoulder. In this study, we collected EMG data only during shoulder elevation. Hence, to further explain how VPAC affects complete upper extremity movement, future EMG studies should include rotator cuff function and measurements during shoulder-lowering phases. In addition, we recognize that the participants' age range could have influenced the study's outcome, as younger individuals may have better trunk-muscle function than older individuals. Therefore, the results of the study are limited to the participants' age group and cannot be generalized to individuals of all ages, inspiring future research that will address other age groups.

We did not evaluate the effects of VPAC on upper extremity movement in a group with shoulder injuries, so any inferences to that group must be established in future studies.

CONCLUSIONS

This study was conducted to examine the effects of VPAC on shoulder-muscle function. Analysis showed that VPAC had no effect on the AD, PD, or LT muscle amplitudes but affected muscle latencies of every muscle during selected VPAC conditions. Specifically, VPAC increased the SA muscle amplitude during D1F and the SA and UT muscle amplitudes during scaption. The AD, PD, and LT amplitudes were not increased during VPAC during the scaption or the D1F movements. Although our findings coincide with those of other investigators with respect to the parascapular response to resistance, we saw no accompanying deterioration in parascapular control responses when participants performed the same movements with VPAC. Thus, it is possible for individuals to incorporate VPAC during D1F and scaption movements to promote a stable trunk during upper extremity control without significant negative consequence on the parascapular muscle responses. Future authors should examine the influence of VPAC on trunk perturbation during dynamic upper extremity movements with and without resistance. To extend this knowledge, future research that incorporates participants with shoulder injuries is warranted.

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