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Published in:
Journal of bodywork and movement therapies

DOI:
10.1016/j.jbmt.2023.11.033

Journal of Bodywork & Movement Therapies 37 (2024) 332–343

Contents lists available at ScienceDirect

Journal of Bodywork & Movement Therapies

journal homepage: www.elsevier.com/jbmt

Effect of verbal instructions on trunk muscle activity during volitional preemptive abdominal contraction

Andrew Ward [a,b], Alexander Drusch [b], Yo-Rong Chen [c], Mark Ouellette [b], Jean-Michel Brismée [b], Troy Hooper [b], Katherine Wilford [b,f], Gesine H. Seeber [b,d,e], Phillip S. Sizer Jr. [b,*]

[a] Department of Physical Therapy, Missouri State University, Springfield, MO, USA
[b] Center for Rehabilitation Research, Texas Tech University Health Sciences Center, Lubbock, TX, USA
[c] Department of Health Science Professions, Angelo State University, San Angelo, TX, USA
[d] University Hospital of Orthopedics and Trauma Surgery Pius-Hospital Oldenburg, University of Oldenburg, School of Medicine and Health Sciences, Oldenburg, Germany
[e] University of Groningen, University Medical Center Groningen, Department of Orthopedics, Groningen, the Netherlands
[f] Physical Therapy Program, Murphy Deming College of Health Sciences, Mary Baldwin University, Fishersville, Virginia, USA

ARTICLE INFO

Handling Editor: Dr Jerrilyn Cambron

Keywords:
Psychomotor
Skill acquisition/Retention
Core stabilization
Abdominal muscles
Electromyography
Imagery

ABSTRACT

Objective: This study investigated the effect of Verbal Instruction (VI) strategies on trunk muscle contraction among healthy subjects. The effect of three VI Abdominal Drawing-In Maneuver (ADIM) and two VI Abdominal Bracing Maneuver (ABM) strategies on left Internal (LIO) and External Oblique (LEO) and bilateral superficial Multifidi (sMf) activation was examined.
Design: Within-subjects, repeated measure design.
Methods: Surface EMG (sEMG) measured LIO, LEO, and sMf activity in 28 subjects (mean age 23.5 $\pm$ 5.5 years). Testing included five supine hook-lying and five quiet standing conditions.
Results: One-way ANOVAs demonstrated no significant main effect for ADIM or ABM in supine or standing ($p > .05$). Muscle activation amplitudes during VPAC conditions demonstrated higher mean values for standing versus supine ($p < .05$) except for two conditions involving LEO. Friedman Tests for dominant strategy demonstrated a significant main effect for ADIM-VI and ABM-VI strategies. Post-hoc testing generally showed the dominant strategy to be significantly higher versus others.
Conclusion: No single preferred VI cue for ADIM or ABM was observed. Each subject's dominant strategy dictated the most suitable VI. Standing was preferred for LIO and sMf activation, whereas position did not change LEO activation. Non-significant correlations between all muscle pairings during all ADIM and ABM strategies were observed. These findings may suggest the need for healthcare providers who understand the intricacies of trunk stability to teach and monitor VPAC with either ADIM or ABM options.

1. Background

Low back pain (LBP) is the leading cause of disability worldwide and responsible for billions of dollars in medical expenditures and lost labor costs(Teyhen et al., 2007). If no structural findings correlate with complaints, the condition is referred to as non-specific LBP (NSLBP)(van Tulder et al., 1997). Spinal dysfunction alters trunk neuromuscular control, which is thought to be a contributing factor to NSLBP risk and development(Hodges and Richardson, 1999; Teyhen et al., 2009). However, growing evidence supports the use of the abdominal muscles and multifidus (Mf) muscles for enhancing lumbar spine neuromuscular control and risk reduction(Beith et al., 2001; Henry and Westervelt, 2005; Hides et al., 2011; Hodges and Richardson, 1997; Matthijs et al., 2014; O'Sullivan et al., 1997; Teyhen et al., 2005).

Coordinated activation of the transverse abdominis (TrA), Mf, external oblique (EO), and longissimus muscles appears to improve trunk neuromuscular control and reduce injury risk(Haddas et al., 2016a; Vera-Garcia et al., 2007). Clinicians instruct patients to use volitional preemptive abdominal contraction (VPAC) to activate these muscles with varying results.

* Corresponding author.Department of Rehabilitation Sciences, Texas Tech University Health Sciences Center, ScD Program in Physical Therapy, Center for Rehabilitation Research, 3601 4th St: STOP 6226, Lubbock, TX, 79430-6226, USA.
E-mail address: phil.sizer@ttuhsc.edu (P.S. Sizer).

https://doi.org/10.1016/j.jbmt.2023.11.033
Received 9 February 2022; Received in revised form 1 October 2023; Accepted 15 November 2023
Available online 26 November 2023

The abdominal bracing maneuver (ABM) and the abdominal drawing-in maneuver (ADIM) are two VPAC approaches that have been heavily examined. Both approaches increase lumbopelvic neuromuscular control through trunk muscle activation(Grenier and McGill, 2007). However, some differences between ADIM versus ABM exist, suggesting one approach may better serve certain subpopulations over the other. The ADIM primarily results in a co-contraction of TrA and Mf without heavily increasing spinal segmental compression(MacDonald et al., 2006; Matthijs et al., 2014; Teyhen et al., 2009). The ABM adds the EO and longissimus muscles to the trunk contractile response, producing a 32% increase in spinal segmental stability and 15% increased segmental compression over the ADIM(Grenier and McGill, 2007). Individuals who exhibit acute symptoms that flare with increased segmental compression may benefit from the ADIM over the ABM, (Grenier and McGill, 2007) while the ABM may be more appropriate for patients who are advanced in their rehabilitation process to include more physically aggressive movements. Thus, it is important for rehabilitation professionals to identify and optimize the patient's preferred VPAC recruitment strategy(Teyhen et al., 2009).

Due to the isometric nature of VPAC, clinicians may rely on verbal and tactile cueing to assist patients in eliciting recruitment. Verbal instructions (VI) for specific muscle activation have been effective at increasing activity or force production by gluteus maximus, hamstrings, and triceps during a variety of tasks(Lewis and Sahrmann, 2009; Paoli et al., 2019; Turner et al., 2018). One study demonstrated that trunk muscle activation increased during a loaded squat when VI was added to the task(Bressel et al., 2009). However, the authors did not assess the co-contractive Mf response to VI. Wang-Price et al. reported increased lumbar Mf thickness in LBP patients and asymptomatic individuals during three VI conditions(Wang-Price et al., 2017). The VI strategies used, however, were not specific to the abdominal region. Moreover, different VPAC approaches were not addressed. To date, there is little evidence identifying the VI strategy most appropriate for maximizing co-contractive abdominal and Mf muscle responses during ADIM and ABM performance.

In addition to VI, body position is another factor to possibly influence trunk muscle activation that is worthy of investigation. Urquhart et al. demonstrated that body position impacts a person's abdominal recruitment(Urquhart et al., 2005). They learned that quiet standing facilitated a higher abdominal contractility versus supine hook-lying, due to an increased proprioceptive response to weightbearing(Jung et al., 2014; Snijders et al., 1995). However, there is a dearth of data quantifying the body position's influence on trunk muscle response to volitional activation strategies(Matthijs et al., 2014).

Therefore, this study aspired to compare three VI strategies when performing ADIM and two VI strategies when performing ABM. This comparison aimed to examine: (1) the effect of VI strategy on internal oblique (IO) and external oblique (EO) activation; (2) the influence of body position on trunk muscle response while performing ADIM and ABM; and (3) the effect of the VI strategy on Mf co-contraction during the same VPAC approaches. The study incorporated the following hypotheses. First, different VI strategies would produce different contractile responses in specific trunk muscles (IO, EO, and Mf) during ADIM (Hypothesis 1a; H1a) and ABM performance (Hypothesis 1b; H1b), respectively. Second, body position (lying versus standing) would significantly influence abdominal and Mf muscle activation during different VI strategies (Hypothesis 2; H2). Third, to further understand co-contractive responses, IO and EO contractile performance would exhibit a positive relationship with Mf contractions during different VI-cued VPAC execution (Hypothesis 3; H3).

2. Methods

This within-subjects cohort investigation examined the effect of different VI strategies on trunk muscle contraction performance among subjects without a history of LBP. A 2 (postural positioning) x 3 (ADIM-VI strategy) within subjects, repeated-measures design was used to test Hypotheses **1a** and **2** for using the ADIM approach. Similarly, a 2 (postural positioning) x 2 (ABM-VI strategy) within subjects, repeated-measures design was used to test Hypotheses **1b** and **2** for ABM use. Finally, a correlation design tested Hypotheses **3**. All study procedures followed the Declaration of Helsinki ethical principles. In accordance, data collection was approved prior to initiation by the local university Institutional Review Board for Protection of Human Subjects (Approval #-L14-036). Prior to enrollment eligible subjects were informed of risks and benefits and then signed an approved informed consent.

