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Revisiting the effect of manipulating lumbar stability with load magnitudes and positions: The effect of sex on trunk muscle activation

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ABSTRACT

Background: Lumbar spine stability is regularly studied by positioning different loads at different heights and distance and measuring trunk muscle activation changes. Some of these studies have reported sex differences, but this needs to be revisited while controlling for confounding factors.
Method: 20 males and 20 females sustained three static standing postures, with various loads (0, 5 and 10% of body weight), to evaluate the effect of height and distance. Activation of 12 trunk muscles was recorded with surface electromyography (EMG).
Results: Females activated their external obliques a little more than males, with increases ranging between 1.5 and 2.3% of maximal voluntary activation (MVA), which corresponds to strong effect sizes (Cohen's d ranging between 0.86 and 1.13). However, the significant Sex × Height, Sex × Distance and Sex × Load interactions observed for different trunk muscles led to small differential effects ($\leq$1% MVA). Increasing load height slightly increased and decreased back and abdominal muscle activation, respectively, generally by less than 1% MVA.
Conclusion: The higher activation of the external obliques observed in females might be of clinical value, relative to the required overall trunk muscle activation (5%), to preserve lumbar stability. Other effects were negligible.

1. Introduction

Spinal instability manifests itself via excessive flexibility (e.g. hypermobility) causing injuries and pain. Using spine biomechanical modeling, Bergmark (1989) showed the manifest importance of trunk musculature and neural activity to ensure spinal stability. Empirical evidence supports the role of trunk muscles in spinal stability and demonstrates trunk muscle cocontraction in response to simultaneous changes in external moment and stability (Cholewicki et al., 1997).

Granata and Orishimo (2001) were the first to isolate the effect of stability by manipulating the potential energy of the system (lifting loads at different heights) while maintaining the external moment constant. The findings demonstrated that back (i.e., agonists) and abdominal (i.e., antagonists) muscle activation increased at higher load elevations, and more so with a heavier load. These findings were replicated in other in vivo studies (Calder and Potvin, 2012; Crommert et al., 2011; Shojaei et al., 2018) while spine modeling in vitro studies further showed that this behavior is associated with increased lumbar stiffness and lumbar stability (Arjmand et al., 2008). Interestingly, Granata and Orishimo (2001) also observed that females recruited 32% more of their abdominals than males. However, as acknowledged in their discussion, they did not control some confounding variables, limiting the interpretation of their findings.

When looking at sex differences, three elements hinder interpretations, namely (1) not normalizing muscle activity, (2) using absolute loads (4.5 and 9.0 kg) regardless of subject strength and (3) lifting at absolute heights (0, 20, 40, 60 and 80 cm) regardless of subject body height (Granata and Orishimo, 2001). To our knowledge, only one other study examined sex differences, but confounding factors were not ruled out (Shojaei et al., 2018). In fact, in both studies, the authors reported the percentage changes of non-normalized muscle activity. Revisiting previous studies while controlling for these factors will help put previous findings in perspective. The increase of abdominal muscle activation associated with an increase of the extension moment by increasing load distance (Crommert et al., 2011) is another strategy to test whether males and females have a different control of lumbar

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stability.

The purpose of this study is to assess trunk muscle activation responses to specific challenges in lumbar stability (load height and distance) in males and females. It was hypothesized (H1) that females activate their abdominal and back muscles more than males with increasing load height (SEX × HEIGHT interaction) and distance (SEX × DISTANCE interaction), (H2) these SEX effects will be furthered increased as the load increases (SEX × HEIGHT × LOAD and SEX × DISTANCE × LOAD interactions). Only the SEX × HEIGHT interaction is clearly supported by previous findings (Granata and Orishimo, 2001) but this pattern might be reflected in SEX × DISTANCE as well as increasing distance also increase abdominal activation (Crommert et al., 2011). As increasing load increases potential energy (as height does) and extension moment (as distance does), it may further increase sex effects (significant 3-way interactions).

2. Methods

2.1. Subjects

Forty healthy participants (20 females, 20 males), aged 18 to 65 but age-matched between sexes, participated. Exclusion criteria were back pain, neck pain or pain in the upper limbs (shoulders, arms, lower-arms, hands) in the preceding month; surgery of the pelvis or spinal column; scoliosis; systemic or degenerative disease; body mass index (BMI) greater than 26 kg^2/m; one positive response to the Physical Activity Readiness Questionnaire (Thomas et al., 1992); history of neurological diseases or deficits not related to back pain (e.g., stroke, peripheral neuropathies, balance deficits); pregnancy; claustrophobia. Exclusion criteria related to BMI and the Physical Activity Readiness Questionnaire were to ensure a high correlation between the shape of the back and that of the spine (Dreischarf et al., 2016) and to eliminate those likely to have heart problems, respectively. Most participants were recruited through physical therapy and kinesiology departments of University of Montreal to increase the likelihood of participants having good motor control abilities. All participants were informed of the experimental protocol and potential risks, and signed written consent before participation. The ethics committee of the Center for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR) approved the study and the consent form.

