

# Differences in motor recruitment and resulting kinematics between low back pain patients and asymptomatic participants during lifting exertions

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## Abstract

**Background.** Low back disorders are a prevalent problem in society today and may lead to chronic debilitating low back pain. Developing our understanding of temporal muscle and kinematic patterns during manual material handling tasks may provide insight for preventing the cascading series of events leading to chronic low back pain.

**Methods.** Sixty-two low back pain patients and 61 asymptomatic participants performed a variety of lifting exertions that varied in lift origin horizontal and vertical distance, lift asymmetry, and weight. Electromyographic activity of 10 trunk muscles as well as trunk and pelvic kinematics was recorded during each exertion. Differences in muscle activation and kinematic parameters were compared between low back pain patients and asymptomatic participants as a function of experimental conditions.

**Findings.** Both the left and right erector spinae activated significantly earlier and were on significantly longer in low back pain patients compared to asymptomatic participants. The horizontal and vertical location of the lift influenced the EMG and kinematic differences between the low back pain patients and asymptomatic participants.

**Interpretation.** These findings indicate that low back pain patients would be exposed to increased muscle activity resulting in higher spine loads for a greater length of time compared to asymptomatic participants. The longer exposure time to increased spine load may lead to greater risk of future low back injury and cascading events leading to debilitating low back pain. The longer muscle activation time suggests that low back pain patients have changed their motor program from an open to a closed loop system.

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**Keywords:** Low back pain; Muscle activation; Electromyography; Trunk kinematics; Motor control

## 1. Introduction

Low back pain continues to have a lifetime prevalence rate as high as 70% (Lawrence et al., 1998). Furthermore, once an individual has an episode of low back pain that individual is more likely to have another

episode (Burton, 1997; Ferguson and Marras, 1997; Kerr et al., 2001; Papageorgiou et al., 1996; Van Poppel et al., 1998). Those individuals with low back pain in the United States had an annual total health care expenditure exceeding \$90 billion (Luo et al., 2004). Thus, in order to reduce the risk of future low back pain episodes, contain costs, as well as reduce pain and suffering we must gain a better understanding of the low back injury and recovery process.

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Many researchers have investigated kinematic and electromyographic (EMG) characteristic differences in those with low back pain and those without. Early research of Floyd and Silver (1995) showed an absence of the flexion-relaxation phenomenon in low back pain patients. More recent studies have confirmed the absence of the flexion relaxation phenomenon in low back pain patient (Kaigle et al., 1998; Shirado et al., 1995; Sihvonen et al., 1991; Triano and Schultz, 1987). These studies add to our basic understanding of differences between healthy and injured muscle function, which may lead to better treatment and rehabilitation methods. However extreme trunk flexion is a known risk factor of low back injury and as such low back pain patients are instructed to avoid such postures during daily activities in order to minimize exacerbation (Cailliet, 1991).

The EMG temporal recruitment patterns have been shown to be significantly different in low back pain patients compared to asymptomatic participants. Hodges and Richardson (1999) found differences in motor recruitment patterns of trunk muscle during limb movement for those with low back pain compared to those without. Newcomer et al. (2002) found differences in trunk muscle firing between patients and asymptomatic participants during toe-up movements while standing (patients tended not to fire muscle when asymptomatic participants did). Leinonen et al. (2000) found no difference in muscle recruitment during flexion and extension but did find a difference in duration of muscle activation. Arendt-Nielson et al. (1995) investigated EMG activation during gait and showed that chronic low back pain patients activated their trunk muscles during the swing phase of gait whereas asymptomatic participants had silent lumbar muscles. These studies examine differences in motor programs during daily activity providing information on muscle functional impairment in low back pain patients, which may have implications on rehabilitation programs. However, there is a lack of research evaluating both temporal trunk muscle activation patterns and trunk kinematic during manual material handling tasks that may place an injured employee returning to work at increased risk of future low back injury.