2.1. Participants

Based on a medium effect size (f = 0.2), an alpha level of 0.05, and 80% power, a convenience sample of 28 asymptomatic male and female subjects between the ages of 18–65 were recruited from a local university and the general public(Portney, 2020).

2.2. Inclusion and exclusion criteria

Eligible subjects met the following inclusion criteria: (1) ability to stand independently without complaints; (2) ability to maintain a supine position without complaints; and (3) cognitive and language competence to follow English language directions(McGalliard et al., 2010; Nagar et al., 2014). Subjects were excluded from the study if they presented with: (1) Existing active spinal pain (including LBP); (2) History of diagnosed LBP within the past 12 months requiring professional health-care management; (3) Any diagnosed and presently active abdominal, respiratory or gastrointestinal condition; (4) A history of spinal and or abdominal surgery; (5) Pregnancy by self-report; (6) Significant spinal deformity or condition to include scoliosis, spina bifida, diagnosed spinal pathologies, tumors, present fractures, or rheumatologic disorders; (7) Known neurological or joint disease affecting the trunk; (8) Current urinary tract infection; (9) Hearing loss that prevents receiving and interpreting VI instructions; or (10); Body mass index (BMI) ≥30(McGalliard et al., 2010; Nagar et al., 2014).

2.3. Preparatory procedures

After reading and signing the approved informed consent form, subjects completed a medical history questionnaire to confirm individual enrollment eligibility. Next, subjects watched an instructional video explaining all experimental procedures. Following, investigators recorded subjects' demographic data including weight, height, and BMI.

Subjects were then instructed on proper ADIM and ABM performance both in supine hook-lying and quiet standing positions. Each subject's ability to volitionally activate the abdominals during both VPAC maneuvers was assessed during three 5-s hold contraction attempts in both positions and for both VPAC conditions. Proper performance was confirmed by an experienced clinician palpating subjects' abdominals just medial to their anterior superior iliac spines. The confirmation ADIM command was "breathe in, purse your lips and blow out like you are blowing out a candle." The confirmation ABM command was "bear down as though you are straining with a bowel movement". These confirmation commands were different from those during data collection so to avoid greater familiarity with one set of verbal cues over another.

A freestanding EMG system (MA-300, Motion Lab Systems, Baton Rouge LA, USA) was used for electromyographic data collection. Surface EMG data were collected with wired, pre-amplified surface EMG electrodes (MA-411, Motion Lab Systems, Baton Rouge LA, USA) from the left EO, IO and bilateral superficial Mf. Electrode placement and signal sampling followed previous investigators' recommendations for examining muscle activation patterns associated with VPAC(Butler et al., 2009; Jamison et al., 2013; Larivière et al., 2002; Marshall and Murphy, 2003). All myoelectric data in the present study were sampled and

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recorded at 2000 Hz(Hodges and Bui, 1996). The EMG impedance was >10 MΩ[5], accompanied by a common mode rejection ratio >100 dB and baseline noise <1.2 μV root-mean-square. One bout each of ADIM and ABM were used to visually confirm proper abdominal muscle activations.

To normalize EMG data across subjects, sub-maximal reference trunk muscle activation trials were performed as previously described(Dankaerts et al., 2004). For ventral trunk muscle normalization, subjects performed three consecutive trials of lifting their feet 2 cm off the table surface from a hook-lying position, holding that position for 3 s. For dorsal trunk muscle normalization, subjects performed three consecutive 10-s end-range hold trials of lifting their flexed (90-degrees) knees 5 cm off the table from a prone-lying position.

2.4. Data collection procedures

Subjects were instructed to perform a specific VI strategy associated with each VPAC approach while positioned in supine hook-lying. For each of the following VI cues, the subject was then instructed to take in a deep breath, then exhale and hold the exhalation while performing a self-selected appropriate volitional contractile response, beginning at the time they completed their exhalation(McGalliard et al., 2010; Teyhen et al., 2005). The strategies were as follows:

ADIM-VI B-Strategy "Pull your belly button up and in towards your shoulder blades," while the tester palpated the umbilicus. This VI was used for Conditions 1 and 6.
ADIM-VI S-Strategy: "Pull your abdominal muscles away from front elastic on the shorts," while the tester pointed to shorts' elastic. This was used for Conditions 2 and 7.
ADIM-VI A-Strategy: "Pull the two front pelvic bones together," while the tester palpated the ASIS's. This was used for Conditions 3 and 8.
ABM-VI P-Strategy: "Prepare to be punched in the belly." This was used for Conditions 4 and 9.
ABM-VI W-Strategy: "Make your waist wide," while the tester placed the subject's first web spaces over their own waist between the iliac crests and lower ribs. This was used for Conditions 5 and 10.

We hypothesized the best ADIM VI to be "Pull your belly button up and in towards your shoulder blades" and the best ABM VI to be "Prepare to be punched in the belly."

For data collection, EMG signals were obtained in each of the 10 conditions. The individual task contractions were held for a total of 10 s and performed for three repetitions per condition. A 10-s recovery period between each contraction allowed subjects to recalibrate and prepare for the next contraction. Subjects were instructed to perform each of the three ADIM tasks and two ABM tasks while in supine hook-lying and standing positions. The supine hook-lying position placed the subject on their back, the head over a thin pillow, the arms placed alongside the torso, the hips at approximately 40–60 degrees of flexion and the knees at approximately 90–100 degrees of flexion with feet flat on the mat. The quiet standing position was maintained with the feet at shoulder width apart, knees extended, hips and lumbar spine in neutral and arms down alongside the torso. To limit subject position changes, all supine tasks were performed together, and all standing tasks were performed together. To control for order effect, we used a randomization table to finalize (1) positioning (supine versus standing) and (2) order of performed tasks (ADIM for 3 conditions versus ABM for 2 conditions).

3. Data reduction and statistical analyses

Following data acquisition, all EMG data were exported into a proprietary Matlab program (MATLAB ver 2018b, MathWorks, Natic, MA) where they were band-pass filtered (20–400Hz) using a 4th-order, two-pass, Butterworth filter. The EMG signal's average root mean square (RMS-EMG) for each sub-maximal muscle contraction was calculated from the last 3 s of the subject's 10-s contraction. The RMS-EMG value was then calculated for each trunk flexor and extensor trial contraction and reported as a percentage of the sub-maximal reference contraction values (or "RMS-EMG%").

Statistical analyses were conducted using the SPSS (v.22 for Windows). Descriptive central tendency (means) and dispersion (standard deviation and 95% confidence intervals (CI)data were established for subject demographics and dependent variable data. Data normality was established using skewness and kurtosis (between −2.0 and + 2.0), as well as the Shapiro-Wilk test (W statistic >0.80 and p-value >.05). Moreover, sphericity (Mauchly's Test; p-value >.05) was examined to test for variances of the differences between all possible pairs of within-subject conditions used for ADIM comparisons.

For research hypotheses 1a and 2 (regarding ADIM), a 2(position) X 3(ADIM-VI strategy) ANOVA was used to test for significant interactions and main effects between each condition's RMS-EMG% values for each muscle (IO, EO, LMf and RMf). Post-hoc pairwise comparisons with a Bonferroni adjustment were used to locate significant differences. For research hypotheses 1b and 2 (regarding ABM), a 2(position) X 2(ABM-VI strategy) ANOVA tested for significant interactions and main effects between each condition's RMS-EMG% values for each muscle (IO, EO, LMf and RMf). Post-hoc pairwise comparisons with a Bonferroni adjustment were used to locate significant differences. Family-wise alpha corrections ($\alpha = 0.0125$) were incorporated during ANOVA testing to reduce the risk of Type-I error. For research hypotheses 3, a Pearson-product moment correlation was used to measure the relationship between the IO and EO RMS-EMG% with the Mf RMS-EMG% during the different VPAC approaches. Significance was set at $\alpha = .05$.