2.2. Experimental conditions and control of confounding variables.

Three randomly assigned upright standing 5-s isometric lifting postures (Fig. 1) were adopted using three randomly assigned load magnitudes: (1) no load (only the bar: 0.44 kg); (2) 5% of body weight (BW); (3) 10% BW. This loading strategy was found better than determining the load according to back strength as shoulder strength had to be considered as well. It was estimated that 10% BW was the maximum load that could be lifted in P3 by the weakest male and female subjects, using previously published data on shoulder flexor strength in the same position (MacDonell and Keir, 2005).

A simple model was developed in Excel to estimate the L5/S1 extension moment generated by the loads and upper-limb segments, using upper-limb body segment parameters (de Leva, 1996), easily measurable inputs (body weight, upper-arm and lower-arm lengths) and estimation of the position of their centre of mass in postures P1, P2 and P3. Moments generated by the trunk and head were neglected.

The trunk overall posture, as measured with the C7 sensor, was kept in the vertical position with the provision of feedback on a screen positioned in front of the subject. To help the subject keeping this vertical trunk position, especially during the task where the load is far from the body, a stabilizing device was positioned below the knee and behind the heels (Fig. 1). Finally, one of the investigators observed the subject to make sure that the L5/S1 joint was not moving horizontally during the tasks. In case of horizontal motion of L5/S1, the trial was stopped and repeated after rest.

2.3. Measurement techniques

Dynamometry. Maximal voluntary contractions (MVC) in six directions (flexion, extension, left and right lateral bending and axial rotation) were performed while standing in an isometric trunk dynamometer, as more thoroughly described elsewhere (Lariviere et al., 2001b). Two trials per direction were performed, with 2-min rest after each trial. Real-time visual feedback of the L5/S1 moment was provided in the primary plane of effort, as well as strong verbal encouragements (Jung and Hallbeck, 2004). The maximal EMG values were retained for EMG normalization purposes while lumbar strength in extension (maximal L5/S1 moments) was computed as reference for latter analyses.

Electromyography. The EMG signals were collected with a Bagnoli-16 system (DS-B04; Delsys Inc., Wellesley, MA) and 14 differential dry surface electrodes (Model DE-2.1, Delsys Inc., Wellesley, MA; bandwidth 20 ± 5 Hz to 450 ± 50 Hz, 80 dB/decade; preamplification gain: 10; CMRR: > 90 dB; noise < 1.2 μV (RMS, R.T.I.)) composed of two parallel silver bars (10 mm long, 1 mm wide) spaced 10 mm apart. After shaving and abrading the skin with alcohol at the electrode sites,

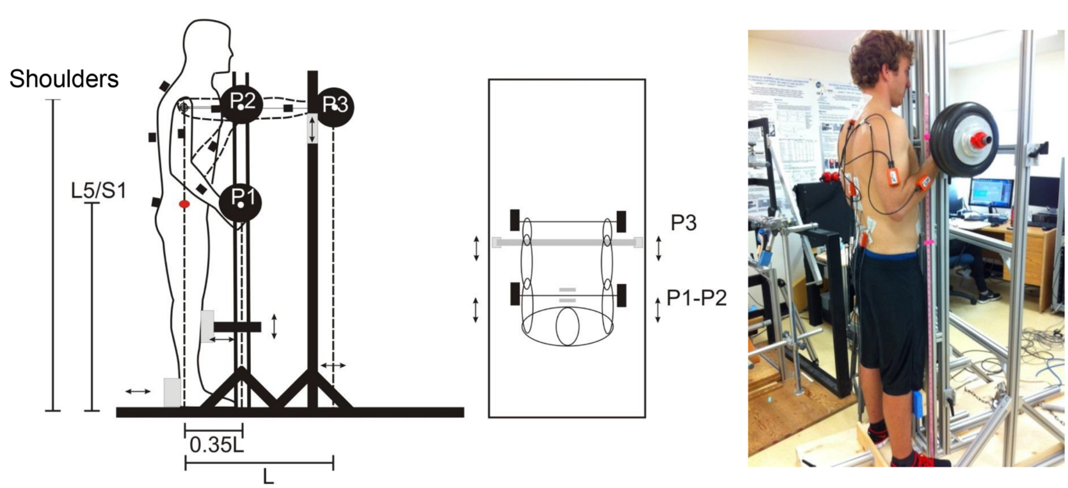

Fig. 1. Illustration of the three postures (P1, P2 and P3), P1 and P2 for testing the HEIGHT effect (L5/S1 and shoulder heights) and P2 and P3 for testing the DISTANCE effect (close: 0.35L, far: L – upper-limb length) at the shoulder level. The vertical structures allow standardization of the position of the whole body and of the upper-limbs across load conditions.

