Directed attention alters the temporal activation patterns of back extensors during trunk flexion–extension in individuals with chronic low back pain

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Abstract In chronic low back pain patients (CLBP), neuromuscular and pain intensity have been identified as contributing factors in the disability of the individual. However, it is unclear whether pain intensity influences neuromuscular activation and if directed attention mediates this relationship. Thus, the purpose of this study was to determine the effect of directed attention in individuals with different pain intensities on back extensor activation profiles. Fifty-four CLBP patients were separated into either high- or low-pain groups. Surface electromyograms were recorded from back muscles while the subjects performed a trunk flexion motion for four different attention conditions. Pattern recognition and repeated measures ANOVAs were used to examine the effect of sex, attention and pain intensity on temporal muscle activation patterns. The results showed that there was a significant sex $\times$ attention $\times$ pain interaction. The largest changes in muscle timing were observed in the low-pain group when their attention was focused on their pain, but the pattern of muscle activation differed between sexes. For males, a rapid decline in activation at mid-extension occurred, whereas females showed delayed activation at the beginning of extension. Overall, this study demonstrated that directed attention on pain had

an effect on trunk muscle temporal recruitment, and that this relationship differed between sexes and pain groups. This suggests that sex-specific mechanisms may alter the neuromuscular control of the spine in CLBP patients for different pain levels.

Keywords Chronic low back pain · Electromyography · Directed attention · Sex differences · Trunk muscles · Temporal recruitment strategies

Introduction

Chronic low back pain (CLBP) is the most prevalent and expensive occupational problem in industrialized countries [8, 13]. It is believed that pain severity may be an important determinant of the recovery profile following musculoskeletal injury [30, 56]. While there are indications that greater pain severity immediately following injury is a significant predictor of prolonged pain and work-related disability [33, 49], the mechanism has been difficult to ascertain.

It is theorized that pain interferes with the normal information processing of the central nervous system (CNS) resulting in altered motor control strategies [11, 22]. While there is limited information regarding clinical pain intensity and CNS processing, there is evidence that experimental pain intensity affects neuromuscular responses [23] and postural control mechanisms via sensorimotor processes [7]. Over time the altered neuromuscular strategies associated with higher pain severity may contribute to the persistence of the disorder [40]. However, whether changes in pain intensity influence motor programming in back extensors is yet to be fully examined.

Evidence suggests that women respond differently to pain compared to men [12, 18, 44]. Studies examining sex

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differences and pain found that there is a higher prevalence of musculoskeletal pain conditions and reports of more intense pain in women in comparison to men [12, 20, 26]. Specific to LBP, females are more likely to report pain in their low back compared to men with increased likelihood of developing chronic pain and prolonged disability [2, 45, 53]. Moreover, evidence from experimental pain studies has shown that females display greater pain sensitivity across multiple pain modalities (pressure, thermal) [12, 18, 20]. In fact, intramuscular injections of algesic substances results in greater pain ratings in women than men providing robust support for the hypothesis that women are more sensitive to muscle pain [10, 14–17]. Since pain influences muscle activation and affects men and women differently, it is reasonable to suggest that motor strategies between sexes may be altered by severity of pain. Thus, examining the impact of pain severity on the neuromuscular response and how it differs between men and women will further elucidate the process by which high-pain severity affects the progression of prolonged work-related disability in women.

One approach to assess the influence of pain severity on motor control strategies is through attention manipulation. The psychoanalgesia hypothesis of distraction suggests that distraction-evoked changes in analgesia are achieved by introducing stimuli that competes with pain for attention/cognitive resources [9, 42]. Distraction from pain has shown to decrease the pain experience [4, 9]. However, the relation between distraction and pain reduction is not as simplistic since distraction-evoked changes are dependent on pain severity and sex. For instance, those reporting high pain-intensity and women are found to have difficulty in engaging in distraction tasks [9, 19, 42]. In addition, evidence suggests that changes in cognitive demands can alter trunk muscle activation, with greater changes shown in symptomatic women than men [34, 58]. Within this context, the manner in which attention manipulation might influence neuromuscular function may be through the reduction of available cognitive resources from greater pain severity. In line with this reasoning, examining the impact of attention manipulation on muscle activation strategies might further elucidate the process by which attention impacts on pain.

In the present study, men and women with chronic low back pain were asked to perform trunk flexion movements while their attention was manipulated. Distraction approaches were used to determine how changes in pain focus influenced trunk muscle activation patterns and whether the relationship was altered by pain intensity and sex. It was hypothesized that directed attention would differentially alter motor control strategies of those with CLBP, and these alterations would differ between sexes and pain-intensity groups.