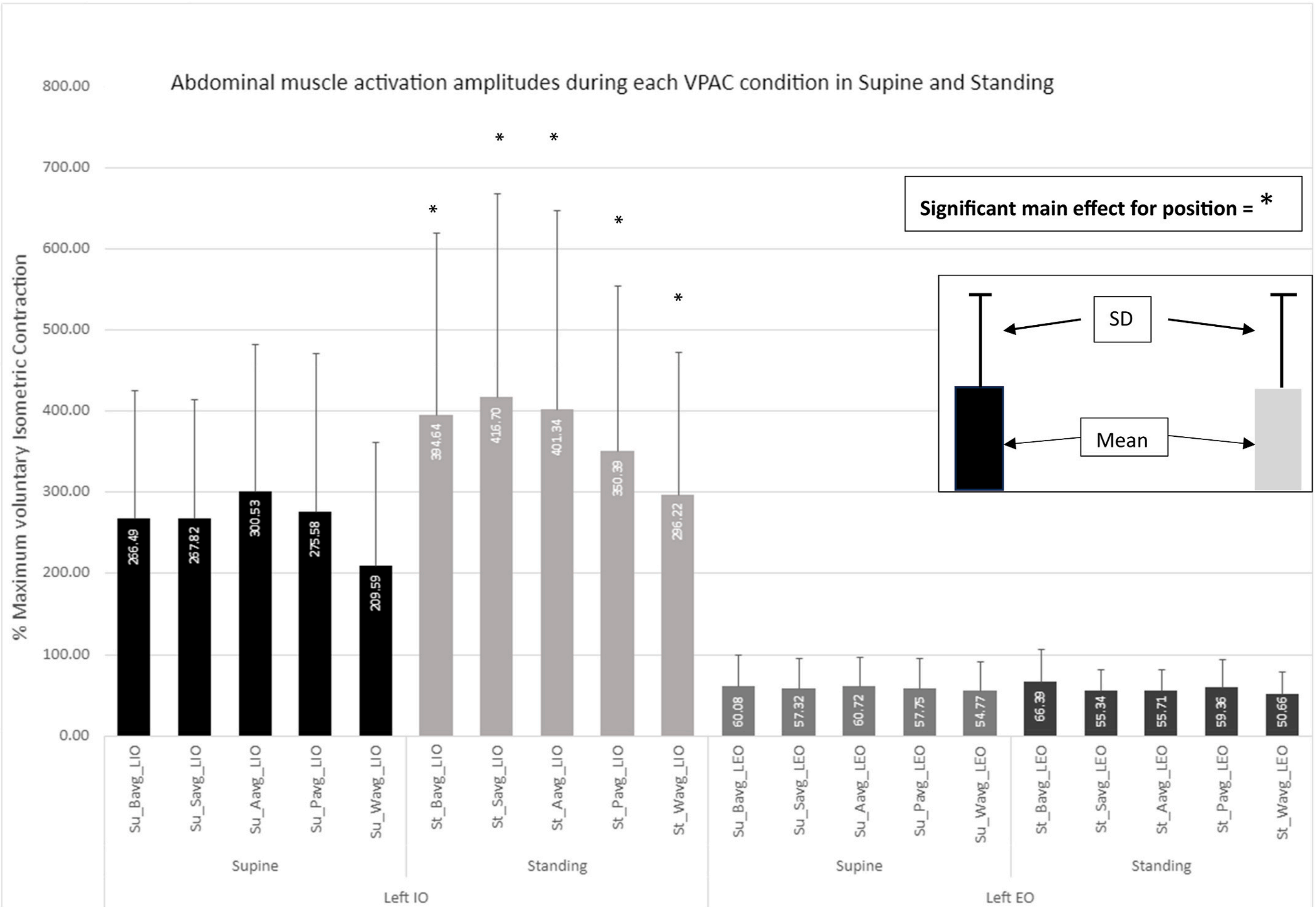
To better understand the most dominant VI strategy for a given subject during ADIM and ABM approaches, unplanned exploratory data analyses were conducted that further examined the effects of VI strategy on muscle contraction amplitude. For that, subjects were separated into subgroups by each VI strategy for each muscle examined (LEO, LIO, LMf and RMf) in supine and standing. A subject's subgroup assignment was based on which strategy produced the highest RMS-EMG% value for the three ADIM-VI strategies (strategies B versus S versus A) and then for the two ABM-VI strategies (strategies P versus W) in supine and standing. Non-parametric repeated measures within-subjects' comparisons were subsequently conducted for each subgroup, comparing the RMS-EMG% means of each ADIM-VI strategy within each subgroup. For ADIM-VI strategies in both supine and standing, a Friedman Test was used to test for main effects ($\alpha = .0125$), followed by a post-hoc Wilcoxon Sign-Ranked Test used to locate significant differences ($\alpha = 0.05$) within each of the three ADIM subgroups. For ABM-VI strategies in both supine and standing, a Wilcoxon Sign-Ranked Test was used to test for significant differences ($\alpha = 0.05$) between the two strategies within each of the two ABM subgroups.

4. Results

Descriptive data were established for the 28 subjects' (18 females, 10 males) age (25.0 ± 4 years), height (169.30 ± 15.24 cm), weight (69.39 ± 22.77 kg) and BMI (23.63 ± 3.9 kg/m^2). The EO, IO and bilateral Mf RMS-EMG% descriptive data were measured during supine and standing VPAC trials (Tables 1 and 2). Data from all but five conditions met at least three of the four normality assumption parameters (Tables 1 and 2), lending to 87.5% of the data completely passing the normality assumption. Therefore, parametric statistical tests were chosen for data analysis. Sphericity test results can be witnessed on Table 3.

Research Hypotheses **1a** and **2** explored whether using different VI strategies would produce different contractile responses in the trunk muscles (EO, IO, and Mf) during the ADIM performances (Table 3). The LEO results demonstrated no significant position-by-strategy interaction ($p = .136$) and no significant main effects for position ($p = .931$) or strategy ($p = .329$). The LIO results demonstrated no significant

Table 1
Entire sample descriptive statistical outcomes for abdominal muscle activation amplitudes during each VPAC condition in Supine and Standing.



Condition	Mean	SD (+)	95%CI	Skewness	Kurtosis	W	Sig - *p*	Normality Pass/Fail
Su_Bavg_LIO	266.49	159.01	204.83–328.15	1.334	2.691	.901	.012	FAIL
Su_Savg_LIO	267.82	146.97	210.83–324.81	1.298	2.387	.906	.015	FAIL
Su_Aavg_LIO	300.53	181.99	229.96–371.09	1.236	1.704	.907	.017	Pass
Su_Pavg_LIO	275.58	194.96	199.98–351.18	1.317	1.789	.883	.005	Pass
Su_Wavg_LIO	209.59	151.92	150.68–268.50	1.442	2.672	.881	.004	FAIL
St_Bavg_LIO	394.64	224.87	307.44–481.84	0.341	−1.088	.936	.087	Pass
St_Savg_LIO	416.70	251.03	319.36–514.04	0.487	−0.997	.923	.042	Pass
St_Aavg_LIO	401.34	246.16	305.89–496.79	0.771	−0.259	.921	.036	Pass
St_Pavg_LIO	350.39	204.17	271.22–429.56	0.347	−0.175	.952	.222	Pass
St_Wavg_LIO	296.22	176.05	227.95–364.48	0.396	−0.828	.928	.054	Pass
Su_Bavg_LEO	60.08	38.69	45.08–75.09	0.769	−0.495	.908	.018	Pass
Su_Savg_LEO	57.32	38.62	42.35–72.30	0.786	−0.532	.904	.014	Pass
Su_Aavg_LEO	60.72	35.43	46.99–74.46	0.479	−0.685	.946	.155	Pass
Su_Pavg_LEO	57.75	37.34	43.28–72.23	1.167	0.789	.879	.004	Pass
Su_Wavg_LEO	54.77	35.84	40.87–68.66	1.067	0.815	.903	.014	Pass
St_Bavg_LEO	66.39	40.39	50.73–82.06	0.789	−0.642	.885	.005	Pass
St_Savg_LEO	55.34	25.66	45.39–65.29	0.493	−0.303	.95	.195	Pass
St_Aavg_LEO	55.71	25.20	45.94–65.48	0.587	0.042	.946	.159	Pass
St_Pavg_LEO	59.36	34.10	46.14–72.58	1.777	3.905	.834	0	FAIL
St_Wavg_LEO	50.66	27.48	40.00–61.32	0.751	−0.273	.921	.037	Pass

Su = Supine, St = Standing, L = Left, R = Right, EO = External Oblique, IO = Internal Oblique, B = Pull your belly button up and in towards your shoulder blades, S = Pull your abdominal muscles away from front elastic on the shorts, A = Pull the two front pelvic bones together, P = Prepare to be punched in the belly, W = Imagine making your trunk/waist wide.

interaction (p = .51) or main effect for strategy (p = .658). However, a significant main effect for position (p = .002) was observed, where the LIO RMS-EMG% was significantly higher in the standing versus supine position. The LMf demonstrated no significant interaction (p = 241) and no significant main effect for strategy (p = .05). However, a significant main effect for position was observed (p < .001), where the LMf RMS-EMG% was significantly higher in standing versus supine position. The RMf (Table 3) demonstrated no significant interaction (p = .024). However, it demonstrated a significant main effect for position (p < .001), where the RMf activation was significantly higher in standing, as