Table 1
Subject demographic, anthropometric, strength, posture and load characteristics.

Variable	Females (n = 20)	Males (n = 20)	*t*-test
	Mean ± SD	Mean ± SD	*p* value
Age (yrs)	23.0 ± 2.2	23.2 ± 2.3	0.724
Height (m)	1.67 ± 0.05	1.81 ± 0.06	< 0.001
Mass (kg)	59.7 ± 7.3	73.2 ± 6.2	< 0.001
BMI (m/kg^2)	21.5 ± 2.2	22.4 ± 1.8	0.178
Back strength (L5/S1 moment in Nm)	166 ± 33	271 ± 70	< 0.001
Lumbar curvature (°)*	31.6 ± 8.4	27.4 ± 8.7	0.127
Distance L5/S1 to guided-bars (cm)	20.1 ± 1.2	22.7 ± 0.9	< 0.001
Distance shoulders to guided-bars (cm)	21.5 ± 3.5	22.4 ± 3.1	< 0.001
Distance L5/S1 to shoulders (cm)	34.4 ± 2.6	38.3 ± 1.9	< 0.001
Load (kg) for 5% of body weight	2.9 ± 0.5	3.6 ± 0.3	< 0.001
Load (kg) for 10% of body weight	6.0 ± 0.9	7.2 ± 0.6	< 0.001

M ± SD: Mean ± standard deviation; BMI: Body Mass Index.
* : measured with dual inclinometry.

the electrodes were positioned bilaterally over the multifidus at the L5 level (MU-L5, ~3 cm from the midline of the back), iliocostalis lumborum at L3 (IL-L3, ~5–6 cm from midline), longissimus at L1 (LO-L1, ~3 cm from midline) as detailed elsewhere (Lariviere et al., 2001a), in accordance with the SENIAM (Surface EMG for Non-Invasive Assessment of Muscles) standards for back muscles electrode placement (Hermens et al., 1999). Two additional electrodes were positioned on the belly of the longissimus at the T10 level (LO-T10, ~5 cm from midline). The difficulty in capturing the lumbar multifidus muscle with surface electrodes (Stokes et al., 2003) is acknowledged, and therefore, the validity of this EMG signal was assigned to the landmarked location (L5) rather than to the multifidus muscle itself. Electrodes on the abdominals were positioned bilaterally over the rectus abdominis (RA, ~2 cm up and 2 cm lateral to the umbilicus), the external and internal obliques (EO and IO) (McGill, 1991). A silver-silver chloride reference electrode (Medi-Trace model, Graphic Controls Canada Limited, Gananoque, Ont., Canada) was positioned over the C7 spinous process. EMG signals were A/D converted at a sampling rate of 1000 Hz (12-bits National Instruments PCI6024E card) and stored on a hard disk for later analysis.

2.4. Procedures

1. Anthropometric measurements (height, weight, upper limb segment lengths);
2. Quantification of lordosis using the dual-inclinometer technique;
3. Positioning of EMG electrodes;
4. Maximal voluntary contractions (MVCs): 6 directions × 2 trials/direction = 12 trials;
5. Positioning and calibration of motion sensors (n = 5) – see supplementary file
6. Experimental conditions (n = 9; counterbalanced between sexes).
   - Familiarization trial before each new posture and load;
   - Experimental conditions: 3 postures × 3 loads × 2 consecutive trials = 18 5-s efforts.

2.5. Signal processing

For each experimental condition, the EMG and kinematics variables were computed using the signals corresponding to the middle 3 s of each 5-s trial.

Electromyography. All EMG signals were bandpass filtered (30 and 450 Hz; 8th order zero-lag Butterworth IRR filter) to remove high frequency noise as well as low-frequency movement and electrocardiogram artifacts. The electrocardiogram is dominant in trunk EMG signals, which mandated the use of a high-pass cut-off frequency [30 Hz; (Redfern et al., 1993)] that is above what is recommended (10 Hz) to remove movement artefacts (JEK standards for reporting EMG data). For the EMG signals recorded during the MVCs, root mean square (RMS) values were calculated over successive (10-ms overlapped) 250-ms time-windows. Then, for each muscle, the peak EMG RMS activity in any of the six exertion directions (hereafter called MVA) was determined as efforts in different directions assist in finding MVA for each trunk muscle. Finally, the RMS scores computed during the experimental conditions were normalized to their muscle-specific MVA value.