EMG amplitude is another characteristic that has been examined in the literature and research has shown that low back pain patients have increased EMG amplitude compared to asymptomatic participants (Lariviere et al., 2000; Ng et al., 2002). During manual material handling tasks, Hemborg and Moritz (1985) found that the level of activation was approximately the same but the duration of erector spinae activation was significantly longer in the patient population compared to the control. Marras et al. (2004) investigated the level of activity in ten trunk muscle and found patients had significant higher activity levels in the external obliques, internal obliques, rectus abdominus and latissimus dorsi

during manual material handling tasks. However, Marras et al. (2004) did not investigate the muscle recruitment patterns or temporal kinematic events. It is hypothesized that differences in muscle recruitment patterns and variations in temporal trunk kinematics may increase the risk of future low back pain episodes. Thus, the first objective of this study is to quantify differences in muscle activation timing, timing of peak activity and duration of activity in low back pain patients and healthy asymptomatic participants during manual material handling tasks. The second objective is to quantify differences between the two groups in the timing of peak trunk and pelvic kinematics events. Understanding these differences may have implications in rehabilitation programs that allow us to reduce the risk of future low back pain episodes.

## 2. Methods

### 2.1. Approach

This study examined temporal EMG and kinematic characteristics in low back pain patients and asymptomatic participants during manual material handling tasks. The weight of the lifting tasks was between 4.5 and 11.4kg, which are considered to be light duty job weight levels that a low back injured worker may return to (Ohio Bureau of Workers Compensation, 2004). The analysis examined the temporal EMG and kinematic components as a function of horizontal, vertical, asymmetry and weight of lift for differences between the low back pain patients and asymptomatic participants.

### 2.2. Subjects

One hundred and twenty-three (123) subjects participated in the study. Sixty-two of the subjects (32 males and 30 females) were suffering from low back pain at the time of the testing and were recruited from several medical practices. Within the low back pain group, 35% reported local low back pain only, 52% reported a distribution of 75% back pain and 25% leg pain, and 13% reported an equal distribution of back and leg pain. The median duration of pain symptoms was 5.5 months. The low back pain characteristics of the group are reported in Table 1. Patients were excluded from the study if physical examination showed signs of lower extremity deficit or hyperflexia.

Sixty-one age-matched asymptomatic participants (31 males and 30 females) with no history of low back pain were recruited to perform the study. The average age was 36.8 (10.1) and 38.4 (9.9) for the asymptomatic participants and patients, respectively. The standing height was not significantly difference 173.0cm for the asymptomatic participants and 172.9cm for the

Table 1  
Pain and SF-36 results

Impairment measure	Mean	St.D.
Pain level (0–10 scale)	5.0	1.9
Duration (months)	10.2	13.6
Million visual analog	68.4	26.6
SF 36 physical functioning	20.7	5.5
SF 36 role—physical	4.8	1.3
SF 36 bodily pain	6.1	2.2
SF 36 general health	17.9	5.1
SF 36 vitality	12.2	4.1
SF 36 social functioning	7.3	2.2
SF 36 role emotional	4.5	1.3
SF 36 mental health	20.9	4.9
SF 36 reported health transition	3.3	0.8

patients. On the other hand the patients were significantly heavier with an average weight of 90.1 (21.1)kg compared to asymptomatic participants at 77.1 (17.4)kg. Thus, the two groups were nearly identical in height however the patients were significantly heavier.

### 2.3. Experimental design

This was a repeated measures within subject design. The independent variables in the study were subject group (low back pain vs. asymptomatic), weight, lift origin region, and lift asymmetry position. The weight variable had four conditions (4.5, 6.8, 9.1 and 11.4kg). Free dynamic lifting condition started from five lift origin regions including shoulder, waist, knee, waist-far, and knee-far. The far conditions had a horizontal moment arm of 60cm while the other conditions had a horizontal moment arm of 30cm. The moment arm was measured from the midpoint of the hands to the midpoint of the ankles. The lift origin asymmetries were symmetric, 45° clockwise, 45° counter-clockwise, 90° clockwise, and 90° counter-clockwise. The lifts ended with the body in an upright position with the weight located at elbow height (elbow angle about 90°).

The dependent variables consisted of EMG temporal components, trunk kinematics and pelvic kinematics. The EMG temporal components consisted of start time, peak time and duration of activity from 10 trunk muscles. The trunk kinematics consisted of the timing of peak position, velocity, acceleration and deceleration in the sagittal, coronal and transverse planes. The pelvic kinematic measures included the timing of peak tilt and rotation position, velocity and acceleration.