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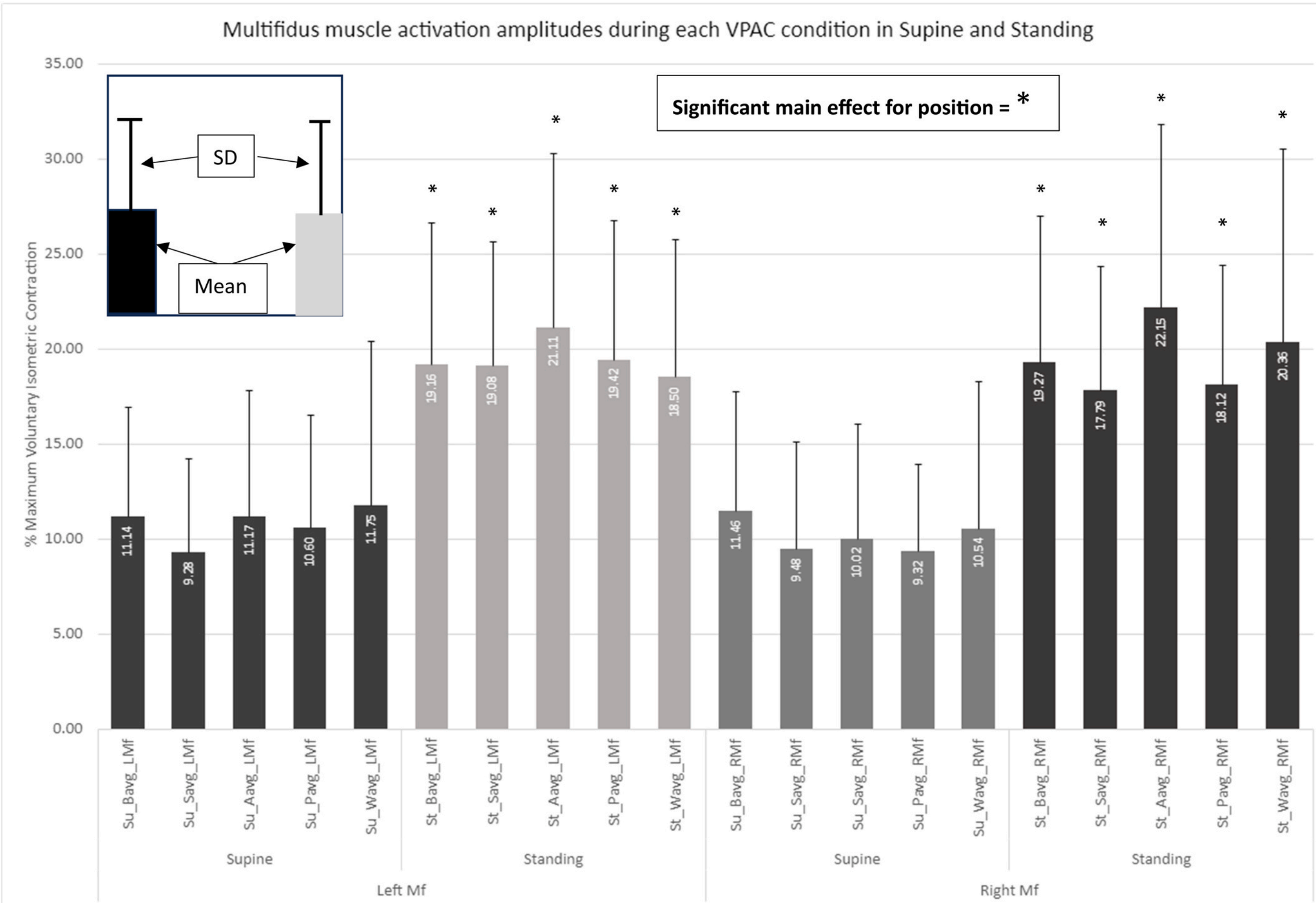
Table 2
Entire Sample descriptive statistical outcomes for multifidus muscle activation amplitudes during each VPAC condition in Supine and Standing.



Condition	Mean	SD (+)	95%CI	Skewness	Kurtosis	W	Sig - *p*	Normality Pass/Fail
Su_Bavg_LMf	11.14	5.81	8.89–13.39	0.453	−0.706	.949	.183	Pass
Su_Savg_LMf	9.28	4.98	7.35–11.21	0.730	0.082	.937	.091	Pass
Su_Aavg_LMf	11.17	6.66	8.59–13.76	0.594	−0.420	.946	.154	Pass
Su_Pavg_LMf	10.60	5.92	8.30–12.89	0.797	−0.158	.903	.013	Pass
Su_Wavg_LMf	11.75	8.65	8.39–15.10	1.596	3.084	.860	.001	FAIL
St_Bavg_LMf	19.16	7.49	16.25–22.06	1.296	1.345	.873	.003	Pass
St_Savg_LMf	19.08	6.55	16.54–21.62	0.952	0.790	.934	.076	Pass
St_Aavg_LMf	21.11	9.14	17.56–24.65	1.153	1.427	.915	.027	Pass
St_Pavg_LMf	19.42	7.33	16.58–22.27	0.278	−0.233	.961	.367	Pass
St_Wavg_LMf	18.50	7.27	15.68–21.32	0.898	0.376	.922	.038	Pass
Su_Bavg_RMf	11.46	6.27	9.03–13.89	0.506	−0.280	.955	.262	Pass
Su_Savg_RMf	9.48	5.62	7.30–11.66	0.901	0.485	.923	.042	Pass
Su_Aavg_RMf	10.02	6.04	7.68–12.36	0.772	−0.068	.927	.053	Pass
Su_Pavg_RMf	9.32	4.60	7.54–11.11	0.558	0.129	.962	.379	Pass
Su_Wavg_RMf	10.54	7.75	7.53–13.54	1.441	1.901	.852	.001	Pass
St_Bavg_RMf	19.27	7.72	16.28–22.26	0.127	−0.593	.964	.427	Pass
St_Savg_RMf	17.79	6.55	15.25–20.33	0.206	−0.780	.971	.612	Pass
St_Aavg_RMf	22.15	9.68	18.40–25.91	0.487	−0.826	.938	.099	Pass
St_Pavg_RMf	18.12	6.28	15.68–20.55	0.330	−0.141	.967	.502	Pass
St_Wavg_RMf	20.36	10.14	16.43–24.29	0.551	−1.077	.906	.016	Pass

Su = Supine, St = Standing, L = Left, R = Right, Mf = Multifidi, B = Pull your belly button up and in towards your shoulder blades, S = Pull your abdominal muscles away from front elastic on the shorts, A = Pull the two front pelvic bones together, P = Prepare to be punched in the belly, W = Imagine making your trunk/waist wide.

well as a significant main effect for strategy ($p = .002$). The post-hoc analysis demonstrated that strategy S (13.31%) was significantly lower than strategy B (15.34%; $p = .007$) and strategy A (15.98%; $p = .003$), whereas strategy B versus A demonstrated no significant differences ($p = 1.00$).

The previously described unplanned, exploratory descriptive analyses were performed to cluster subjects according to which ADIM- VI strategy in supine or standing produced the highest RMS-EMG% output for each muscle in each subject (Appendices A – D). This resulted in three subject clusters per muscle, where each cluster represented the dominant strategy for the subjects in each cluster (ADIM-Strategy B; ADIM-strategy S; ADIM-strategy A). The Friedman Test demonstrated a significant main effect for ADIM-VI strategy, with exception to SupADIM-S, where both the LMf and RMf activation each demonstrated

Table 3
2 Position x 3 Strategy ANOVA tests during ADIM for the Entire Sample.

Source	Muscle	df	F	Sig	PES	PWR	Mauchly's W	Approx. Chi- Sq	df	Sig.	Epsilon GG
(Pos) x (Strat) Interaction*	LEO	1.53, 41.23	2.18	.136	.08	.37	0.69	9.64	2	.008	.76
Pos Main Effect	LEO	1, 27	0.01	.931	0	.05					
Strat Main Effect*	LEO	1.62, 43.68	1.11	.329	.04	.21	0.76	7.00	2	.030	.81
(Pos) x (Strat) Interaction*	LIO	2, 54	0.68	.510	.03	.16	0.95	1.26	2	.533	.96
Pos Main Effect	LIO	1, 27	12.12	.002	.31	.92					
Strat Main Effect*	LIO	2, 54	0.42	.658	.02	.12	0.85	4.35	2	.114	.87
(Pos) x (Strat) Interaction*	LMf	1.54, 41.57	1.47	.241	.05	.26	0.70	9.24	2	.010	.77
Pos Main Effect	LMf	1, 27	27.71	<.001	.51	.99					
Strat Main Effect*	LMf	2, 54	3.17	.050	.11	.58	0.88	3.37	2	.185	.89
(Pos) x (Strat) Interaction*	RMf	1.52, 41.11	4.56	.024	.15	.67	0.69	9.78	2	.008	.76
Pos Main Effect	RMf	1, 27	47.80	<.001	.64	1					
Strat Main Effect*	RMf	2, 54	7.06	.002	.21	.92	0.80	5.93	2	.051	.83

Pos = Position, Strat = Strategy, L = Left, R = Right, EO = External Oblique, IO = Internal Oblique, Mf = Multifidi. *Greenhouse-Geisser correction for sphericity violation; Significant at α = 0.012.

non-significant test results. For those analyses that demonstrated a significant main effect, exploratory Wilcoxon Sign Ranked post-hoc test comparison outcomes between three different strategies in the cluster generally showed the dominant strategy to be significantly higher than the other two strategies, while those other two strategies generally did not significantly differ (exception: StADIM-S versus StADIM-A for LIO).

Hypotheses **1b** and **2** investigated whether using different VI strategies would produce different contractile responses in EO, IO, and Mf during the ABM performances. The LEO (Table 4) demonstrated no significant interaction (p = .680) or main effects for position (p = .398) and strategy (p = .154). The LIO (Table 4) demonstrated no significant interaction (p = .660) but produced a significant main effect for position (p = .003), where the LIO activation was higher for standing versus supine position. A main effect for strategy (p = .001) was observed, where strategy P (324.95%) was significantly higher than strategy W (248.54%).

