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Changes in muscle activation patterns and subjective low back pain ratings during prolonged standing in response to an exercise intervention

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ABSTRACT

Background: Low back pain (LBP) development has been associated with occupational standing. Increased hip and trunk muscle co-activation is considered to be predisposing for LBP development during standing in previously asymptomatic individuals. The purpose of this work was to investigate muscle activation and LBP responses to a prescribed exercise program. Pain-developing (PD) individuals were expected to have decreased LBP and muscle co-activation following exercise intervention.
Methods: Electromyography (EMG) data were recorded from trunk and hip muscle groups during 2-h of standing. An increase of >10 mm on visual analog scale (VAS) during standing was threshold for PD categorization. Participants were assigned to progressive exercise program with weekly supervision or control (usual activity) for 4 weeks then re-tested.
Results: Forty percent were categorized as PD on day 1, VAS = 24.2 (±4.0) mm. PD exercisers (PDEX) had lower VAS scores (8.93 ± 3.66 mm) than PD control (PDCON) (16.5 ± 6.3 mm) on day 2 ($p = 0.007$). Male PDEX had decreased gluteus medius co-activation levels ($p < 0.05$) on day 2.
Discussion: The exercise program proved beneficial in reducing LBP during standing. There were changes in muscle activation patterns previously associated with LBP. Predisposing factors for LBP during standing were shown to change positively with appropriate exercise intervention.

1. Introduction/background

Low back pain (LBP) is a major contributor to escalating health care costs and disability in North America. Epidemiological studies have shown that standing occupations have a strong association with LBP development (Andersen et al., 2007; Roelen et al., 2008; Tissot et al., 2009). Checkout clerks, bank tellers, assembly line workers and individuals in other occupations often have long periods of standing and are known to develop LBP as the length of time on their feet increases (Kim et al., 1994). In a 2-year prospective study of Danish workers across 30 different industries, Andersen and colleagues (2007) found requiring prolonged periods of occupational standing (>30 min out of each hour) was one of the strongest predictors of LBP with a hazard ratio of 2.1 (95% CI 1.3–3.3). Another study in Dutch workers reported that prolonged standing was related to increased pain reporting in the low back and thoracic region (Roelen et al., 2008).

A functionally induced LBP protocol that simulates occupational standing has been previously used to identify and characterize clinical and biomechanical factors that predispose individuals to develop LBP during prolonged standing (Nelson-Wong and Callaghan, 2010; Nelson-Wong et al., 2008; Gregory and Callaghan, 2008). This model is unique in that participants in these studies were required to have no prior history of LBP, and only a percentage of participants developed LBP during the protocol. This enabled the differentiation of pain developers (PD) from non-pain developers (NPD) based on factors that differed between the two groups in the early stages of the standing exposure and prior to subjective complaints of LBP (Nelson-Wong and Callaghan, 2010).

Most clinical guidelines for the treatment of LBP include some form of supervised exercise as an intervention (Airaksinen et al., 2006) and exercise is an accepted part of physical therapy practice. Exercise based interventions are included as a stand-alone first-line treatment or as an adjunct to manual therapy for patients with LBP in most practice patterns (Ferreira et al., 2007; Hayden et al., 2005). In a systematic review, Hayden and colleagues (2005) found that the most effective exercise intervention strategy was to individually tailor a program to the patient, deliver it in a supervised format with regular follow-up with the therapist, and encourage patient adherence to the program in order to achieve high dosage. These authors also reported that exercise programs with an emphasis on muscle strengthening appear to be most effective. Other research has investigated the response to stabilization-based

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exercise intervention in patients with low back pain, with a primary focus on identification of predictive factors for positive outcomes with this intervention (Hicks et al., 2005).

Few studies have investigated the quantifiable effects of physical therapy interventions on muscle activation patterns in people with LBP. Leinonen et al. (2000) did find changes in the muscle activation patterns of women with chronic LBP, specifically in timing and duration of gluteus maximus activity during trunk flexion/extension, following 5 weeks of physical therapy intervention. Although the specific interventions were not well described in this study, this lends support for the importance of including assessment and intervention aimed at the hip musculature in female patients with LBP. Since both genders were not included these results may not be generalizable to males. To the authors' knowledge, there have not been studies conducted on the effects of exercise intervention on individuals who are predisposed to develop LBP in response to a prolonged task exposure.

Although several factors have been associated with LBP development during standing exposures, it is unknown whether these factors are modifiable through conservative interventions such as prescribed exercise programs. Therefore, the purpose of this research study was to investigate the impact of a commonly utilized physical therapy exercise intervention on LBP development, clinical and biomechanical factors that have been identified as being related to LBP development during a prolonged standing task. A controlled pre-test/post-test design was used with participants being identified as PD/NPD after the pre-test, and then randomly assigned to exercise intervention or control groups for a 4-week period.