### 2.4. Apparatus

EMG activity was collected through the use of bi-polar silver–silver chloride electrodes that have a 4mm diameter and were spaced approximately 3cm apart. Electrodes recorded the trunk muscle activity of the erector spinae, latissimus dorsi, rectus abdominus, exter-

nal oblique and internal oblique on both the left and right sides. EMG preparation and electrode placement has been described previously (Marras and Mirka, 1993). The EMG signal was pre-amplified, high-pass filtered at 30Hz, low pass filtered at 1000Hz, rectified and smoothed with a 20 ms sliding window filter. Skin impedance was maintained below 100K $\Omega$ .

Trunk kinematics were monitored with a tri-axial goniometer (lumbar motion monitor). The lumbar motion monitor is an exoskeleton of the spine that measured instantaneous three-dimensional position, velocity and acceleration of the spine. The device design accuracy and application have been reported previously (Marras et al., 1992). A set of electro-goniometers in conjunction with a forceplate were used to document pelvic tilt and rotation during exertions.

### 2.5. Muscle activation threshold and normalization

The muscle activity start time occurred when the muscle activity level was 10% above the resting muscle activity level. The peak time occurred at the time of maximum EMG activity for that muscle. The end time was the time at which the muscle activity dropped below 10% of the resting muscle activity level. The duration of muscle activity was the difference between the end time and start time.

All timing characteristics were normalized on a 0–1 scale. The initial activity (IT) was the earliest start time from all 10 muscles. The IT was considered 0. The total time in Eq. (1) is the total data collection time. Eq. (1) shows the normalization equation, which results in all activities being on a 0–1 scale thereby negating any effect of patients performing tasks slower than asymptomatic participants. The duration of muscle activity was calculated using normalized start and end times.

$$((\text{Timing characteristics}-IT)/(\text{Total time}-IT)) \quad (1)$$

### 2.6. Statistical analysis

Statistically significant differences in timing characteristics were evaluated with a repeated measures analysis of covariance structure implementing mixed modeling procedures using SAS software (SAS, 2001). The mixed procedure allowed for fixed effects as well as random effects. Fixed effects were the lift origin region, weight, asymmetry and subject group. The random effect was subject. Mixed modeling procedures were used to identify significant differences due to the main effect of subject group, lift origin region, weight, asymmetry and all two- and three-way interactions for timing characteristics. Post hoc contrast were used to identify significant differences between asymptomatic participants and patients within each asymmetric condition, weight level, lift region and their interactions at the 0.05 level of significance.

3. Results

3.1. EMG start time

There were significant differences in the muscle activation start times between the patients and participants. Table 2 indicates which muscles were significant for the group differences between low back pain patients and asymptomatic participants as well as each two- and three-way interaction with group. Fig. 1 illustrates the differences in the start, peak and duration for the left and right erector spinae. The left and right erector spinae was on 3% earlier in the low back pain patients than in the asymptomatic participants.

The differences in muscle activation start times between low back pain patients and asymptomatic participants were influenced by the region of the lift, as indicated in Table 2. The left external oblique was on 5% earlier in the patients compared to the asymptomatic participants in the shoulder region, whereas in the other regions the difference varied from 1% to 3%. The left internal oblique was on 3% earlier in the waist region, which was statistically significant whereas the differences were less than 1% earlier in the other regions. Thus patients activated muscles significantly earlier than asymptomatic participants in the shoulder and waist lifting

regions but not in the knee, knee-far and waist-far regions.

The relative difference between EMG activation times for the patients and asymptomatic participants also changed as a function of lift asymmetry. The right erector spinae was on 5% earlier in the patients at clockwise 90° and 3.5% earlier in patients at 45° clockwise. The left erector spinae was similarly on earlier in the counter-clockwise task asymmetries for the patients. Thus, the patients were activating their erector spinae earlier than necessary in preparation for the lift.