The LMf and RMf (Table 4) demonstrated no significant interaction (p = .368) or main effect for strategy (p = .712). However, a significant main effect was demonstrated for position (p < .001), where the LMf activation was higher in standing versus supine.

The previously mentioned unplanned, exploratory descriptive analyses found that subjects were clustered according to which ABM-VI strategy in supine or standing produced the highest RMS-EMG% output for each muscle in each subject. This resulted in two subject clusters per muscle, where each cluster represented the dominant strategy for that cluster (ABM-strategy P; ABM-strategy W). With respect to each muscle group, the Wilcoxon Sign Ranked Test for the dominant strategy in each cluster overall demonstrated a significant difference between strategies, where the dominant strategy was higher than the other strategy (Appendix E). The only exception can be found for the dominant StABM-W strategy in standing for LEO.

Hypotheses 3 tested for a co-contraction relationship between abdominal and Mf contractile responses during different VI strategies. Pearson product-moment correlations between LEO, LIO, LMf and RMf produced poor, non-significant results between all muscle pairings during all ADIM and ABM strategies in supine (Appendix F). Similarly, we generally observed poor, non-significant correlations (≤.25) between muscle pairings during the ADIM and ABM strategies in standing, with two exceptions (Appendix G)(Portney, 2020). We observed fair, non-significant correlations (0.25–0.50) for two ADIM-B strategy muscle pairings in standing: St_Bavg_LEO paired with St_Bavg_LMf, as well as St_Bavg_LEO paired with St_Bavg_RMf (Appendix G)(Portney, 2020).

Table 4
2 Position x 2 Strategy ANOVA tests during ABM for the Entire Sample.

Source	Muscle	df	F	Sig	PES	PWR
(Pos) x (Strat) Interaction	LEO	1, 27	0.174	.680	.006	.069
Pos Main Effect	LEO	1, 27	0.736	.398	.027	.131
Strat Main Effect	LEO	1, 27	2.154	.154	.074	.293
(Pos) x (Strat) Interaction	LIO	1, 27	0.198	.660	.007	.071
Pos Main Effect	LIO	1, 27	11.091	.003	.291	.894
Strat Main Effect	LIO	1, 27	13.571	.001	.335	.944
(Pos) x (Strat) Interaction	LMf	1, 27	0.838	.368	.030	.143
Pos Main Effect	LMf	1, 27	40.264	<.000	.599	1.000
Strat Main Effect	LMf	1, 27	0.139	.712	.005	.065
(Pos) x (Strat) Interaction	RMf	1, 27	0.254	.618	.009	.077
Pos Main Effect	RMf	1, 27	40.562	<.000	.600	1.000
Strat Main Effect	RMf	1, 27	2.387	.134	.081	.320

Pos = Position, Strat = Strategy, L = Left, R = Right, EO = External Oblique, IO = Internal Oblique, Mf = Multifidi. Significant at α = 0.0125.

5. Discussion

This is the first study to examine the effect of specific VI strategies on trunk muscle contractile performance during two VPAC approaches in two body positions. This was an innovative undertaking, as it could aide clinicians in decision-making with respect to VI strategy selection during lumbar functional testing and rehabilitative training. Furthermore, this study examined methods to optimize trunk control, potentially enhancing functional performance,(Hooper et al., 2016; McGalliard et al., 2010; Shirey et al., 2012) and decreasing low back injury risk (Hides et al., 2001; Richardson and Jull, 1995). Our results revealed comparable recruitment profiles between ADIM and ABM VI strategies. Subjects demonstrated increased LIO and bilateral Mf recruitment in the standing versus supine position with both ADIM and ABM approaches. There was no influence of position or strategy on, LEO recruitment. Unplanned exploratory analysis results suggest people may exhibit individualized VI preferences that could guide strategy selection.

Our findings revealed no difference in ADIM or ABM VI strategy across the entire sample (Hypotheses 1a and 1b, respectively). We speculated the best ADIM VI to be "Pull your belly button up and in towards your shoulder blades." However, we did not observe that outcome for any muscle across the entire sample. In a similar fashion, we speculated the best ABM VI to be "Prepare to be punched in the belly." This was observed for only LIO.

Two potential issues arise from our overall findings. First, our findings imply either of the other two strategies would be preferential for activating RMf, rendering our original hypothesis unsupported. Second, we did not observe the same outcome with the LMf. While this finding may have been a function of no true strategy impact, it could also have been the result of insufficient sample size, based on a partial eta squared effect size of .105 that is considered to be moderate-to-high(Portney, 2020).

Investigators have suggested abdominal muscle activation increases trunk stability and reduces low back injury risk(Hides et al., 2006; O'Sullivan et al., 1997). Teyhen et al. reported ADIM activates deep abdominal muscles and stabilizes the lumbar spine(Teyhen et al., 2009). Furthermore, they reported ADIM increases TrA thickness 45–49% in LBP subjects and 65–67% in healthy subjects(Teyhen et al., 2009). Vera-Garcia et al. reported ABM enhanced trunk co-contraction, increased trunk stability, and decreased lumbar displacement in healthy subjects(Vera-Garcia et al., 2007). Haddas et al. reported lumbar spine movement and stability can be improved with the same approach (Haddas et al., 2016b). Additionally, Haddas et al. reported VPAC may reduce injury risk and episodic frequency in individuals with recurrent LBP(Haddas et al., 2016b; Hides et al., 2001; Richardson and Jull, 1995). These findings suggest different VPAC approaches may serve as an appropriate lumbar spine stabilizer, as well as a potential for reducing LBP onset risk.

Wang-Price et al. investigated lumbar spine Mf muscle thickness in response to VI in asymptomatic and symptomatic individuals(Wang-Price et al., 2017). These authors reported VI may increase lumbar Mf muscle thickness when viewed with ultrasound parasagittal imaging (Wang-Price et al., 2017). The L4-5 level Mf demonstrated a significant main effect for VI, however the between-cues differences did not significantly interact with group. Additionally, the authors did not observe significant interactions or main effects for the same variables at L5-S1. Moreover, neither the L4-5 nor L5-S1 segments demonstrated a main effect for group. Wang-Price et al. noted the majority of LBP group subjects rated "draw your belly button in towards your spinal column" (similar to the current study's ADIM-B strategy) as the most helpful command for Mf activation(Wang-Price et al., 2017). However, they found this VI demonstrated the lowest muscle thickness change on ultrasound parasagittal images at L4-5 and L5-S1.

It is noteworthy that only one of the three Wang-Price et al. VI strategies focused on activating the abdominal muscles versus the five VI strategies in our study(Wang-Price et al., 2017). While sounding similar to Wang-Price et al., our study's ADIM-B strategy ("pull your belly button up and in towards your shoulder blades") did not demonstrate similar significant contractile response differences in EO, IO and Mf (Wang-Price et al., 2017). In addition, the subjects' position in the Wang-Price et al. study was prone to accommodate ultrasound Mf measurement, versus the clinically relevant supine hook-lying and quiet standing positions allowed in our study in response to surface EMG use (Wallwork et al., 2007; Wang-Price et al., 2017). Our L5 surface EMG electrode placement was selected based on previous investigators to optimize surface EMG signal reception to reduce the chances of crosstalk with other paraspinals (such as iliocostalis)(Butler et al., 2009; Matthijs et al., 2014; Seze and Cazalets, Jean-Rene, 2008).

Wang-Price et al. outcomes, as well as our findings for the entire sample (other than RMf), could have been influenced by three different possible factors(Wang-Price et al., 2017). One possibility is that there are no differences between strategies, where all of the VI strategies produce statistically similar outcomes. Conversely, the finding could have been influenced by sample size. However, the effect sizes were minimum-to-moderate for all analyses with exception to RMf, suggesting that the sample appears appropriate for true non-significance. Finally, different subject subgroups may have produced different results across different strategies. If that was the case, then differences in VI strategy's dominance for different subjects could cancel one another out for a given VI across the entire sample. With this in mind, we chose to perform unplanned exploratory post-hoc analyses to further test that possibility and better explain the study outcomes for the entire sample. Such findings could suggest whether subject subgroups could demonstrate different VI strategy dominance.

With these ideas in mind, we were inspired to cluster subjects according to their highest performance outcome among the different strategies. We then looked to see if, within a given subgroup, one strategy statistically outperformed the others within each approach (for both ADIM and ABM). While our findings cannot be deemed conclusive due to the unplanned nature of the exploratory analyses and the small subgroup sample sizes, the results allowed us to begin to understand strategy dominance may differ for individuals, suggesting strategy suitability for a given subject. The data suggest that different people can use different approaches that are unique to them. For example, a subject's dominant strategy's mean contractile output was significantly higher than the other two strategies for the vast majority of muscles, while the other two strategies did not differ from each other in each case. We observed a similar outcome during ADIM and ABM in both supine and standing. To this point, Avrillon et al. reported coordination strategies may be individualized with functional consequences effecting motor performance(Avrillon et al., 2018).