Based on previous studies that have shown elevated hip and trunk muscle co-contraction and decreased muscle rest time in PD groups (Nelson-Wong and Callaghan, 2010; Nelson-Wong et al., 2008), the following hypotheses were made: (1) PD assigned to the exercise intervention group (PD_{EX}) would have decreased subjective LBP, as measured by visual analog scale (VAS), compared with PD assigned to the control group (PD_{CON}). (2) It was expected that PD_{EX} would have decreased co-contraction of the bilateral gluteus medius muscles during prolonged standing compared to the PD_{CON} group.

2. Methods

Ethics approval for research involving Human Subjects was obtained from the Office for Research Ethics at the University of Waterloo and written informed consent was obtained from all participants prior to their involvement in the study. Forty-three participants (22 males, 21 females) were recruited from the University of Waterloo and surrounding community populations. Participant characteristics are reported in Table 1. Exclusion criteria included any lifetime event of LBP that was significant enough to seek care from a health care professional or that resulted in greater than 3 days off work or school; current low back or hip pain; previous hip surgery; inability to stand for greater than 4 h; inability to complete questionnaires; and employment in an occupation requiring extended static standing during the previous 12-months.

2.1. Experimental protocol

Pre- and post-test protocols were identical and performed 4 weeks apart to allow for the intervention to take place. The complete protocol has been described in detail previously (Nelson-Wong and Callaghan, 2010). In brief, psychosocial and physical activity questionnaires, clinical assessment measures, electromyography (EMG), three-dimensional kinetic and kinematic data were collected, however only those measures that were identified in the pre-test as predisposing factors for LBP development (Nelson-Wong and Callaghan, 2010) during standing are described here.

A baseline measure of LBP using a 100-mm visual analog scale (VAS) with end-point anchors of 'no pain' and 'worst pain imaginable' was established prior to data collection. A licensed physical therapist (ENW) then performed a standardized assessment, identical to what would be done in a clinical setting for a patient with LBP. This assessment including trunk and hip range-of-motion, lumbar segmental mobility, active core stability measures, assessment of lumbar segmental instability, and trunk muscle endurance tests (Nelson-Wong and Callaghan, 2010).

Participants were then prepped for surface electromyography (EMG) electrode placement. Disposable pre-gelled EMG Ag–AgCl electrodes (Blue Sensor, Medicotest, Inc., Olstykke, Denmark) with a 2 cm centre-to-centre inter-electrode distance were applied over seven bilateral muscle groups: thoracic erector spinae (5 cm lateral to T_9 spinous process) (Callaghan et al., 1998), lumbar erector spinae (above and below L_1 spinous process) (Danneels et al., 2001), rectus abdominis (1 cm above umbilicus and 2 cm lateral to midline) (Ng et al., 1998), internal oblique (1 cm medial to ASIS and beneath a line joining bilateral ASIS) (Ng et al., 1998), external oblique (below the ribcage, along a line connecting the inferior costal margin and the contralateral pubic tubercle) (Ng et al., 1998), gluteus medius (2.5 cm distal to the midpoint of the iliac crest) (Zipp, 1982), and gluteus maximus (midway between the greater trochanter and the sacrum) (Zipp, 1982). All electrode placements were confirmed through palpation and manual resistance. Raw EMG signals were amplified (AMT-8, Bortec, Calgary, Canada; bandwidth = 10–1000 Hz, CMRR = 115 db at 60 Hz, input impedance = 10 GΩ) and collected with a sampling frequency of 2048 Hz using a 16-bit A/D card with a ±2.5 V range. Manual resistance was applied to obtain maximal voluntary contractions (MVCs) for EMG normalization in the following positions: Beiring-Sorensen for trunk extensors (Dankaerts et al., 2004), prone hip extension for hip extensors, sidelying hip abduction for hip abductors, supine straight-leg curl up and diagonal curl up to the left and right for trunk flexors (Dankaerts et al., 2004). Rest

Table 1
Baseline characteristics of participants.

	Group statistics					
	Group	*N*	Mean	Std. deviation	Std. error mean	Independent *t*-test *p*-value
Age (years)	NPD	23	22.13	2.974	0.620	0.203
	PD	20	23.45	3.706	0.829	
BMI (kg/m^2)	NPD	23	23.849	3.4124	0.712	0.852
	PD	20	23.661	3.0774	0.688	
MMPA – previous 4 weeks	NPD	23	14367.96	7733.418	1612.529	0.353
	PD	20	16757.59	8937.845	1998.563	
Baseline VAS – low back (mm)	NPD	23	0.48	1.039	0.217	0.088
	PD	20	3.05	6.337	1.417	

trials were collected in supine and prone positions to determine the resting activation level of the monitored muscles.

Participants who reported a non-zero VAS score (average 1.85 ± 0.71 mm) following instrumentation had this value subtracted as a bias from the remaining VAS scores collected. VAS was collected every 15 min during the 2-h standing period for a total of 9 VAS scores including the baseline measure.