2.6. Statistical analyses

The EMG and kinematics variables were first averaged across the two trials and then the EMG variables were further averaged across homologous muscles.

Three-way ANOVAs (2 POSTURE × 3 LOAD × 2 SEX) for repeated measures on two factors (POSTURE, LOAD) were performed to test for differences between two postures (Height-study: P1 vs P2; Distance-study: P2 vs P3), between loads (0, 5% and 10% BW) and between sexes (males, females). The dependent variables were the controlled variables (trunk angle as measured with the T1/T2 sensor, L5/S1 relative loading) and the outcome variables of interest (EMG activation, lumbar curvature). Post hoc comparisons were performed with the Tukey-Kramer test. Effect sizes corresponding to effects detected for between-subjects (SEX) and within-subjects (HEIGHT, DISTANCE, LOAD) factors were computed using the Cohen d_s and d_{av} formulations, respectively (Lakens, 2013), as well as means, SDs and sample sizes (d ~ 0.2 is :“low”, 0.5 “average” and 0.8 “strong”).

3. Results

While males and females were the same age and BMI, males were taller and heavier, as expected (Table 1). Males were also stronger with regard to back and shoulder muscles, as also expected, but lumbar curvature was similar, although a little more lordotic in females (by 4°). The loads and their position across subjects are also described in Table 1.

The L5/S1 relative loads generated during the Height-study experimental conditions ranged approximately between 2 and 9% MVC (Fig. 2). During the Distance-study, the L5/S1 relative loads almost reached 30% MVC when the maximal load (10% BW load) was sustained at the maximal distance (P3). As detailed in the supplementary file, the relative L5/S1 loading and trunk posture are not significantly different between males and females. The lumbar curvature was affected by various interactions, but all effects (from pairwise comparisons) were equal or below 2° (supplementary file).

No three-way interactions were statistically significant for any EMG (H2 rejected), so only two-way interactions are presented hereafter.

Table 2
Statistical results (*p*-values) corresponding to the Height-study with regard to trunk muscle activation outcomes.

Electrode	ANOVA *p*-values						Post-hoc test (Tukey-Kramer)		
site	SEX (S)	HEIGHT (H)	LOAD (L)	S × H	S × L	H × L	SEX*	HEIGHT†	LOAD‡
MU-L5	0.640	< **0.001**	< **0.001**	0.928	0.324	< **0.001**	/	P1 < P2 (d = 0.09)	L0 < L5 (d = 0.47) L0 < *L*10 (d = 0.91) L5 < *L*10 (d = 0.62)
IL-L3	0.924	**0.001**	< **0.001**	0.977	0.349	0.078	/	P1 < P2 (d = 0.05)	L0 < L5 (d = 0.39) L0 < *L*10 (d = 0.82) L5 < *L*10 (d = 0.42)
LO-L1	0.345	< **0.001**	< **0.001**	0.234	0.333	< **0.001**	/	P1 < P2 (d = 0.20)	L0 < L5 (d = 1.46) L0 < *L*10 (d = 2.12) L5 < *L*10 (d = 0.90)
LO-T10	0.504	< **0.001**	< **0.001**	**0.002**	0.776	**0.003**	/	P1 < P2 (d = 0.29)	L0 < L5 (d = 1.30) L0 < *L*10 (d = 1.83) L5 < *L*10 (d = 0.69)
RA	0.129	< **0.001**	**0.031**	**0.011**	0.159	**0.001**	/	P1 > P2 (d = -0.14)	L0 > L5 (d = 0.13)
IO	0.867	0.702	< **0.001**	0.667	0.078	0.903	/	/	L0 < L5 (d = 0.13) L0 < *L*10 (d = 0.31) L5 < *L*10 (d = 0.18)
EO	**0.001**	< **0.001**	0.491	0.129	0.120	**0.008**	F > M (d = 0.96)	P1 > P2 (d = −0.20)	/

* M: males; F: females; *d:* Cohen d.
† P1: L5-S1 height; P2: shoulder height; ‡ L0: 0% BW; L5: 5% BW; *L*10: 10% BW (body weight).

3.1. EMG results from the Height-study (Table 2)

Activity of back muscles. All back muscles were more activated as the height and load increased. The significant SEX × HEIGHT interaction (H1) for LO-T10 showed that elevating the load increased activation in males more (by 1.3% MVA) than females (by 0.7% MVA). HEIGHT × LOAD interactions (Fig. 3) reached statistical significance for all except one back muscle (IL-L3; p = .078). Overall, as height increased, activity of the various back muscles increased by 0.4 to 0.8% MVA, with slight differences between loads (explaining the interactions), except for LO-T10 which showed increases of 1.0 and 1.2% MVA for 5 and 10% BW loads, respectively. Ignoring these small interactions, the main HEIGHT effects were relatively small, all effect sizes being lower than 0.30. The highest effect (1% MVA), corresponding to a 21% change, was observed for LO-T10.