3.2. EMG peak time

The EMG peak time was not influenced by group overall however the difference between the groups was influenced by region of the lift as indicated in Table 2. The shoulder region had the largest differences between patients and asymptomatic participants and all the muscles were peaking earlier in the patients compared to the asymptomatic participants. The statistically significant differences were in the right latissimus dorsi, the right and left rectus abdominus, and right external oblique muscles, the low back pain patients peaked 6–8% earlier than the asymptomatic group. In other regions, the patient’s antagonistic muscles tended to peak after the asymptomatic group however none of the differences were statistically significant.

3.3. EMG duration

The results of the mixed model for the muscle duration showed several significant differences as indicated in Table 2. The right latissimus dorsi, left and right erector spinae and left and right external obliques showed significant differences between low back pain patients and asymptomatic participants. In all cases the muscle was on longer in the low back pain patient population than in the asymptomatic group. Fig. 1 illustrates the difference in duration for the left and right erector

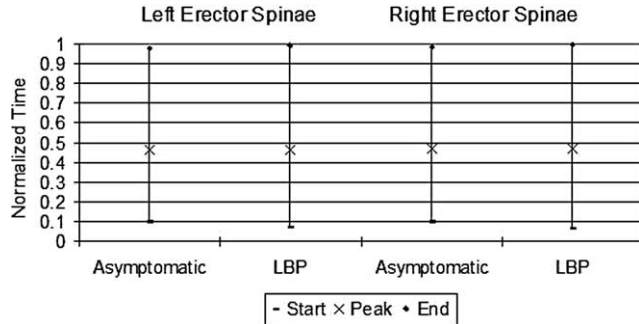


Fig. 1. Normalized start, peak and end times for the left and right erector spinae as a function of group. Note: LBP—low back pain.

Table 2 Mixed model results for asymptomatic vs. low back pain patients for EMG start times, peak time and duration

Effect	P-values for mixed model									
	RLT	LLT	RES	LES	RAB	LAB	REO	LEO	RIO	LIO
Group	D		S, D	S, D			D	D		
Group * Region	P		P, D	D	S, P, D	S, P, D	P	S, P	P	S, D
Group * Weight	D	D								
Group * Region * Weight										
Group * Asymmetry		S, D	S, D	S, D			P	P	S	
Group * Region * Asymmetry	P	S	S, D							
Group * Weight * Asymmetry					P					

S = significant difference in start times between groups at alpha = 0.05, P = significant difference in peak times between groups at alpha = 0.05, D = significant difference in duration of activation between groups at alpha = 0.05.

RLT = right latissimus dorsi, LLT = left latissimus dorsi, RES = right erector spinae, LES = left erector spinae, RAB = right rectus abdominal, LAB = left rectus abdominus, REO = right external oblique, LEO = left external oblique, RIO = right internal oblique, LIO = left internal oblique.

spinae. The significant differences varied from 3% to 5% in all the muscles.

Table 2 indicates that in several muscles the difference between patients and asymptomatic participants were significantly influenced by region. The patient population had significantly longer muscle activation in the shoulder and waist region for the left and right erector spinae. The right erector spinae also showed a significant difference in the waist-far region whereas the left erector spinae did not. The other regions showed no significant differences. The left internal oblique was on 4% longer (statistically significant) in the patient population compared to the asymptomatic in the waist region but not in any other regions.

The differences between low back pain patients and asymptomatic participants were influenced by the lift asymmetry for both the right and left erector spinae as well as left latissimus dorsi. The right erector spinae was on 4% longer at 45° clockwise and 6% longer at 90° clockwise. The right erector spinae was not significantly different between groups for the symmetric or 45° counter-clockwise. The 90° counter-clockwise had a 3% differences. The left erector spinae was significantly different at 90° counter-clockwise 6% different but not at 45° counter-clockwise (only 2% difference).

The right and left latissimus dorsi both show significant difference in duration between asymptomatic participants and low back pain patients as a function of weight. The patient's muscle duration was longer than the asymptomatic group as illustrated in Fig. 2. The differences decreased as task weight increased. The figure indicates that at 4.5 and 6.8 kg the difference was statistically significant whereas at higher weight levels the difference was not significant.