Participants then entered into the prolonged standing task. The experimental set-up is shown in Fig. 1. A work surface was positioned in front of the participant and adjusted to a standardized working height (Kroemer and Grandjean, 1997). Participants were instructed to stand 'in their usual manner as if they were standing for an extended period' with the only stipulations being that they could not rest their foot on the standing table frame, and they could not lean on the table surface with their upper extremities to support their body weight. Another baseline VAS was collected just prior to the start of the 2-h standing period to account for any discomfort that may have developed during the instrumentation period.

Three different tasks were performed to simulate light occupational activities (Nelson-Wong and Callaghan, 2010). These included a 'sorting' task, a small object 'assembly' task, and a task termed 'boredom/waiting' where participants were asked to stand without any activity. Tasks were presented in a block fashion using a random number generator, with 30-min blocks for each task. EMG data were collected continuously for the 2 h of standing in 15-min blocks with a sampling frequency of 2048 Hz.

Participants were classified into PD and NPD groups immediately following the standing protocol based upon their reported LBP scores on the VAS. Based on the minimal clinically important difference (MCID) of 8 mm for worsening LBP symptoms in a clinical population reported by Hagg et al. (2003), and the relatively low-level pain inducing stimulus used in this study, the decision was made to use a relative increase of 10 mm from baseline on VAS as the cut-point to categorize participants in this study as PD or NPD.

Participants were assigned to either an exercise intervention or control (usual activity) group. Participants were assigned on an alternating basis according to gender and PD/NPD group immediately after completing the pre-test data collection. Every other male PD was assigned to exercise, every other male PD assigned to control, and likewise for male NPD, female PD and female NPD. This was done because it was unknown *a priori* whether individuals would be categorized as PD or NPD. In this way, an attempt was made to balance the intervention groups by PD/NPD group and gender.

Signal processing was done through the use of custom programs written in Matlab R2008a, version 7.6.0 (The Mathworks, Inc., Natick, MA, USA). All EMG data underwent a similar algorithm of DC bias removal and bandpass filtering to remove ECG artifact (cutoff frequencies 30–500 Hz) (Drake and Callaghan, 2006) and bandstop (cutoff frequencies 59–61 Hz) (Mello et al., 2007) for removal of 60 Hz electrical contamination. Following the removal of the noise components, each EMG signal was full-wave rectified and low pass filtered (dual-pass Butterworth, fourth-order, effective cutoff frequency of 2.5 Hz) (Brereton and McGill, 1998; Winter, 2005) to create a linear envelope. Resting activity level was subtracted from the EMG signals and signals were normalized to %MVC. EMG data were then down-sampled to 32 Hz prior to further analysis as a data reduction measure.

Co-contraction index (CCI) (Lewek et al., 2004) was used to quantify the level of co-activation between all possible muscle pairs using the following equation:

$$CCI = \sum_{i=1}^{N} \left(\frac{EMG_{low_i}}{EMG_{high_i}}\right)(EMG_{low_i} + EMG_{high_i})$$

The CCI provides a quantitative measure of the degree of co-activation for a pair of muscle groups over a specified number of data points, *N*. 'EMG_{low}' and 'EMG_{high}' in the equation are the relative magnitudes of the linear enveloped EMG for the muscle pairs under consideration, *with* 'EMG_{high}' being the EMG signal with the higher magnitude at each instant in time. Data were collapsed by taking an average of 15 1-min window CCI values to yield 8 CCI values for the 2-h standing period for each of the possible 91 muscle pairings.

A Gaps analysis was also performed to determine if there were differences in the amount of rest time for individual muscles during the static standing task. A 'Gap' was defined as the period of time when the EMG level dropped below 0.5% MVC for a period of 0.2 s or longer (Veiersted et al., 1990). The number of Gaps for each monitored muscle, average duration for each Gap, and total

Fig. 1. The experimental set-up for the prolonged standing protocol.

Gap time were calculated for each 15-min block during the 2-h standing protocol.

2.2. Exercise intervention

A decision was made to utilize an exercise intervention that was largely based on previous work by Hicks and colleagues (2005). This progressive, independent exercise program emphasized strengthening of the trunk musculature, was relatively high intensity, and required weekly therapist supervision for progression and monitoring. The exercise program is shown in Fig. 2. Participants were considered to be 'adherent' to their prescribed intervention program if they attended all scheduled one-on-one sessions with the physical therapist, and completed their home exercise program four times per week (including the scheduled one-on-one session). This standard is well within the range of what has been considered to be acceptable for exercise adherence in the literature (White et al., 2005).

Participants assigned to exercise intervention were requested to meet with the primary investigator (ENW) who is also a licensed physical therapist, on a weekly basis to monitor and progress their exercise program. The general format for each instructional session was as follows. The participant was shown a picture and written description of each exercise, and had the purpose and goal of the exercise explained to them verbally. The participant was then asked to demonstrate the exercise, and was provided any necessary verbal and tactile cues to ensure correct performance. The participant continued to perform the exercise, with decreasing levels of cueing, until the investigator, and the participant, were satisfied the participant would be able to perform the exercise independently at home. Every participant was started at the same level for the first week. Each participant was provided with a handout that had illustrations and written cues and descriptions for each exercise. They were also provided with a 7-day exercise log (Appendix A) that specified their goal frequency and duration for the week, as established by the primary investigator. They were asked to complete the log and return it at the next meeting with the primary investigator.