While these outcomes suggest individualized strategy dominance across different subject cluster groups, further research is needed to confirm the findings across a larger sample that includes LBP individuals. Hug and Tucker reported that because a unique muscle coordination strategy could have a distinct impact on the musculoskeletal system, the ability to recognize these strategies may yield an observation of possible patterns elemental in the evolution of painful musculoskeletal conditions(Hug and Tucker, 2017). If differences could be identified by clinicians, they could individualize patient instructions that could enhance VPAC performance, increase spine stability, and lower injury risk.

Regarding Hypothesis 2, our findings revealed a significant main effect for position for LIO, LMf and RMf but not for LEO, where subjects produced higher muscle output responses in standing versus supine during both ADIM and ABM approaches. Our results suggest the standing position should be chosen over a supine position when maximal VPAC contractile output is prioritized. This is clinically meaningful, as introducing VPAC in a standing position may provide an improved opportunity to facilitate muscle contraction of the IO and Mf increasing trunk stability. Furthermore, more functional tasks are performed in standing. This task-specific preference appears to encourage VPAC training in a standing versus supine position.

The impact of body position on lower quarter muscle activation has been debated. Huseth et al. assessed neuromuscular activity and reported no position-related differences in muscular activation of tibialis anterior, gluteus medius, adductor longus, rectus abdominis, EO, IO/transverse abdominis during isometric contraction in supine versus standing(Huseth et al., 2020). Conversely, Urquhart et al. observed delayed postural response activity of abdominal muscles in sitting versus standing with rapid unilateral shoulder flexion(Urquhart et al., 2005). They postulated the use of a back support, a larger base of support, and a lower center of mass may contribute to greater trunk stability in sitting, requiring less muscle activation. Furthermore, O'Sullivan et al. noted stabilizing muscle facilitation in the lumbopelvic region is augmented through erect postural alignment in weightbearing positions, whereas non-weightbearing or improperly aligned postures could inhibit lumbopelvic muscle activity enhancement(O'Sullivan et al., 2002).

In response to current literature, the question arises whether the trunk muscle recruitment profile is due to loading or serves a purely postural function. One would surmise that standing requires increased trunk muscle activity to control the center of mass against gravity lending to a postural support function. However, Hyde et al. observed an increase in IO and TrA muscle thickness with simulated lower limb load bearing tasks in a recumbent (supine) position(Hyde et al., 2012). This suggests that the loading response through the lower extremities may additionally influence changes in trunk muscle activation. Further research is necessary to better elucidate the role of each mechanism in muscular response to position change.

Regarding Hypothesis 3, we observed few meaningful correlations between Mf side and either IO or EO muscles. MacDonald et al. reported Mf contributes approximately 66% of the stiffness at the L4-5 segment and activity of the deep Mf does not require co-contraction of antagonist muscles(MacDonald et al., 2006). Yet, other investigators observed a co-contraction of Mf activation in response to VPAC(Matthijs et al., 2014; Wilhelm, n.d.). As a possible explanation for this discrepancy, Hug and Tucker hypothesized that individuals exhibit distinct motor control strategies based on unique musculoskeletal characteristics(Hug and Tucker, 2017). Huseth et al. observed maximum voluntary isometric contraction and noted considerable inter-individual variance, indicating a preference for specific motor control strategies(Huseth et al., 2020). This within-strategy Mf variance in response to each VPAC strategy may help explain the lack of correlation in this study.

6. Study limitations, delimitations and future research

The first limitation centers on the authors' choice to use surface EMG to record superficial LMf and RMf muscle contraction. In retrospect, the use of indwelling fine-wire EMG electrodes to record the deep multifidi may have been a better indicator of segmental trunk stabilization. However, indwelling fine wire EMG would have rendered the subject uncomfortable in the clinically relevant supine position, accompanied by potentially damaging forces imposed on the electrodes in the process.

Second, subjects were allowed to self-adjust their spine position during the VPAC trials. O'Sullivan et al. reported poorly aligned posture increased postural sway, decreased activation of superficial lumbar Mf, IO and thoracic erector spinae muscles, and increased rectus abdominis activation(O'Sullivan et al., 2002). The same authors concomitantly observed increased sway posture while standing. This suggests a reliance on passive support by means of bony and ligamentous tissues versus active support produced from trunk muscle activation. The current study's subjects were allowed to self-select their spine position in standing and may have chosen a more passive postural position. This oversight may have impacted the results for entire sample comparisons.

The first study delimitations centered on enlisting subjects through a convenience sample. This recruitment method may have limited subject variability and thus cannot truly represent the general population. Another delimitation focuses on subject sex, age range, and health status. There was a disparity between the number of females (18) versus males (10), where the general population may not be well represented. Future research should examine the influence of sex on similar study outcomes using an equal number of females and males.

All subjects were young and healthy (BMI<30 and no comorbidities), limiting the applicability of the findings to a more general population. This study recruited healthy subjects to establish a baseline for any future VPAC studies involving LBP subjects. Future research will need to focus on subjects with current LBP or previous LBP history with no current symptoms. Finally, future studies may need to evaluate the influence of leg dominance on Mf response to VPAC during standing activities.

7. Conclusion

While this study did not observe an influence of strategy effect on the entire sample, unplanned analysis results suggest that there is no one single preferred VI cue for ADIM or ABM. The study incorporated five acceptable and commonly used VI cues for VPAC. The results exhibited unique VI dominant strategy patterns for different subject subgroups, suggesting which VI strategy is most suitable for each subgroup. This study's results suggest the LEO activation is not altered by position; however, activation of the LIO, LMf and RMf is improved in standing versus supine. These findings may suggest a need for healthcare providers to teach and monitor VPAC with either ADIM or ABM approaches, with special attention to the VI strategy that creates the best contractile response. Additionally, standing was a superior position for IO, EO and Mf activation amplitude as compared to supine. Future studies with a larger subject population to include those with a history of LBP are needed to examine these findings with an application towards clinical management.

Clnical relevance

- Results suggest activation of LIO, LMF and RMf is improved in standing versus supine.
- Results suggest LEO activation not influenced by position (supine versus standing).
- Unplanned analysis suggests no one single preferred VI cue for ADIM or ABM
- Clinicians and clients may benefit from identifying the VI strategy that creates the best contractile response.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Andrew Ward: Conceptualization,Formal analysis,Investigation, Methodology,Visualization,Writing – original draft,Writing – review & editing.**Alexander Drusch:** Investigation.**Yo-Rong Chen:** Investigation.**Mark Ouellette:** Conceptualization,Methodology.**Jean-Michel Brismée:** Conceptualization,Methodology.**Troy Hooper:** Conceptualization,Data curation,Methodology.**Katherine Wilford:** Writing – review & editing.**Gesine H. Seeber:** Visualization,Writing – review & editing.**Phillip S. Sizer:** Conceptualization,Formal analysis,Methodology,Supervision,Writing – original draft,Writing – review & editing.

Declaration of competing interest

The authors affirm that they have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct conflict of interest in any matter included in this manuscript.

Acknowledgements

The authors would like to thank the Texas Tech University Health Science Center Doctor of Physical Therapy (TTUHSC DPT) Classes of 2020 and 2021 for volunteering to participate to further the pursuit of clinical research.

APPENDICES.

Appendix A. Non-Parametric Statistical Test results of ADIM clustered data sets for LEO/LIO tested muscles in Supine

Muscle	Dominant Strategy Group	Comparison	Statistic	Sig
LEO	ADIM-B	SuADIM-B vs. SuADIM-S vs. SuADIM-A γ	N = 6, $\chi^2 = 9$	.011
LEO	ADIM-B	SuADIM-B vs. SuADIM-S φ	−2.201	.028
LEO	ADIM-B	SuADIM-B vs. SuADIM-A φ	−2.201	.028
LEO	ADIM-B	SuADIM-S vs. SuADIM-A φ	−0.105	.917
LEO	ADIM-S	SuADIM-S vs. SuADIM-B vs. SuADIM-A γ	N = 6, $\chi^2 = 9.333$	.009
LEO	ADIM-S	SuADIM-S vs. SuADIM-B φ	−2.201	.028
LEO	ADIM-S	SuADIM-S vs. SuADIM-A φ	−2.201	.028
LEO	ADIM-S	SuADIM-B vs. SuADIM-A φ	−0.943	.345
LEO	ADIM-A	SuADIM-A vs. SuADIM-S vs. SuADIM-B γ	N = 16, $\chi^2 = 24.500$	<.001
LEO	ADIM-A	SuADIM-A vs. SuADIM-S φ	−3.516	<.001
LEO	ADIM-A	SuADIM-A vs. SuADIM-B φ	−3.516	<.001
LEO	ADIM-A	SuADIM-S vs. SuADIM-B φ	−0.931	.352
LIO	ADIM-B	SuADIM-B vs. SuADIM-S vs. SuADIM-A γ	N = 9, $\chi^2 = 14.00$	.001
LIO	ADIM-B	SuADIM-B vs. SuADIM-S φ	−2.666	.008
LIO	ADIM-B	SuADIM-B vs. SuADIM-A φ	−2.666	.008
LIO	ADIM-B	SuADIM-S vs. SuADIM-A φ	−0.178	.859
LIO	ADIM-S	SuADIM-S vs. SuADIM-B vs. SuADIM-A γ	N = 7, $\chi^2 = 11.143$	.004
LIO	ADIM-S	SuADIM-S vs. SuADIM-B φ	−2.366	.018
LIO	ADIM-S	SuADIM-S vs. SuADIM-A φ	−2.366	.018
LIO	ADIM-S	SuADIM-B vs. SuADIM-A φ	−0.507	.612
LIO	ADIM-A	SuADIM-A vs. SuADIM-S vs. SuADIM-B γ	N = 12, $\chi^2 = 19.500$	<.001
LIO	ADIM-A	SuADIM-A vs. SuADIM-S φ	−3.059	.002
LIO	ADIM-A	SuADIM-A vs. SuADIM-B φ	−3.059	.002
LIO	ADIM-A	SuADIM-S vs. SuADIM-B φ	−1.804	.071