### 3.4. Trunk kinematics

The results of the mixed model for the timing of peak trunk kinematic activities showed several significant differences. Table 3 lists the *p*-values as a function of trunk kinematic characteristic and effect. The time of peak lat-

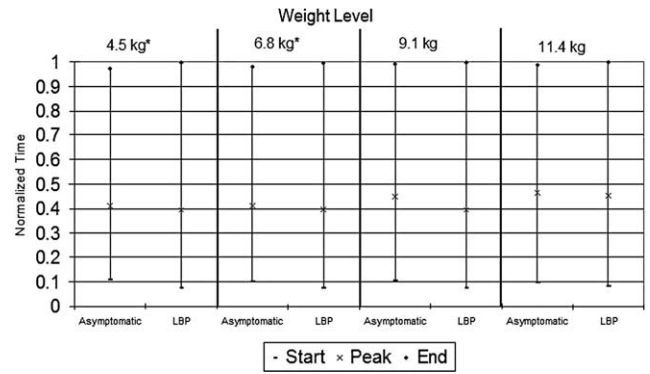


Fig. 2. Normalized time duration (start, peak and end) as a function of weight level and group. Note: LBP—low back pain.

eral deceleration was significantly earlier in low back pain patients compared to the asymptomatic participants.

Table 3 indicates that the differences between asymptomatic participants and low back pain patients in several trunk kinematic measures were significantly influenced by region. Sagittal peak position occurred significantly earlier in asymptomatic participants compared to low back pain patients in the knee (10%), waist-far (7%) and knee-far (8%) conditions. There was not a significant difference in the waist or shoulder regions. Twisting velocity peaked 5% earlier in asymptomatic participants than in patients in the knee and knee-far regions. There was no significant difference in the other regions. The time of the sagittal peak acceleration was earlier in asymptomatic participants in the knee and knee-far region. Similar trends were found in the timing of peak twisting acceleration. Interestingly, the time of peak twisting deceleration was 6% earlier in the patients than in the asymptomatic participants for the shoulder region. There were no significant differences in the remaining regions.

The difference between asymptomatic participants and low back pain patients was influenced by lift asymmetry for the time of peak twisting velocity, peak sagittal acceleration, twisting acceleration and twisting deceleration as indicated in Table 3. Peak twisting velocity occurred 8%

Table 3  
Mixed model for asymptomatic vs low back pain patient group for effects of peak trunk kinematics events

Effect	P-Values for mixed models											
	Sagittal				Lateral				Twist			
	Pos.	Vel.	Acc.	Dec.	Pos.	Vel.	Acc.	Dec.	Pos.	Vel.	Acc.	Dec.
Group	0.1254	0.2783	0.6800	0.6812	0.4885	0.9380	0.3150	0.0293*	0.7447	0.4362	0.6916	0.3575
Group * Region	0.0001*	0.7998	0.0001*	0.0109*	0.6347	0.1084	0.6886	0.6156	0.7664	0.0001*	0.0080*	0.0001*
Group * Weight	0.5816	0.3257	0.6291	0.6410	0.9367	0.9647	0.7763	0.5105	0.7993	0.7184	0.2779	0.6652
Group * Region * Weight	0.2217	0.5431	0.8366	0.6523	0.9983	0.3010	0.3389	0.1310	0.8716	0.8479	0.8476	0.5315
Group * Asymmetry	0.6053	0.3142	0.0065*	0.6759	0.9324	0.3090	0.2016	0.1483	0.1086	0.0001*	0.0027*	0.0116*
Group * Region * Asy.	0.0150*	0.3013	0.6368	0.1732	0.0073*	0.0148*	0.4879	0.3643	0.2187	0.8827	0.1609	0.3381
Group * Weight * Asy.	0.3952	0.7031	0.9223	0.2923	0.5205	0.8252	0.9025	0.8307	0.5333	0.7991	0.4590	0.9161

\* Significant effect at alpha = 0.05.

earlier in the asymptomatic participants than in patients at 90° clockwise and 6% earlier at 45° clockwise.

### 3.5. Pelvic kinematics

The time of peak pelvic rotation was influenced by group overall. The asymptomatic participants reached peak position 4% earlier than the patients. None of the other measures were influenced by group overall. The difference in the timing of peak pelvic tilt was influenced by region. The peak tilt position occurred earlier in asymptomatic participants than in patients in all regions. It was 15% earlier in the waist region and 11% earlier in the waist-far region. All other regions were not significantly different.