At subsequent weekly meetings, each participant had their exercise program progressed according to how well they were performing the previous week's program. The threshold for progression was based on the ability to complete the goal number of repetitions, and to demonstrate correct execution (as determined by the physical therapist, ENW) of each exercise.

Participants who were assigned to the control group were asked to participate in their usual activities over the 4-week

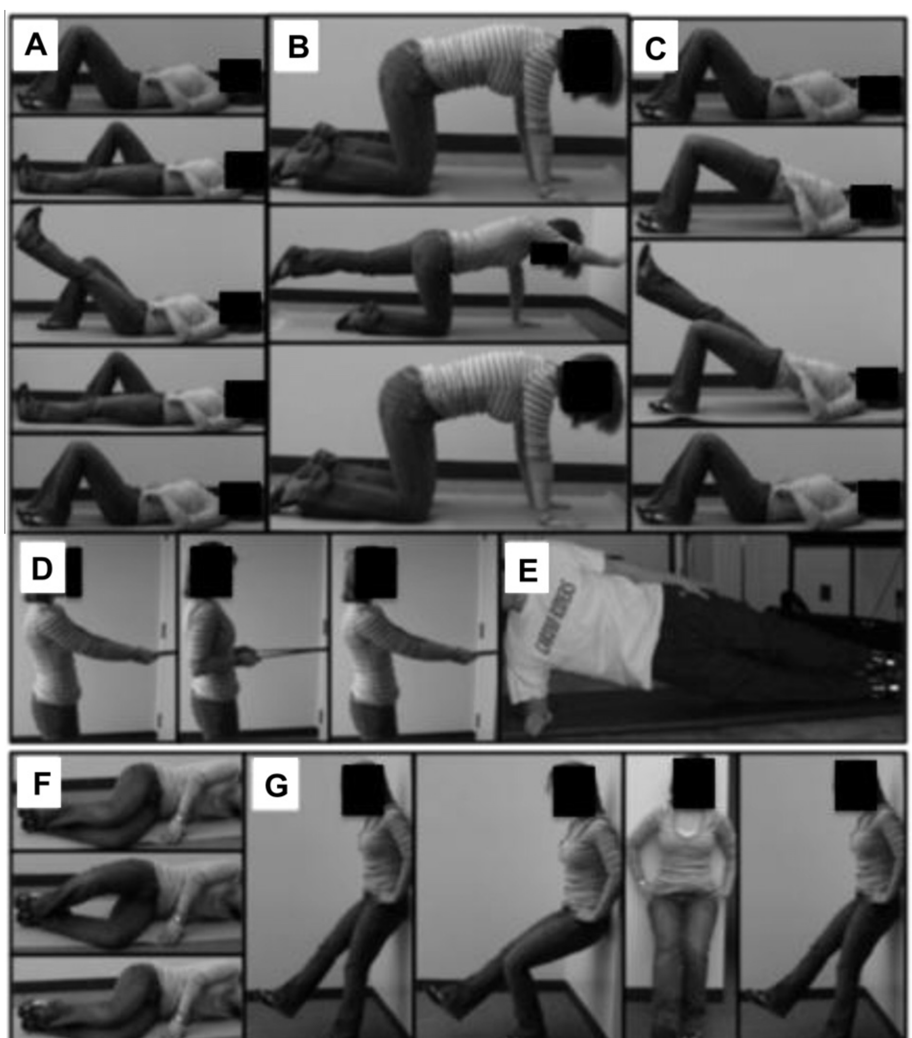

Fig. 2. The exercise intervention included: (A) abdominal bracing with heel slides and straight leg raises; (B) arm and leg extensions in quadruped (arm raise is shown); (C) bridging in supine; (D) standing rows with resistance band; (E) side bridge support; (F) 'clamshells' in sidelying; (G) single leg wall-slide squat with abdominal bracing.

Table 2
Sample distribution among groups following participant dropout.

		Exercise	Control	Total
Pain developers (PD)	Male	$n = 4$	$n = 3$	$n = 7$
	Female	$n = 5$	$n = 5$	$n = 10$
	Total	$n = 9$	$n = 8$	$n = 17$
Non-pain developers (NPD)	Male	$n = 6$	$n = 8$	$n = 14$
	Female	$n = 4$	$n = 6$	$n = 10$
	Total	$n = 10$	$n = 14$	$n = 24$
Total		$n = 19$	$n = 22$	$N = 41$

period between data collections. They were also requested to refrain from initiating any new exercise programs during this 4-week period.

There were two participants who did not complete the post-test for personal reasons. These participants were both in the NPD group, one male who was assigned to control and one female who was assigned to exercise. Their data were therefore removed from the analysis for the between day comparisons. This left the sample distribution as $N = 19$ assigned to exercise and $N = 22$ assigned to control as reflected in Table 2.