Activity of abdominal muscles. Females showed significant more activity than men, but for EO only (♀ > ♂; 4.5 ± 1.8% > 2.8 ± 1.6% MVA; d = 0.96). RA showed a significant SEX × HEIGHT interaction (H1), activation in males decreasing less (by 0.1% MVA) than females (by 0.4% MVA). Two HEIGHT × LOAD interactions were significant. Increasing the load height, decreased the RA activity more with a 0% BW load (by 0.5% MVA) than with a 5% BW or 10% BW load (by 0.1% MVA),

Table 3
Statistical results (*p*-values) corresponding to the Distance-study with regard to trunk muscle activation outcomes.

Electrode	ANOVA *p*-values						Post-hoc test (Tukey-Kramer)		
site	SEX (S)	DISTANCE(D)	LOAD (L)	S × D	S × L	D × L	SEX*	DISTANCE†	LOAD‡
MU-L5	0.448	< **0.001**	< **0.001**	0.580	0.174	**0.031**	/	P2 < P3 (d = 1.48)	L0 < L5 (d = 0.57) L0 < *L*10 (d = 1.00) L5 < *L*10 (d = 0.46)
IL-L3	0.878	< **0.001**	< **0.001**	0.301	**0.021**	< **0.001**	/	P2 < P3 (d = 1.51)	L0 < L5 (d = 0.69) L0 < *L*10 (d = 1.14) L5 < *L*10 (d = 0.56)
LO-L1	0.568	< **0.001**	< **0.001**	0.592	**0.001**	< **0.001**	/	P2 < P3 (d = 1.86)	L0 < L5 (d = 0.89) L0 < *L*10 (d = 1.33) L5 < *L*10 (d = 0.58)
LO-T10	0.767	< **0.001**	< **0.001**	0.339	0.119	**0.002**	/	P2 < P3 (d = 1.51)	L0 < L5 (d = 0.85) L0 < *L*10 (d = 1.25) L5 < *L*10 (d = 0.51)
RA	0.107	< **0.001**	< **0.001**	**0.001**	**0.014**	< **0.001**	/	P2 < P3 (d = 0.28)	L0 < L5 (d = 0.20) L5 < *L*10 (d = 0.16) L0 < *L*10 (d = 0.37)
IO	0.934	< **0.001**	< **0.001**	0.846	0.182	< **0.001**	/	P2 < P3 (d = 0.49)	L0 < L5 (d = 0.30) L5 < *L*10 (d = 0.38) L0 < *L*10 (d = 0.65)
EO	**0.001**	< **0.001**	< **0.001**	0.085	0.145	< **0.001**	F > M (d = 0.79)	P2 < P3 (d = 0.41)	L0 < L5 (d = 0.25) L5 < *L*10 (d = 0.35) L0 < *L*10 (d = 0.56)

* M: males; F: females; *d:* Cohen d.
† P2: shoulder height – close; P3: shoulder height – far; ‡ L0: 0% BW; L5: 5% BW; *L*10: 10% BW (body weight).

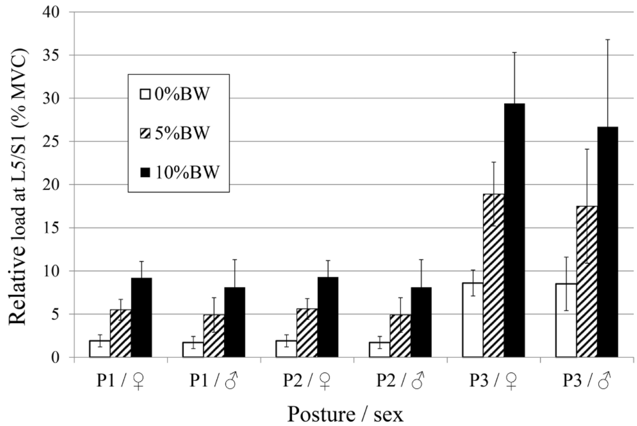

Fig. 2. Averaged relative load at L5/S1 (extension moment) corresponding to the postures, load magnitude and sex.