Methods

Fifty-four subjects between the ages of 20 and 50 years with CLBP participated in this study. Individuals who reported pain located between the lower ribs and gluteal folds, with minimal radiation to the thigh and never below the knee during most days of the week for a minimum 3 months were included [48]. Furthermore, inclusion in the study required no cardiovascular, neurological or orthopedic conditions, and reported no nerve root pain, neurological signs and symptoms, complications such as tumor or infection, previous spinal surgery, spinal fracture, or structural deformity such as scoliosis or spondylolisthesis [57]. Prior to testing, subjects signed an informed consent, which was approved by the Institute Review Board at McGill University and the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal.

Subjects were asked to identify their current pain intensity on an 11-point visual analog scale (VAS) anchored with “no pain” and “extreme pain” after testing. Based on a median split of pain-intensity ratings for each sex (2.7 for males and 4.2 for females), subjects were divided into either a high (14 males, 14 females) or low (13 males, 13 females) pain group. Participants also completed a series of questionnaires to assess different dimensions of their pain experience; the Tampa Scale for Kinesiophobia (TSK) assessed fear of movement or re-injury [29], and the Pain Catastrophizing Scale (PCS) examined catastrophic thinking related to pain [50]. Moreover, the degree of functional disability was assessed using the Roland-Morris low back pain and disability questionnaire (RMD) [43] (Table 1).

Experimental task

From a standing position, subjects were asked to perform a trunk flexion–extension movement with respect to the cadence of a metronome, maximum flexion of the trunk (4 s), relax in the maximum flexed position for 2 s (full flexion) and extension of their trunk to the original upright position (4 s). Subjects performed the task during four conditions where their attention was manipulated: (1) baseline, (2) pain focus, (3) two-digit and (4) four-digit recall. For the distraction conditions (2- and 4-digit recall), the numbers were displayed for 1 s on a computer screen located in front of the subject at eye level. After performing the movement for each condition, the subject was asked to recall the number. If the subject recalled an incorrect number, the trial was repeated. During the directed pain condition, subjects were asked to focus on their pain and rated their level of pain in the low back at the end of the movement trials (11-point scale: 0 no pain, 10 extreme pain). For each condition (block randomized), subjects

Table 1 Subject demographics and questionnaire results

	Low pain		High pain		<i>p</i> value		
	Male	Female	Male	Female	Pain	Sex	Pain × sex
Age (years)	38.7 (11.3)	40.9 (8.7)	41.1 (6.8)	40.4 (8.5)	0.714	0.395	0.269
BMI (kg/m ²)	24.4 (3.0)	24.2 (5.6)	24.8 (3.6)	25.6 (4.3)	0.131	0.787	0.328
TSK	41.5 (6.6)	41.1 (7.6)	47.3 (10.6)	43.3 (8.2)	0.086	0.344	0.435
PCS	19.8 (9.9)	20.7 (14.7)	28.1 (13.1)	24.9 (13.7)	0.083	0.755	0.568
RMD	16.7 (11.6)	25.0 (14.3)	37.2 (11.6)	41.9 (21.4)	0.083	0.225	0.666
VAS	1.2 (0.6)	2.9 (1.1)	5.0 (1.4)	6.0 (1.3)			

were asked to perform flexion–extension five times in succession; however, only artifact-free trials were included in the analysis.

Surface electromyography analysis

The EMG electrodes (10-mm inter-electrode distance) were placed bilaterally along the orientation of muscle fibers from four back extensor muscles: longissimus thoracis (5 cm from T10), longissimus lumborum (3 cm from L1), iliocostalis lumborum (6 cm from L3) and the multifidus (L5 at 3 cm from midline) [32]. The EMG signals were collected (amplified by a factor of a 1,000; band-pass filtered 20–450 Hz; sampling rate 1,000 Hz) using a 16-channel surface EMG system (Myomonitor, Delsys Inc., Wellesley, MA, USA), and stored on a personal computer for off-line processing.

Motion analysis

Angular displacement of the spinal column and pelvis was estimated by a three-dimensional motion system (X-Sens Motion Technologies, Enschede, The Netherlands). Motion sensors were placed over the spinous processes of the seventh cervical and 12th thoracic vertebrae as well as the second vertebra of the sacrum. Motion data were collected at 100 Hz.