The difference between asymptomatic participants and patients for time of peak rotation position, velocity and acceleration were all influenced by task asymmetry. Peak rotation position was 13% later in patients at 90° counter-clockwise. Peak rotation position was 9% later in patients at 45° counter-clockwise. Both of these differences were statistically significant. Peak rotation velocity was 5% earlier in asymptomatic participants at 45° and 90° counter-clockwise. Peak rotation acceleration was 7% earlier in asymptomatic participants.

## 4. Discussion

This study examined the timing of EMG and kinematic events during manual material handling tasks in both asymptomatic participants and low back pain patients. The low back pain patients activated their muscles earlier and the muscles were on longer than the asymptomatic participants. However, the resulting trunk and pelvic motion timing events showed that peak kinematic events occurred in asymptomatic participants prior to low back pain patients except for lateral deceleration. These differences were small but statistically significant and may be magnified under more complex manual material handling tasks. Also, [Table 1](#) indicates that the study participants were mildly impaired, it is hypothesized that more severely impaired participants may have greater temporal differences. These findings have several implications in terms of spine loading, motor programs, stability and rehabilitation.

The normalized time of muscle activation was longer in the patients than in the asymptomatic participants. This finding was similar to that of [Hemborg and Moritz \(1985\)](#). The increased time of muscle activation has a “cost” in terms of spine loading. The cost is that the low back pain group would be exposed to increased spine loading due to muscle activation for a longer period of time when performing the same task as an asymptomatic control. The longer exposure time may increase the risk of future low back disorders.

The findings from this study may suggest that low back pain patients and the asymptomatic group had different types of motor control systems. [Magill \(2004\)](#) has defined two systems of motor programs a closed loop system that allows for feedback within the system and an open loop system that does not allow for feedback. The earlier activation and longer duration in the low back pain patients as well as the later peak position and acceleration times may suggest that the motor program in the low back pain patients has changed from an open to a closed loop systems. Recently, [Descarreaux et al. \(2004\)](#) examined the time required to reach peak force in both participants and low back pain patients and found that low back pain patients required more time to achieve a peak force during an isometric exertion than participants. [Descarreaux's](#) suggested the increased time to reach peak was the result of a less open system. In our case the peak sagittal position occurred significantly earlier in the asymptomatic participants than low back pain patients in the knee, knee-far and waist-far regions. The delay in the timing of sagittal peak position for low back pain patients in the more physically demanding regions may indicate the motor program has changed from open loop to closed loop system. The delay would allow more time for feedback, which is characteristic of a closed loop system. Thus, a change in the motor program in low back pain patients is task dependent. Other researchers have also found that changes in motor recruitment patterns are a function of task demands ([Danneels et al. \(2002\)](#), [Hodges and Richardson \(1999\)](#)).

A motor program can change not only in the time parameter but also in the muscle parameter ([Magill, 2004](#)). In this particular case, not only can the muscle recruitment be examined but also the time of resulting kinematic trunk and pelvic events. [Fig. 3A and B](#) illustrate the sequence of events for internal muscle activation and peak kinematic events during a symmetric lift at knee level and 30cm horizontal distance. There is one very noticeable difference between the two sequences. [Fig. 3A and B](#) illustrates that in the asymptomatic group the agonist muscles activated followed by peak sagittal position whereas the low back pain group activated both the agonists and the antagonists before the peak sagittal position was achieved. It is proposed that this change in the sequence of events suggests that the antagonists must activate to help stabilize and control the spine earlier in the lift in the patient population than in the asymptomatic participants. Along these same lines, among the agonist muscles activating the left and right erector spinae are typically the first two muscles to activate however in the patients in the waist-far condition during symmetric lifts the right erector was the third muscle to activate. This suggests that not only does a time parameter in the motor program of low back pain patient's change but also a muscle parameter may change depending on the demand of the task. The