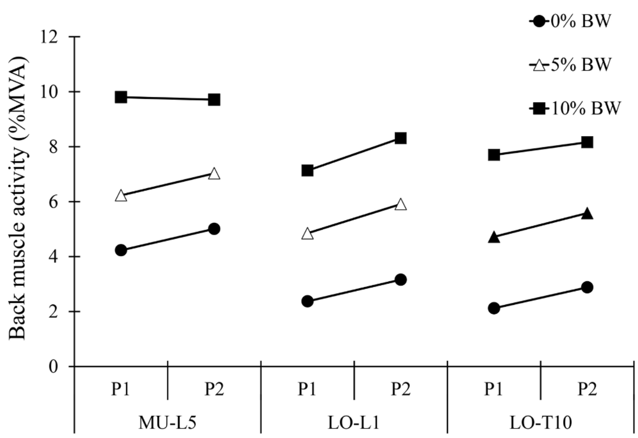

Fig. 3. Statistically significant HEIGHT × LOAD interactions on back muscle activity, namely the multifidus at L5 (MU-L5), longissimus at T10 (LO-T10) and longissimus at L1 (LO-L1). Standard deviations are not displayed for clarity but their range, across postures and load magnitudes, were 3.4 – 6.6% MVA for MU-L5, 1.0 – 3.9% MVA for LO-L1 and 1.1 – 3.8% MVA for LO-T10.

while the EO activity decreased more with a 0% BW load (by 0.7% MVA) than with a 5% BW or 10% BW load (by 0.1% MVA). Ignoring these small interactions, the HEIGHT effects observed for RA and EO were small (d = −0.14 and −0.20), which corresponds to a −10% change.

3.2. EMG results from the Distance-study (Table 3)

Activity of back muscles. All back muscles were more activated as the distance and load increased. IL-L3 and LO-L1 showed a significant SEX × DISTANCE interaction (H1), activation in females increasing more (by 4.0 and 10.0% MVA, respectively) than males (by 3.0 and 4.5% MVA, respectively). As expected, all DISTANCE × LOAD interactions were statistically significant.

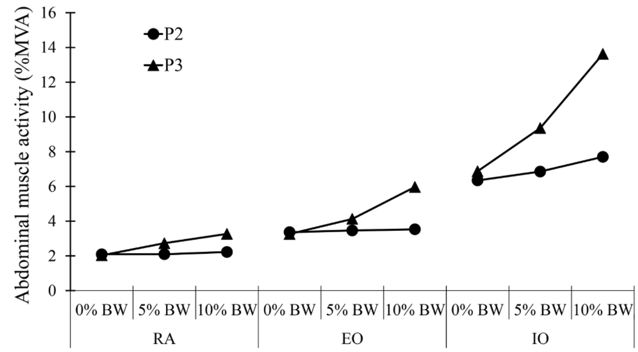

Fig. 5. Statistically significant DISTANCE × LOAD interactions on abdominal muscle activity, namely the rectus abdominis (RA), the external obliques (EO) and internal obliques (IO). Standard deviations are not displayed for clarity but their range, across postures and load magnitudes, were 1.4 – 2.6% MVA for RA, 1.7 – 3.9% MVA for EO and 4.4 – 9.1% MVA for IO.

Activity of abdominal muscles. Females showed significant more activity than men, again for EO only (♀ > ♂; 4.9 ± 2.8% > 3.0 ± 1.9% MVA; d = 0.79). Two interactions involving the SEX factor were observed for RA (Fig. 4). SEX × DISTANCE (H1) showed that activation increased more in females (by 1.0% MVA) than in males (by 0.3% MVA), while SEX × LOAD showed the same increases, that is, activation increased more in females (by 1.0% MVA) than in males (by 0.3% MVA) across load levels. DISTANCE × LOAD interactions were also statistically significant for all abdominal muscles. The DISTANCE effect was absent at 0% BW but increased in importance as the load increased (Fig. 5). More specifically, as can be observed in Fig. 5, this interaction was relatively small for RA and progressively increased for EO and then, IO. The corresponding difference between P2 and P3, for a 10% BW, reached 1.0 (d = 0.48), 2.4 (d = 0.82) and 6.1% MVA (d = 0.82) respectively.

4. Discussion

The main findings of this study show that (1) females demonstrated higher EO activation than males for each posture (P1, P2, P3), but the significant SEX × HEIGHT (LO-T10; RA), SEX × DISTANCE (IL-L3, LO-L1, RA) and SEX × LOAD (RA) interactions were small and not in the expected direction (H1 rejected); (2) none of the three-way interactions were statistically significant (H2 rejected). Increasing load height slightly increased and decreased back and abdominal muscle activation,