2.3. Statistical analyses

Unless otherwise noted, statistical analyses were performed through 4-way general linear models, with between factors of gender, PD/NPD group and intervention, and a within factor of testing day. To investigate the response of participants to the exercise intervention, the interaction of interest was any significant 3-way interaction of PD/NPD group, intervention and testing day. Bonferroni corrected p-values were used for multiple comparisons. Where data were not spherical based on Mauchly's test, Huynh–Feldt adjusted p-values were used to determine significance. Unless otherwise noted, pairwise comparisons were used for post hoc testing. Criterion for significance was set *a priori* at $p < 0.05$. SPSS version 16.0 (SPSS, Inc., Chicago, IL, USA) was used for all statistical analyses.

3. Results

The primary measures that were found to differ between PD and NPD individuals on the pre-test were as follows. The PD group had elevated co-contraction of bilateral gluteus medius and trunk flexor/extensor muscles especially during the early stages of the standing exposure, and lower total Gaps length for the gluteus medius and maximus muscles, indicating decreased rest time for these muscle groups (Nelson-Wong and Callaghan, 2010).

3.1. Exercise compliance

Participants assigned to the exercise intervention performed the exercise program on average 4.0 (±0.3) times per week over the 4-week period for an average weekly time spent exercising of 103.0 (±12.2) min (in addition to the weekly meeting with the primary investigator reviewing the exercises). There were no significant correlations between VAS change and frequency or duration of exercise ($p > 0.05$). All of the participants assigned to exercise intervention progressed through the 4 levels of the exercise program.

3.2. Pain development

Independent t-tests were conducted on VAS scores of PD and NPD assigned to exercise intervention (PD_{EX} and NPD_{EX}) compared to those assigned to control (PD_{CON} and NPD_{CON}) to ensure that there were no differences between the intervention groups initially. All comparisons were non-significant ($p > 0.10$).

Maximum VAS (change from baseline) scores from collection days 1 and 2 were entered into the general linear model and there was a significant interaction between PD/NPD group and collection day ($F_{2.98,116.39} = 14.22$, $p < .001$). There was no effect of gender on VAS score. Four 1-tailed (directional hypotheses), paired t-tests were conducted (with Bonferroni corrected alpha of $p < 0.0125$ for significance) for VAS levels in NPD_{CON}, NPD_{EX}, PD_{CON}, and PD_{EX} with repeated measure of collection day to determine whether there was a subjective response to the exercise intervention. There were no differences in VAS score for either control group or the NPD_{EX} group ($p > 0.05$). The PD_{EX} group showed a significant change in VAS score after 4 weeks of exercise ($t_8 = 3.11$, $p = 0.007$), with a large effect size (Cohen's $d = -3.78$). VAS scores for the PD_{CON} and PD_{EX} groups are shown in Fig. 3.

3.3. Activity level between testing sessions

Minnesota Leisure Time Physical Activity Questionnaire (MPAQ) (Folsom et al., 1986) scores for the 4-week period prior to entering into the study and for the 4-week period in between the two collection days were compared with paired t-tests to ensure that activity level for the control group did not change. There were no significant differences detected in activity level ($t_{21} = 1.75$, $p > 0.05$) for the control group participants, providing confidence that this group was compliant with instructions to continue with their usual level of activity.

3.4. Gluteus medius muscle co-activation during prolonged standing

Data for one female participant (NPD_{CON} group) were excluded for this measure due to not having good EMG signal on gluteus medius for collection day 1. Gluteus medius CCI pre- and post-test data were entered into a 5-way general linear model with between factors of gender, PD/NPD group and intervention and within factors of time (8 levels) and testing day (2 levels). There was a significant 4-way interaction of gender, PD/NPD group, testing day and intervention ($F_{1,29} = 16.33$, $p < 0.001$, Cohen's $d = 1.88$). This interaction was largely driven by the male PD_{EX} exhibiting an overall decrease during the 2-h of standing on the post-test, while female PD_{EX} showed no change between testing days in co-contraction of the gluteus medius muscles (Fig. 4). There were no differences

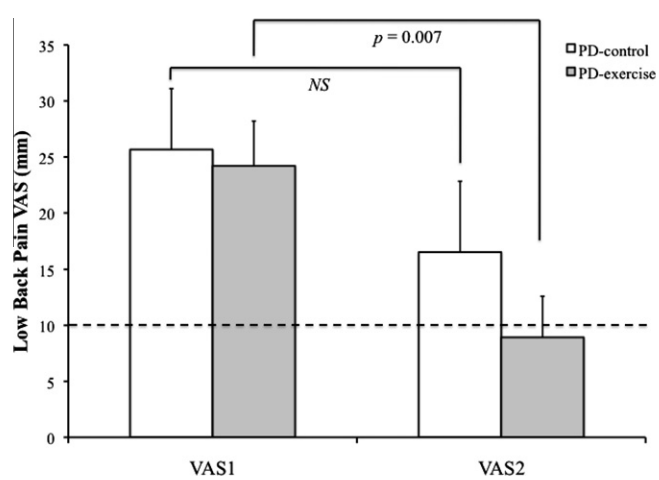

Fig. 3. PD_{EX} had a significant ($p < 0.0125$) change following the 4-week exercise intervention, while PD_{CON} had no significant ($p > 0.05$) change in VAS score. The dashed gray line shows the cutoff threshold for PD/NPD classification.