Data analysis

All motion and EMG data were processed with customized MatlabTM programs (vR2006b Mathworks, Inc.). The motion signals were filtered with a bidirectional zero phase-lag second order Butterworth digital filter with the cut-off frequency determined automatically using the technique of residual analysis [60] (ranged between 1.3 and 4.7 Hz for the C7 sensor). Angles were estimated in the sagittal and frontal planes by calculating the inclination of the accelerometer vectors in these planes, as described by Hansson [21]. The maximum angular displacement of the C7 and S2 motion sensors were computed, as well as the

angle corresponding to the lumbar spine (subtraction between T12 and S2 sensors).

The raw EMG signal was filtered with a recursive fifth order Butterworth high-pass filter at 30 Hz to remove the ECG artifact and then corrected for bias [5]. The corrected signal was full-wave rectified and low-pass filtered at 2.5 Hz using a zero-lag, second-order Butterworth filter [6]. The EMG waveform was time normalized to 100% of the flexion–extension movement using a linear interpolation algorithm, and then the amplitude was normalized to the average amplitude over the entire movement [24]. This normalization approach removes physiological variation and variation due to volume conducting properties and allows the examination of changes in temporal activation. The movement trials from the right- and left-sided muscle sites were averaged to create ensemble-average muscle waveforms for each subject and condition.

Pattern recognition techniques were applied to the ensemble-average profiles [27]. Specific descriptions of the analytical process have been previously published [24]. In brief, the pattern recognition or eigenvector decomposition was applied to the cross product matrix of the ensemble-average profiles from the back muscles ([54 subjects × 4 conditions × 4 muscles] = 864 × 101). The first three principal patterns (PP) were extracted. These patterns accounted for the majority of the variability (>95%) and represented independent/orthonormal patterns from the waveform data. Next, each subject's waveform was scored (PP_{*i*} score) based on how similar their waveform was to the corresponding feature; the scores were subsequently used for statistical analyses. To aid in the interpretation of each feature (1) portions of movement time are highlighted in the figures reflecting the waveform feature captured by the corresponding principal pattern [25] and (2) the mean of a subsample of waveforms that correspond to high and low PP_{*i*} scores are presented [1, 25].

Two-way (group, sex) ANOVAs were used to test the differences in age and BMI. A four-way (group, sex, condition, muscle) ANOVA (repeated measures factors: condition, muscle) was used to test the differences in PP_{*i*} scores ($p < 0.05$). For the kinematic variables, a three way

(group, sex, condition) ANOVA was used (repeated measures factor: condition). Tukey post hoc tests were used to examine pair-wise differences in PP_i scores and angular range of motion (ROM). In cases where normality was not attained, variables were transformed prior to statistical testing. All statistical testing was performed using Minitab statistical software (Minitab Inc, State College, PA, USA).

Results

There were no significant pain groups or sex effects ($p > 0.05$) for the demographic and questionnaire variables (Table 1). However, there was a main effect for pain group for trunk ROM ($p = 0.037$). In the low-pain group, trunk ROM (113.7 ± 15.7) was 7.5° larger compared to the high-pain group (106.2 ± 12.4).

EMG waveform analysis

The back extensor ensemble waveforms during flexion–extension showed a biphasic activation profile; however, the timing and relative changes in activation amplitudes of these muscles differed throughout the movement (Fig. 1). Three principal patterns explained 96.5% of the total variance of the measured back muscle waveforms with principal pattern one (PP1) explaining the majority of the variance (87.7%) in the measured data. While PP1 represents overall shape and average magnitude of activation for all muscle sites, the other principal patterns captured changes in temporal phasing and changes in relative amplitudes of the waveform (Fig. 2). For each pattern, example waveforms that correspond to high and low PP_i score (Fig. 3a–c) and significant results (Fig. 3d–g) are identified. For interpretation purposes, different waveforms that have similar PP_i score magnitudes and same polarity are temporally synchronized. However, a different polarity indicates a different temporal recruitment between waveforms. Summary data for the pattern recognition analysis are presented in Table 2.

Results revealed a statistically significant muscle main effect for PP1, principal pattern two (PP2) and principal pattern three (PP3). For each pattern, significant differences were observed among all muscle comparisons ($p < 0.000$). The higher PP_1 scores associated with the lumbar erector spinae sites (longissimus and iliocostalis) showed a similar biphasic pattern that was more responsive temporally than the thoracic erector spinae (lower scores) (Figs. 1, 3a). PP2 captured a phase shift to the right for the longissimus site compared to the multifidus and iliocostalis sites. Figure 3b clearly demonstrates delayed onset and later peak during extension for the longissimus (low scores) and is seen in the ensemble average waveforms

Fig. 1 Mean waveforms for back muscles during trunk flexion–extension motion

Fig. 2 First three principal patterns

(Fig. 1). PP3 is best described as a difference operator that captures different changes in muscle activity between full flexion (minimal activity) and extension (large burst) for different muscles, i.e. low scores reflect smaller relative changes in amplitude resulting in a flatter temporal pattern as shown for the thoracic erector spinae (Figs. 1, 3g).