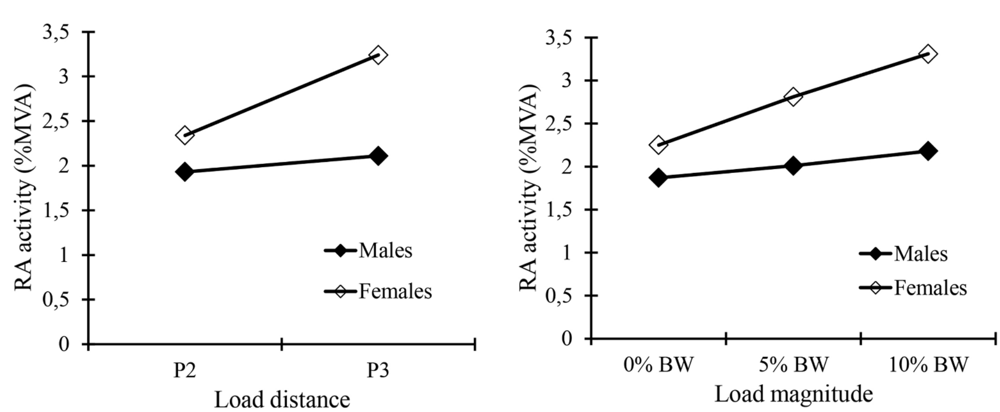

Fig. 4. Statistically significant SEX × DISTANCE (left plot) and SEX × LOAD (right plot) interactions on rectus abdominis (RA) activation for the Distance-study. Standard deviations are not displayed for clarity but their range were 1.5 – 2.4% MVA (left plot) and 1.4 – 2.3% MVA (right plot).

respectively. The DISTANCE × LOAD interaction was significant for abdominal muscle activation only.

Before discussing the EMG findings, it can be concluded that the L5/S1 relative loading, trunk posture and lumbar curvature cannot explain the effects discussed below (see supplementary file).

4.1. Effect of SEX on trunk muscle activation

The SEX factor involved four interactions, namely two SEX × HEIGHT for LO-T10 and RA (Height-study) and two SEX × LOAD for IL-L3 and LO-L1 (Distance-study), but the between-group differences across heights or loads were all less than 1% and are consequently considered clinically negligible. Consequently, the main SEX effect can be interpreted without considering the other factors.

Females showed significantly more EO activity than males, with a strong effect size at P1 (d = 1.13), P2 (d = 0.86) and P3 (d = 1.00), females showing activations ranging between 4.2 and 5.6% MVA and males between 2.7 and 3.3% MVA across postures. The differences were relatively small (P1 = 1.9; P2 = 1.5; P3 = 2.3% MVA), but might not be negligible considering that only about 5% of overall trunk muscle activation is required to preserve lumbar stability in the standing upright position (Cholewicki et al., 1997). To compare with the 32% increase of EO and RA combined activity reported by Granata and Orishimo (2001), which reflects the percentage changes between raw EMG amplitudes (EMG not normalized to maximal EMG), the SEX effects observed here for EO were reported as percentage changes as well, which leads to 39 and 34% for P1 and P2, respectively, and 42% for P3. The present findings allow a better understanding of this SEX effect, actually ~ 1.5–2% MVA, without the influence of confounding variables. Others have also observed higher activity of different trunk muscles in females during therapeutic exercises (Arokoski et al., 2001, Arokoski et al., 1999; Cynn et al., 2006), but these results may be due to a higher relative load generated by the body segments in females.

Why is this so? Females may be better at activating the trunk muscles to stabilize the lumbar spine (protective effect). Alternatively, females may activate their trunk muscles more because they have less passive lumbar stiffness, which is supported by studies estimating intrinsic stiffness with protocols inducing small trunk disturbances in the standing position (Hendershot et al., 2011; Muslim et al., 2013). The overall mean prevalence (across studies) of LBP across all age groups, which is higher in females (35%), comparatively to males (29%) (Hoy et al., 2012), might be partially explained by lumbar stiffness. However, no sex differences were observed in other measures related to intrinsic stiffness or lumbar stability, such as direct measures obtained on vertebral units (Kumar, 2011) or estimates of dynamic lumbar stability during repeated trunk movements (Graham et al., 2012; Granata and Gottipati, 2008). A better understanding of how these different outcomes are interrelated is necessary to better appreciate the clinical/biomechanical significance of these sex effects.

4.2. Interaction of LOAD with HEIGHT and DISTANCE

Significant HEIGHT × LOAD interactions were reached for all but two muscles (IL-L3, IO), but all revealed negligible interactions, allowing us to interpret the HEIGHT main effect with confidence. However, all effect sizes corresponding to the HEIGHT effect were small ($d < 0.30$) as MU-L5 and LO-L1 back muscle activity increased by 0.4–0.8% MVA while RA and EO abdominal muscle activity decreased by 0.5% MVA at best. Only the LO-T10 back muscle activity increased by 1 to 1.2% MVA, which represents ~20% of the overall trunk muscle activation (5% MVA) required to preserve lumbar stability in the standing unloaded upright position (Cholewicki et al., 1997). However, this small effect (d = 0.29) likely has a limited biomechanical effect.