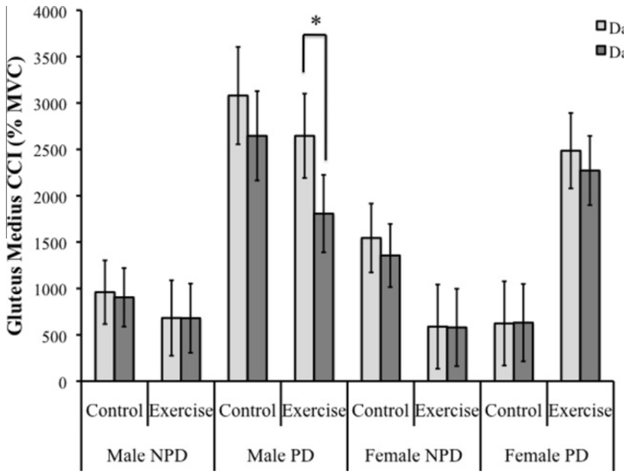

Fig. 4. The male PD_{EX} group was the only group that had differences in gluteus medius CCI between collection days (*$p < 0.05$).

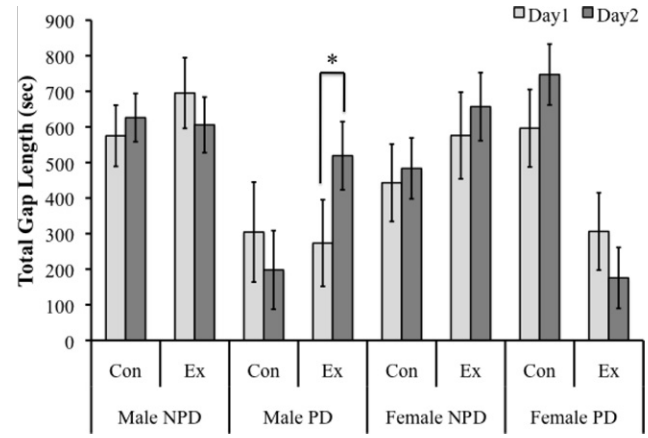

Fig. 6. Male PD_{EX} demonstrated longer rest periods for the right gluteus medius muscle during prolonged standing following exercise intervention ($p < 0.05$).

fbetween testing days in gluteus medius co-contraction for PD_{CON}, NPD_{Ex} or NPD_{CON} for either gender.

3.5. Trunk flexors/extensors muscle co-contraction during prolonged standing

There was a significant 4-way interaction of testing day, time, intervention and PD/NPD group ($F_{4.40,136.25} = 2.44$, $p < 0.05$, Cohen's $d = 0.27$) for the trunk flexor/extensor CCI data. Post hoc testing (Tukey's HSD) revealed that the PD_{EX} group had a significant decrease in trunk flexor/extensor CCI during the initial 15 min of the standing exposure only and then maintained similar levels to the pre-intervention data for trunk co-contraction throughout the remainder of the standing exposure (Fig. 5a). The PD_{CON} group demonstrated significant decreases in trunk flexor/extensor co-contraction throughout the standing exposure (Fig. 5b).