The phase shift featured in PP2 also resulted in a significant sex $\times$ pain $\times$ condition interaction ($p = 0.030$), which indicates that depending on the focus of attention temporal phasing changed from baseline, but the direction of this change was dependent on sex and pain severity. Significant results from the pair-wise comparisons are identified in Fig. 4. Examination of changes in directed attention conditions from baseline showed inconsistent findings across sexes and pain groups. For low-pain females, the baseline condition was different from all other conditions, while in the low-pain male group, only pain-focus and 2-digit conditions were different from baseline. Among the directed attention conditions, the pain-focus condition differed from: (1) both 2- and 4-digit recall conditions in low-pain males and (2) the 2-digit recall in both female low-pain

Fig. 3 Mean back waveforms with *shaded portions* of the waveform representing the neuromuscular feature for **a** PP1, **b** PP2 and **c** PP3. Mean PP_i scores and standard error of the mean for **d** PP1, **e** PP2 and

g PP3. Different capital letters, where indicated, represent significant differences among pair-wise comparisons

Table 2 Summary table: variation explained, neuromuscular interpretation and significant effects with *p* values

PP _i	Variation explained (%)	Significant effects	<i>p</i> value	Neuromuscular interpretation
1	87.7	Muscle	0.000	Magnitude/biphasic shape throughout motion
2	5.2	Muscle	0.000	Phase shift: muscle timing differences at 20–70 and 80–90%
		Pain × sex × condition	0.030	
3	3.6	Muscle	0.000	Phase shift: muscle timing differences at 25–60, 70–80 and 90–100%

and male high-pain groups. In addition, the 4-digit recall condition differed from the 2-digit condition for the male low- and high-pain groups. Sex differences also were observed for all conditions in the low-pain groups; however, only the 2-digit recall was different between sexes for the high-pain group. The comparison between high- and low-pain groups showed differences for the males across attention conditions, whereas for the females, the pain-focus and 2-digit recall conditions differed. These results suggest that when focused on pain, muscle timing was altered for the low-pain group, whereas its effects were minimal in the high-pain group. Specifically, the male low-pain group showed a rapid decline in back extensor activity at 80% of the movement, and the females showed delayed activation when preparing for trunk extension.

Discussion

The back extensor temporal activation patterns changed as a function of attention. Pain severity and sex modified this

Fig. 4 Significant pain × sex × condition interaction showing mean PP₂ scores and standard error of the mean for PP2

response. Overall, the largest change in muscle timing was observed in the low-pain group when they focused on their pain, whereas negligible changes were found across the attention conditions for the high-pain group. More specific,

during pain-focused conditions, males who reported less intense pain showed a rapid decline in back extensor activity during mid-extension, whereas females showed a delayed response at the beginning of extension. It appears that the relationship between directed attention and trunk muscle control is complex with the characteristics of the individual (sex and pain severity) playing a central role.

Effect of pain intensity

Consistent with our hypotheses, different attention conditions resulted in differential temporal activation patterns between low and high pain-intensity groups (PP2). While the low pain-intensity group showed different responses in muscle timing among conditions, those with high-pain levels showed minimal changes. The questionnaire results assessing psychological pain variables such as catastrophizing and fear of pain showed no differences between pain groups and sexes (Table 1). This suggests that these variables are equally represented between groups, thus limiting their impact on the present findings.

Pain intensity has been identified as a central variable that interferes with attention processing by competing for the limited cognitive resources available, thereby impairing the motor and cognitive performance of a given task [4, 9, 31, 37, 39, 51]. In fact, those with high-intensity pain show significant decrements in cognitive performance during tasks compared to those who report low-intensity pain [9, 28, 59]. It has been suggested that those with high pain are unable to divide their cognitive resources between competing attention demands of pain and distraction. This may explain, in part, why those in high pain in the present study were not influenced by directed attention, but those in low pain demonstrated changes in motor control with different attention conditions. In other words, high pain may account for a greater proportion of the finite cognitive resources available for reorganization of motor programs required during attention manipulation. Our results are in line with the hypothesis that CLBP patients may use a smaller repertoire of motor control strategies than healthy controls [36, 54]. The present results further extend this idea by suggesting that *intensity of pain* alters motor programming among CLBP patients with individuals in high pain having a stronger adherence to preferred motor strategies and less responsiveness to changing task conditions.