Two studies (Calder and Potvin, 2012; Shojaei et al., 2018) addressed approximately the same questions (Height-study) as Granata and Orishimo (2001), but again, only percentage of changes in muscle activation with regard to the control condition were reported. Calder and Potvin (2012) observed significant increases in activity of 14 out of 15 back and abdominal muscles as load was elevated, ranging between 114 and 148% at 40 cm and between 142 and 212% at 70 cm. When comparing the no-load condition, Shojaei et al. (2018) detected no effect of elevating the load at 30 cm (0–10% of maximal trunk flexion) on abdominal muscles, while for back muscles, only males showed an increase (57%–94% at high height, 37% at low height), but only with the lowest load (3.5 kg). In the present study, the highest effect sizes were observed for LO-L1 (d = 0.62) and LO-T10 (d = 0.62) with 0% BW load, these ~ 0.7% MVA effects corresponded to a 33–36% change. For RA and EO, the highest effect sizes (d = −0.33 and −0.38) were also seen with 0% BW load, these ~ 0.5–0.7% MVA effects corresponded to a −18 to −20% change.

The findings of the Height-study differed (effects amplitudes and directions) from previous studies (Calder and Potvin, 2012; Granata and Orishimo, 2001; Shojaei et al., 2018). While our experimental conditions are comparable with regard to the range of loads sustained (here: 2.9–7.2 kg; Granata: 4.5–9.0 kg (13.2–26.5 Nm); Calder: 6.7 to 13.3 Nm; Shojaei: 3.5–7 kg) and to the horizontal distance from L5/S1 (here: 20–23 cm; Granata: 30 cm; Calder: 25 cm; Shojaei: not reported), the present study and the Shojaei studies considered a much lower range of heights (here: 34–38 cm; Granata: up to 80 cm; Calder: up to 70 cm; Shojaei: ~30 cm). This likely explains why both the Shojaei and present study findings were not as strong and consistent. Moreover, sex differences may be more obvious (for more than one muscle group) with the consideration of greater heights.

One study provided results that can be directly contrasted with the present study. Crommert et al. (2011) used free weights of 3 kg (6 kg total) positioned around the sacrum (position 3) and above the head (position 5), at approximately 20–30 cm (lever arm). Using intramuscular electrodes for TrA and IO, they observed a HEIGHT effect for TrA (~4% MVA) while no significant increase (~1% MVA) was observed for the IO, RA (no EO EMG) and erector spinae muscles (n = 11 males). Interestingly, when positioning the free weight at the hip, shoulder and over the head (arms extended) on the side of the body (minimal lumbar moment), the TrA activity increased even more (from ~ 7%, 10% and 16% MVA), but again without significant reaction of the other muscles (~2–3% MVA).

The significant DISTANCE × LOAD interactions on abdominal muscles showed that their cocontraction was minimal for RA, moderate for EO and strong for IO, which reflects the same relative contributions to lumbar stability as simulated in a modeling study (Arjmand et al., 2008) and measured in other in vivo studies (Crommert et al., 2011; Silfies et al., 2005)

The results of our study should be interpreted in the light of our study limitations. These results cannot be generalized to people with back pain. Results are also limited to young adults (18–30 years) as trunk muscle activation is different in older subjects during standing isometric (Kienbacher et al., 2016) and dynamic tasks (Crawford et al., 2018; McGill et al., 1999). The load applied on the lower back was low (limited by the shoulder strength) and the task involved short isometric contractions with the trunk in the upright position, which may affect the generalizability of the findings to normal activities. For example, increased stiffness of the trunk (via increased trunk muscle activation) with the increase of the stability demand (height) and equilibrium demand (load and distance in the present study) was observed only when the background stiffness was low, namely when the trunk was in the upright position (Shojaei et al., 2018). Finally, while deep muscles have been recognized to be important in stabilizing the lumbar spine, surface EMG limited the investigation to trunk superficial muscles.

5. Conclusion

The only sex effect (but a strong one) was observed for EO, with females showing more activity than males at each posture to the extent of having some biomechanical/clinical significance. The statistically significant interactions of sex with other factors (height, distance, load) did not change these sex effects enough to have further biomechanical/clinical significance. Contrary to expectations, increasing load height only negligibly increased and decreased back and abdominal muscle activation, respectively. On the other hand, the interaction between load and distance factors was significant for the antagonist abdominal muscles. The highest cocontraction was seen for IO, followed by EO and then RA, which is suggestive of their relative contribution to lumbar stability.

Conflict of interest

There are no known conflicts of interest associated with this publication and there has been no financial support for this work that could influence its outcome.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jelekin.2019.03.001.

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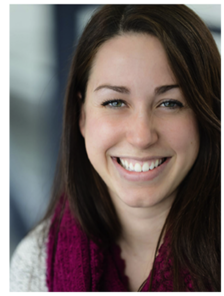

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