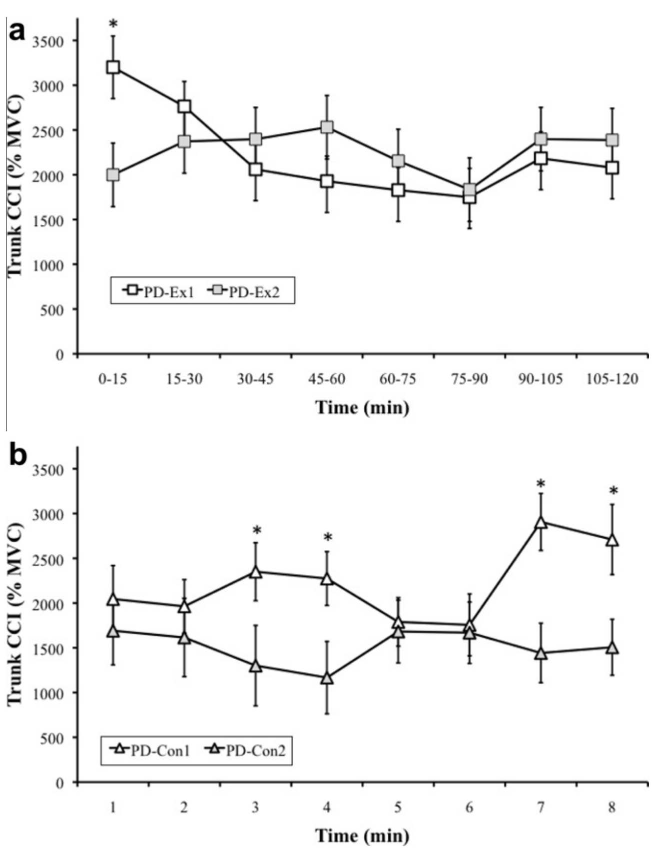

Fig. 5. (a) PD_{EX} had a decrease in trunk co-contraction during the initial 15 min of standing. (b) PD_{CON} demonstrated decreased trunk co-contraction on post-test throughout the 2-h standing period. Significant pairwise differences on Tukeys HSD post hoc test are designated by $*$.

3.6. Gaps in muscle activation during standing

There were no significant interactions between testing day, intervention, or PD/NPD group on total Gap length for either left or right gluteus maximus or the left gluteus medius. Significant group differences that were observed on the pre-intervention test day persisted on the post-intervention test day, with the PD groups having shorter total Gap length over the 2-h of standing for bilateral gluteus maximus and medius.

There was a significant 4-way interaction ($F_{1,32} = 4.79$, $p < 0.05$, Cohen's $d = 0.83$) between PD/NPD group, gender, intervention and testing day for total Gap length on the right gluteus medius. As shown in Fig. 6, male PD_{EX} had an overall increase in gap length of the right gluteus medius muscle following exercise intervention, while there were no significant between day changes for the other groups.

4. Conclusions and discussion

Individuals who initially developed LBP in response to prolonged standing were positively impacted by completing a 4-week exercise program focused on core stabilization' exercises for trunk and hip control. The hypothesis that those in the PD_{EX} group would demonstrate improvement in their VAS scores during the second standing exposure compared with those in the PD_{CON} group (Hypothesis 1) was supported. There was a significant decrease (average decrease from 24.2 ± 4.0 mm to 8.93 ± 3.66 mm) in VAS scores for those who participated in the exercise intervention. This is similar in magnitude to the reported MCID of 15 mm for decreased VAS in LBP (Hagg et al., 2003) and is also showed very large effect size ($d = -3.78$). This indicates that this would be a clinically meaningful reduction in LBP during standing for these participants.

Co-contraction of the bilateral gluteus medius muscles and trunk flexor/extensor muscles in people predisposed to LBP development during standing has been a consistent finding. It was therefore expected that if PD were going to benefit from exercise intervention by having decreased LBP, they would also have decreased co-contraction of these muscle groups (Hypothesis 2). There were mixed results in this outcome measure, with differences in response based on gender, and also different responses between the two muscle groups. In partial support of the hypothesis male PD_{EX} did have a decrease in co-contraction of the gluteus medius muscles with a large effect size ($d = 1.88$), however female PD_{EX} did not demonstrate similar responses. In previous work investigating the benefit of an ergonomic intervention (standing on a sloped surface) on LBP development (Nelson-Wong and Callaghan, 2010b), a decrease in gluteus medius co-contraction and subjective LBP were observed in PD, and was seen equally across genders. In opposition to the hypothesis, a different response with only a small effect size ($d = 0.27$) was observed for trunk flexor/extensor co-contraction. PD_{EX} had an initial decrease followed by a sustained level in trunk CCI, where on the pre-intervention test day this group initially had elevated CCI of the trunk, followed by a decrease as standing duration progressed (Nelson-Wong and Callaghan, 2010). PD_{CON} had decreased trunk CCI on the post-intervention test day, and there were no significant differences between genders. It is possible, as suggested in previous work (Nelson-Wong and Callaghan, 2010), that co-contraction of the trunk flexor/extensor musculature is beneficial for preventing LBP development during a static, prolonged posture, and the sustained levels seen in the PD_{EX} group may be a reflection of a positive response to the intervention. The PD_{EX} individuals may have been attempting to 'brace' the trunk musculature during standing since this bracing maneuver was emphasized during the exercise intervention. The NPD_{EX} group did not demonstrate this same pattern, however they may have responded differently during the standing protocol since they did not have a pain experience on the first collection day and therefore may have not attempted to utilize abdominal bracing. The PD_{CON} group followed a similar modulation of trunk CCI as was seen in the pre-intervention testing day (Nelson-Wong and Callaghan, 2010), with a marked decrease in trunk CCI during the middle stages of standing (from 30 to 60 min).

Differences were found in pre-testing in the total Gap length for the gluteal muscles, with the PD group spending less time at rest in these muscle groups. There were no significant between day changes in the left gluteal muscles or the right gluteus maximus. There were, however significant changes in the right gluteus medius muscle. Males in the PD_{EX} group demonstrated longer total Gap lengths for the right gluteus medius during the standing exposure, indicating they were increasing the amount of time the muscle was spending in the resting state following the exercise intervention. This is consistent with the finding of decreased CCI in the male PD_{EX} group. It is likely that the decrease in gluteus medius CCI for these individuals was driven by decreased activation periods for the right gluteus medius.