Su = Supine, ADIM = Abdominal Drawing In Maneuver, L = Left, EO = External Oblique, IO = Internal Oblique, B = "Pull your belly button up and in towards your shoulder blades," S = "Pull your abdominal muscles away from front elastic on the shorts," A = "Pull the two front pelvic bones together," ADIM B = ADIM Group with dominant B strategy; ADIM S = ADIM Group with dominant S strategy; ADIM A = ADIM Group with dominant A strategy; γ = Friedman Test; φ = post-hoc Wilcoxon Sign-Ranked Test. Significance was set at α = .0125 for main effects tests and α = 0.05 for post hoc tests.

Appendix B. Non-Parametric Statistical Test results of ADIM clustered data sets for LEO/LIO tested muscles in Standing

Muscle	Dominant Strategy Group	Comparison	Statistic	Sig
LEO	ADIM-B	StADIM-B vs. StADIM-S vs. StADIM-A γ	N = 9, $\chi^2 = 14.00$	.001
LEO	ADIM-B	StADIM-B vs. StADIM-S φ	−2.666	.008
LEO	ADIM-B	StADIM-B vs. StADIM-A φ	−2.666	.008
LEO	ADIM-B	StADIM-S vs. StADIM-A φ	−0.533	.594
LEO	ADIM-S	StADIM-S vs. StADIM-B vs. StADIM-A γ	N = 8, $\chi^2 = 12.00$	.002
LEO	ADIM-S	StADIM-S vs. StADIM-B φ	−2.521	.012
LEO	ADIM-S	StADIM-S vs. StADIM-A φ	−2.521	.012
LEO	ADIM-S	StADIM-B vs. StADIM-A φ	−0.56	.575
LEO	ADIM-A	StADIM-A vs. StADIM-S vs. StADIM-B γ	N = 11, $\chi^2 = 18.727$	<.001
LEO	ADIM-A	StADIM-A vs. StADIM-S φ	−2.934	.003
LEO	ADIM-A	StADIM-A vs. StADIM-B φ	−2.934	.003
LEO	ADIM-A	StADIM-S vs. StADIM-B φ	−2.134	.033
LIO	ADIM-B	StADIM-B vs. StADIM-S vs. StADIM-A γ	N = 8, $\chi^2 = 14.250$	.001
LIO	ADIM-B	StADIM-B vs. StADIM-S φ	−2.521	.012
LIO	ADIM-B	StADIM-B vs. StADIM-A φ	−2.521	.012
LIO	ADIM-B	StADIM-S vs. StADIM-A φ	−1.960	.05
LIO	ADIM-S	StADIM-S vs. StADIM-B vs. StADIM-A γ	N = 11, $\chi^2 = 16.545$	<.001
LIO	ADIM-S	StADIM-S vs. StADIM-B φ	−2.934	.003
LIO	ADIM-S	StADIM-S vs. StADIM-A φ	−2.934	.003
LIO	ADIM-S	StADIM-B vs. StADIM-A φ	−0.267	.790
LIO	ADIM-A	StADIM-A vs. StADIM-S vs. StADIM-B γ	N = 9, $\chi^2 = 13.556$	.001
LIO	ADIM-A	StADIM-A vs. StADIM-S φ	−2.666	.008
LIO	ADIM-A	StADIM-A vs. StADIM-B φ	−2.666	.008
LIO	ADIM-A	StADIM-S vs. StADIM-B φ	−0.770	.441

The Wilcoxon Signed Ranks Test results of ADIM clustered data sets for LEO/LIO tested muscles in Standing. St = Standing, ADIM = Abdominal Drawing In Maneuver, L = Left, EO = External Oblique, IO = Internal Oblique, B = "Pull your belly button up and in towards your shoulder blades," S = "Pull your abdominal muscles away from front elastic on the shorts," A = "Pull the two front pelvic bones together," ADIM B = ADIM Group with dominant B strategy; ADIM S = ADIM Group with dominant S strategy; ADIM A = ADIM Group with dominant A strategy; γ = Friedman Test; φ = post-hoc Wilcoxon Sign-Ranked Test; Significance was set at α = .0125 for main effects tests and α = 0.05 for post hoc tests.

Appendix C. Non-Parametric Statistical Test results of ADIM clustered data sets for LMf/LMf tested muscles in Supine

Muscle	Dominant Strategy Group	Comparison	Statistic	Sig
LMf	ADIM-B	SuADIM-B vs. SuADIM-S vs. SuADIM-A γ	N = 18, χ^2 = 26.056	<.001
LMf	ADIM-B	SuADIM-B vs. SuADIM-S φ	−3.622	<.001
LMf	ADIM-B	SuADIM-B vs. SuADIM-A φ	−3.724	<.001
LMf	ADIM-B	SuADIM-S vs. SuADIM-A φ	−0.414	.679
LMf	ADIM-S	SuADIM-S vs. SuADIM-B vs. SuADIM-A γ	N = 4, χ^2 = 5.200	.074
LMf	ADIM-S	SuADIM-S vs. SuADIM-B φ	Not Performed	
LMf	ADIM-S	SuADIM-S vs. SuADIM-A φ	Not Performed	
LMf	ADIM-S	SuADIM-B vs. SuADIM-A φ	Not Performed	
LMf	ADIM-A	SuADIM-A vs. SuADIM-S vs. SuADIM-B γ	N = 6, χ^2 = 9.000	.011
LMf	ADIM-A	SuADIM-A vs. SuADIM-S φ	−2.201	.028
LMf	ADIM-A	SuADIM-A vs. SuADIM-B φ	−2.201	.028
LMf	ADIM-A	SuADIM-S vs. SuADIM-B φ	−0.943	.345
RMf	ADIM-B	SuADIM-B vs. SuADIM-S vs. SuADIM-A γ	N = 16, χ^2 = 24.000	<.001
RMf	ADIM-B	SuADIM-B vs. SuADIM-S φ	−3.516	<.001
RMf	ADIM-B	SuADIM-B vs. SuADIM-A φ	−3.516	<.001
RMf	ADIM-B	SuADIM-S vs. SuADIM-A φ	−0.466	.641
RMf	ADIM-S	SuADIM-S vs. SuADIM-B vs. SuADIM-A γ	N = 5, χ^2 = 8.400	.015
RMf	ADIM-S	SuADIM-S vs. SuADIM-B φ	Not Performed	
RMf	ADIM-S	SuADIM-S vs. SuADIM-A φ	Not Performed	
RMf	ADIM-S	SuADIM-B vs. SuADIM-A φ	Not Performed	
RMf	ADIM-A	SuADIM-A vs. SuADIM-S vs. SuADIM-B γ	N = 7, χ^2 = 11.143	.004
RMf	ADIM-A	SuADIM-A vs. SuADIM-S φ	−2.366	.018
RMf	ADIM-A	SuADIM-A vs. SuADIM-B φ	−2.366	.018
RMf	ADIM-A	SuADIM-S vs. SuADIM-B φ	−1.521	.128

Sup = Supine, ADIM = Abdominal Drawing In Maneuver, L = Left, R = Right, Mf = Multifidi, B = "Pull your belly button up and in towards your shoulder blades," S = "Pull your abdominal muscles away from front elastic on the shorts," A = "Pull the two front pelvic bones together," ADIM B = ADIM Group with dominant B strategy; ADIM S = ADIM Group with dominant S strategy; ADIM A = ADIM Group with dominant A strategy; γ = Friedman Test; φ = post-hoc Wilcoxon Sign-Ranked Test; Significance was set at α = .0125 for main effects tests and α = 0.05 for post hoc tests.