Effect of directed attention to pain

Only those who reported low pain showed considerable changes in temporal activation profiles across attention conditions. Interestingly, directed attention to pain showed the largest effect on muscle timing for both sexes.

Unfortunately, there is no one study that we can compare these findings. However, comparisons with studies examining individual variables, i.e. pain, attention or motor control may be helpful in the interpretation of our findings. At present, there is evidence that attention conditions designed to be stressful increase trunk muscle activation and spinal loads [3, 34, 35]. Often, the experience of pain is a powerful stressor, and has been consistently shown to alter motor control strategies in individuals with LBP and in asymptomatic subjects participating in experimental pain studies [10, 24, 35, 55]. Further, imaging studies show that attention demands modify pain-related brain activity (e.g. greater activity during painful conditions) [46]. Interestingly, Sullivan [51, 52] showed more protective pain behaviors when CLBP individuals were focused on their pain, suggesting that protective motor programs might be initiated automatically. Continuing this line of reasoning, focusing on pain may act as a catalyst to initiate physiological responses similar to stress responses such as increased sympathetic outflow, impaired proprioception and *altered* neuromuscular response [35, 41, 47]. Results from this study suggest that the different motor responses found for pain and distraction conditions are indicative of reorganization of motor programming due to pain focus. In addition, these findings point to a possible neurophysiologic pathway for attention pain focus to potentially act on the mechanical loads on the spine via muscle activation.

Effect of sex

Interestingly, reduced back extensor activity occurred at different times during the movement for men and women (low-pain group only). When female subjects focused on their pain, an earlier decline in back extensor activity during flexion and delayed activation when returning to an upright position was found. In contrast, men showed a rapid decline in activity at mid-extension. No sex difference was observed for the trunk ROM, rejecting this variable as a possible explanation. Furthermore, an extensive kinematics analysis (results not reported here) of the lumbar–pelvic coordination during the movement revealed no sex effect. In addition, the CNS relies on sensory information from the periphery to coordinate motor control strategies for a given task. It has been shown that the central processing of nociceptor information is different for men and women with women more sensitive to muscle pain [12]. It is possible that the differential processing of muscle pain between men and women contributes to the observed unique motor control strategies between men and women in the present study. Overall, the results from the present study suggest that sex-specific mechanisms may

alter the neuromuscular control of the spine in CLBP patients for different pain levels. Additional research needs to further examine sex differences, clinical pain and its impact on neuromuscular control to provide clinically relevant information regarding therapeutic interventions and return-to-work programs since women are at a greater risk for developing LBP.

Clinical implications

Assessing physical (neuromuscular response), psychological (attention) and individual (sex and pain experience) variables in the present study allows the findings to have widespread implications within the clinical community to treat longtime LBP sufferers. Overall, the key clinical message from this study is that therapeutic approaches need to take into account the interrelated factors associated with the “individual” to help design effective interventions. For instance, in a number of cases, distraction is used as a cognitive-behavioral treatment approach to reduce pain for LBP patients. Our findings suggest that this treatment option may be more beneficial for those who experience lower levels of pain rather than applying this method to all CLBP patients. In addition, traditional physical rehabilitation programs in the treatment of LBP patients have not considered sex-specific treatment approaches. The differences in the neuromuscular response between men and women which occurred at different movement phases clearly indicate that treatment interventions need to consider these sex differences. Clinically objective examinations of temporal changes may need to be included in the rehabilitation process to enhance treatment outcomes. However, more evidence is needed before definitive conclusions can be drawn.

Limitations

These findings must be interpreted within the context that pain-intensity reports were higher for females than males. Absolute pain ratings are subjective with inherent variability that makes it difficult to quantify pain, but a 30% change in pain report is thought to have clinical relevance [38]. While the magnitude of the difference in pain ratings between men and women did not meet this criterion, the difference between pain groups did. If the sexes, however, were not separated within each pain group, there would have been no differential effect of attention on motor control between the low- and high-pain groups (i.e. similar PP_i scores) as well as no differential neuromuscular sex response to pain intensity. Interestingly, no sex differences were observed in the psychological pain measures (Table 1) adding further support for the separation of sexes in the present study.

Conclusion

In this sample of CLBP patients, different temporal activation patterns were observed among different attention conditions, suggesting that the neuromuscular response is sensitive to directed cognitive demands, but only when attention resources are available, i.e. lower pain. Furthermore, sex differences in temporal activation of back muscles depended on whether they were focused on their pain or distracted from it. The sex-specific muscle response (reduced back extensor activity) also depended on the phase of the movement (full flexion for females and returning upright in men). Taken together, these findings may be important contributors to the observed higher sensitivity and longer disability-related LBP among women in comparison to men.

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