While the exact mechanisms of LBP development during standing cannot be isolated, it is clear from this study that exercise intervention directed at the trunk and hip does have some effect on the muscle activation patterns of those muscle groups during the prolonged standing task. Although there was a significant decrease in subjective VAS scores in the exercise group on the second standing exposure, it is difficult to say unequivocally that this was entirely due to the exercise intervention. However, a repeatability analysis conducted on the control groups in this study sample showed excellent between-day repeatability with ICCs > 0.70 for all of the measures under consideration (Nelson-Wong and Callaghan, 2010a), which provides a higher level of confidence that the responses found in this study were intervention-based. The accompanying changes in muscle activation patterns during the second standing exposure do indicate that there may be promise for this type of intervention in addressing LBP development during standing. Although both genders had equivalent decreases in pain response, they showed distinct differences in their muscle activation responses, particularly at the hip. This may be due to anthropometric differences in the pelvis between genders, leading to necessary differences in gluteus medius muscle activation and control. Gluteus medius co-contraction appears to be independent of hip rotation angle during standing as these data were not significantly correlated ($p > 0.05$) over the 2-h standing period.

Findings from previous studies indicate that low-level muscle fatigue may be one of the mechanisms underlying the LBP development observed in this protocol (van Dieen et al., 2009). The finding that PD_{EX} had increased rest time for the right gluteus medius in the initial stages of standing, combined with decreased VAS scores, provide some support for this theory. It could be that gluteus medius co-contraction is a maladaptive response for an inability to provide adequate postural control at the trunk, and is therefore a predisposing factor for LBP development during this task. Co-contraction of the trunk musculature, on the other hand, may be an appropriate adaptation and may serve as protection against LBP development during sustained postural demands.

There are some limitations to this study. Primarily, the participants in this study were asymptomatic individuals without history of LBP. While these findings support the exercise intervention being investigated as a possible preventative measure against LBP development during this specific standing task, these results cannot be generalized to a clinical population. The small sample sizes in this study may also limit generalizability, and this protocol needs to be repeated using a larger sample. The many factors that were included in this study resulted in significant higher-order interactions. While the time-varying modulation of the trunk flexor/extensor co-contraction patterns show clear differences responsible for the interactions, future studies should be designed to isolate and explore this response more specifically. Examiners were not blinded to group allocation, and while it is unlikely this had an impact on the muscle activation data, this could have biased the subjective pain reports. The monitored muscle groups were by necessity limited to those easily accessed for surface EMG, and there are potentially other deeper muscle groups (quadratus lumborum, psoas) that could be important factors in this LBP scenario.

It is encouraging to find that a commonly prescribed exercise intervention does have some impact on the motor control and muscle activation profile observed in these individuals. The goal of any clinically prescribed program is to effect a change in the system, and if it can be directed toward the appropriate mechanisms that are driving the impairment that would be ideal. While it would be premature to extrapolate these findings to a clinical LBP population, these study results show that there is some benefit to an exercise program directed at the trunk and hip in previously asymptomatic individuals predisposed to LBP during standing. While the specific underlying mechanisms have yet to be completely characterized and determined, it provides a foundation for future work to build upon.

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Appendix A. Daily exercise log

Please complete the log each day that you exercise. Your target goal for each week will be highlighted for you at each individual weekly session with the researcher.

Participant number ____________	Date ____________	Total time exercising ____________	
Primary muscle group	Exercises	Goal	Actual
Transversus abdominus	Abdominal bracing	30 reps with 8-s hold	
	Bracing with heel slides	20 reps per leg with 4-s hold	
	Bracing with leg lifts	20 reps per leg with 4-s hold	
	Bracing with bridging	30 reps with 8-s hold, progress to 1 leg	
	Bracing in standing	30 reps with 8-s hold	
	Bracing with standing row exercise	20 reps per side with 6-s hold	
	Bracing with walking		
Erector spinae/multifidus	Quadruped arm lifts with bracing	30 reps with 8-s hold each side	
	Quadruped leg lifts with bracing	30 reps with 8-s hold each side	
	Quadruped alternating arm/leg lifts with bracing	30 reps with 8-s hold each side	
Quadratus lumborum	Side support with knees flexed	30 reps with 8-s hold each side	
	Side support with knees extended	30 reps with 8-s hold each side	
Oblique abdominals	Side support with knees flexed	30 reps with 8-s hold each side	
	Side support with knees extended	30 reps with 8-s hold each side	
Gluteus medius/TFL	Sidelying ‘clamshells’ with bracing	30 reps each side	
	Sidelying ‘clamshell’ with hip abduction + extension and bracing	20 reps each side	
Gluteus medius/TFL	Single leg wall slide	10 reps each side	
	Single leg wall slide	25 reps each side	

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