Appendix D. The Wilcoxon Signed Ranks Test results of ADIM clustered data sets for LMf/RMf tested muscles in Standing

Muscle	Dominant Strategy Group	Comparison	Statistic	Sig
LMf	ADIM-B	StADIM-B vs. StADIM-S vs. StADIM-A γ	N = 10, χ^2 = 15.800	<.001
LMf	ADIM-B	StADIM-B vs. StADIM-S φ	−2.803	.005
LMf	ADIM-B	StADIM-B vs. StADIM-A φ	−2.803	.005
LMf	ADIM-B	StADIM-S vs. StADIM-A φ	−1.172	.241
LMf	ADIM-S	StADIM-S vs. StADIM-B vs. StADIM-A γ	N = 8, χ^2 = 1.290	.004
LMf	ADIM-S	StADIM-S vs. StADIM-B φ	−2.521	.012
LMf	ADIM-S	StADIM-S vs. StADIM-A φ	−2.366	.018
LMf	ADIM-S	StADIM-B vs. StADIM-A φ	−0.700	.484
LMf	ADIM-A	StADIM-A vs. StADIM-S vs. StADIM-B γ	N = 10, χ^2 = 15.200	.001
LMf	ADIM-A	StADIM-A vs. StADIM-S φ	−2.803	.005
LMf	ADIM-A	StADIM-A vs. StADIM-B φ	−2.803	.005
LMf	ADIM-A	StADIM-S vs. StADIM-B φ	−0.866	.386
RMf	ADIM-B	StADIM-B vs. StADIM-S vs. StADIM-A γ	N = 8, χ^2 = 12.452	.002
RMf	ADIM-B	StADIM-B vs. StADIM-S φ	−2.521	.012
RMf	ADIM-B	StADIM-B vs. StADIM-A φ	−2.521	.012
RMf	ADIM-B	StADIM-S vs. StADIM-A φ	−0.423	.672
RMf	ADIM-S	StADIM-S vs. StADIM-B vs. StADIM-A γ	N = 3, χ^2 = 4.667	.097
RMf	ADIM-S	StADIM-S vs. StADIM-B φ	Not Performed	
RMf	ADIM-S	StADIM-S vs. StADIM-A φ	Not Performed	
RMf	ADIM-S	StADIM-B vs. StADIM-A φ	Not Performed	
RMf	ADIM-A	StADIM-A vs. StADIM-S vs. StADIM-B γ	N = 17, χ^2 = 23.059	<.001
RMf	ADIM-A	StADIM-A vs. StADIM-S φ	−3.621	<.001
RMf	ADIM-A	StADIM-A vs. StADIM-B φ	−3.621	<.001
RMf	ADIM-A	StADIM-S vs. StADIM-B φ	−0.213	.831

St = Standing, ADIM = Abdominal Drawing In Maneuver, L = Left, R = Right, Mf = Multifidi, B = "Pull your belly button up and in towards your shoulder blades," S = "Pull your abdominal muscles away from front elastic on the shorts," A = "Pull the two front pelvic bones together," ADIM B = ADIM Group with dominant B strategy; ADIM S = ADIM Group with dominant S strategy; ADIM A = ADIM Group with dominant A strategy; γ = Friedman Test; φ = post-hoc Wilcoxon Sign-Ranked Test; * = Non-significant comparison. Significance was set at α = .0125 for main effects tests and α = 0.05 for post hoc tests.

Appendix E. The Wilcoxon Signed Ranks Test results of ABM clustered data sets for all tested muscles in Supine and Standing

Muscle	Comparison	Group	Z	Sig
SUPINE				
LEO	SuABM-P vs. SuABM-W	ABM-1	−3.724	<.001
LEO	SuABM-W vs. SuABM- P	ABM-2	−2.803	.005
LIO	SuABM-P vs. SuABM-W	ABM-1	−3.823	<.001
LIO	SuABM- W vs. SuABM- P	ABM-2	−2.666	.008
LMf	SuABM-P vs. SuABM-W	ABM-1	−3.517	<.001
LMf	SuABM- W vs. SuABM- P	ABM-2	−3.062	.002

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(*continued*)

Muscle	Comparison	Group	Z	Sig
RMf	SuABM-P vs. SuABM-W	ABM-1	−3.516	<.001
RMf	SuABM- W vs. SuABM- P	ABM-2	−2.803	.005
STANDING				
LEO	StABM-P vs. StABM-W	ABM-1	−4.107	<.001
LEO	StABM- W vs. StABM- P	ABM-2	−2.201	.028
LIO	StABM-P vs. StABM-W	ABM-1	−3.920	<.001
LIO	StABM- W vs. StABM- P	ABM-2	−2.521	.012
LMf	StABM-P vs. StABM-W	ABM-1	−3.516	<.001
LMf	StABM- W vs. StABM- P	ABM-2	−3.059	.002
RMf	StABM-P vs. StABM-W	ABM-1	−2.934	.003
RMf	StABM- W vs. StABM- P	ABM-2	−3.621	<.001

Su = Supine, St = Standing, ABM = Abdominal Bracing Maneuver, L = Left, R = Right, EO = External Oblique, IO = Internal Oblique, Mf = Multifidi, P = "Prepare to be punched in the belly," W = "Imagine making your trunk/waist wide," Group 1 = dominant strategy = P, Group 2 = dominant strategy = W. α = 0.05.

Appendix F. The Pearson's Correlation Coefficient results of ADIM and ABM clustered data sets for all tested muscles in Supine

Strategy	Muscle 1	Muscle 2	Pearson's Correlation Coefficient	p-value
ADIM	Bavg_LIO	Bavg_LMf	0.062	0.755
ADIM	Savg_LIO	Savg_LMf	0.212	0.280
ADIM	Aavg_LIO	Aavg_LMf	0.138	0.484
ADIM	Bavg_LIO	Bavg_RMf	−0.230	0.240
ADIM	Savg_LIO	Savg_RMf	−0.218	0.265
ADIM	Aavg_LIO	Aavg_RMf	0.149	0.448
ADIM	Bavg_LEO	Bavg_LMf	0.104	0.598
ADIM	Savg_LEO	Savg_LMf	0.067	0.736
ADIM	Aavg_LEO	Aavg_LMf	0.008	0.967
ADIM	Bavg_LEO	Bavg_RMf	0.193	0.326
ADIM	Savg_LEO	Savg_RMf	0.219	0.263
ADIM	Aavg_LEO	Aavg_RMf	0.104	0.600
ABM	Pavg_LIO	Pavg_LMF	0.061	0.757
ABM	Wavg_LIO	Wavg_LMF	−0.048	0.807
ABM	Pavg_LIO	Pavg_RMF	−0.210	0.284
ABM	Wavg_LIO	Wavg_RMF	−0.131	0.507
ABM	Pavg_LEO	Pavg_LMF	0.137	0.488
ABM	Wavg_LEO	Wavg_LMF	−0.103	0.602
ABM	Pavg_LEO	Pavg_RMF	−0.193	0.324
ABM	Wavg_LEO	Wavg_RMF	0.241	0.216

Sup = Supine, ADIM = Abdominal Drawing In Maneuver, ABM = Abdominal Bracing Maneuver, L = Left, R = Right, EO = External Oblique, IO = Internal Oblique, Mf = Multifidi, B = "Pull your belly button up and in towards your shoulder blades," S = "Pull your abdominal muscles away from front elastic on the shorts," A = "Pull the two front pelvic bones together," P = "Prepare to be punched in the belly," W = "Imagine making your trunk/waist wide".

Appendix G. The Pearson's Correlation Coefficient results of ADIM and ABM clustered data sets for all tested muscles in Standing

Strategy	Muscle 1	Muscle 2	Pearson's Correlation Coefficient	p-value
ADIM	Bavg_LIO	Bavg_LMf	−0.037	0.852
ADIM	Savg_LIO	Savg_LMf	0.145	0.461
ADIM	Aavg_LIO	Aavg_LMf	0.128	0.517
ADIM	Bavg_LIO	Bavg_RMf	0.024	0.903
ADIM	Savg_LIO	Savg_RMf	0.165	0.402
ADIM	Aavg_LIO	Aavg_RMf	0.221	0.258
ADIM	Bavg_LEO	Bavg_LMf	0.274	0.158
ADIM	Savg_LEO	Savg_LMf	0.133	0.499
ADIM	Aavg_LEO	Aavg_LMf	0.173	0.378
ADIM	Bavg_LEO	Bavg_RMf	0.346	0.071
ADIM	Savg_LEO	Savg_RMf	0.072	0.714
ADIM	Aavg_LEO	Aavg_RMf	0.248	0.203
ABM	Pavg_LIO	Pavg_LMF	−0.013	0.948
ABM	Wavg_LIO	Wavg_LMF	0.000	0.999
ABM	Pavg_LIO	Pavg_RMF	0.107	0.589
ABM	Wavg_LIO	Wavg_RMF	0.130	0.508
ABM	Pavg_LEO	Pavg_LMF	−0.036	0.856
ABM	Wavg_LEO	Wavg_LMF	0.125	0.527
ABM	Pavg_LEO	Pavg_RMF	−0.047	0.812
ABM	Wavg_LEO	Wavg_RMF	0.174	0.376

Sup = Supine, ADIM = Abdominal Drawing In Maneuver, ABM = Abdominal Bracing Maneuver, L = Left, R = Right, EO = External Oblique, IO = Internal Oblique, Mf = Multifidi, B = "Pull your belly button up and in towards your shoulder blades," S = "Pull your abdominal muscles away from front elastic on the shorts," A = "Pull the two front pelvic bones together," P = "Prepare to be punched in the belly," W = "Imagine making your trunk/waist wide".

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