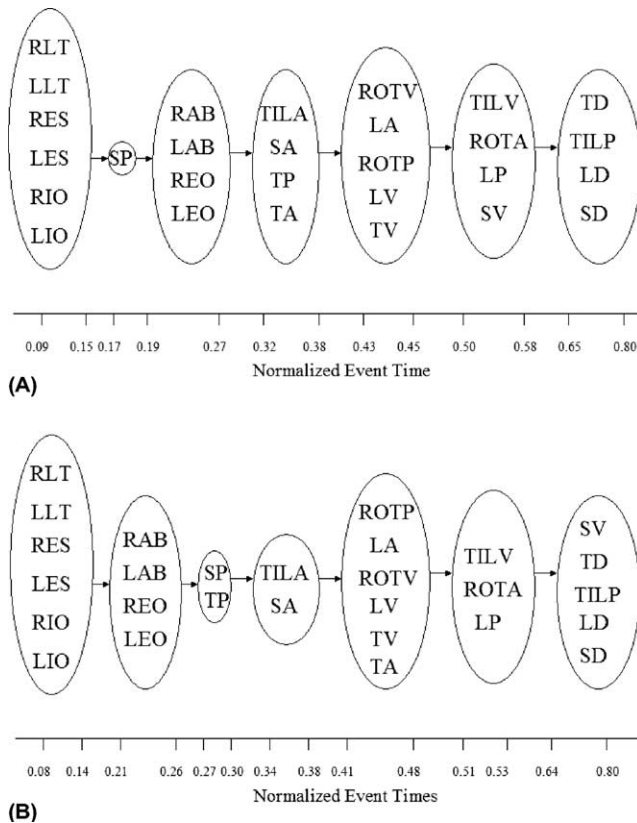


Fig. 3. (A) Normalized event times for asymptomatic group performing sagittal lift at knee level and horizontal distance of 30 cm. RLT = right latissimus dorsi, LLT = left latissimus dorsi, RES = right erector spinae, LES = left erector spinae, RIO = right internal oblique, LIO = left internal oblique, SP = sagittal trunk position, RAB = right rectus abdominal, LAB = left rectus abdominus, REO = right external oblique, LEO = left external oblique, TILA = pelvic tilt acceleration, SA = sagittal trunk acceleration, TP = twisting trunk position, TA = Twisting trunk acceleration, ROTV = pelvic rotation velocity, LA = Lateral trunk acceleration, ROTP = pelvic rotation position, LV = lateral trunk velocity, TV = twisting trunk velocity, TILV = pelvic tilt velocity, ROTA = pelvic rotation acceleration, LP = lateral trunk position, SV = sagittal trunk position, TD = twisting trunk deceleration, TILP = pelvic tilt position, LD = lateral deceleration, SD = sagittal deceleration. (B) Normalized event times for low back pain patients performing sagittal lift at knee level and horizontal distance of 30 cm.

change in the muscle parameter may influence the shear and compressive loads on the spine.

Theoretically the feedback in a motor program may come from one of three levels including cognitive, pattern control variables and execution (Latash, 1998). Hodges et al. (2003) suggest that fear of pain may disrupt normal control of trunk muscles, which represents a change in the motor program at the cognitive level. The differences in the kinematic events were most apparent in the more physically demanding regions (knee, knee-far and waist-far), which may suggest that the tasks may have been perceived as potentially harmful. Furthermore, peak lateral deceleration was the only kinematic measure that occurred in low back pain patients

earlier than asymptomatic participants. It appears in our data that the feedback to control motion resulted in perturbations in the acceleration profile. It is hypothesized that quantifying the smoothness of the acceleration as well as the magnitude may provide a good indicator of recovery from low back injury however further research is necessary to confirm this concept.

Van Dieen et al. (2003) in a recent literature review proposed that alterations in trunk muscle recruitment patterns in patients are functional. It may be hypothesized that this function is to stabilize the trunk however the increased stability comes at the cost of increased spine loading as discussed earlier. The earlier activation of the muscles means that the spine will be exposed to increased loads for a longer period of time in low back pain patients. Furthermore, Marras et al. (2004) has shown that the change in the recruitment pattern found here resulted in significantly greater anterior/posterior shear as well as compression. The increased level of anterior/posterior shear may be of greater concern because spinal tolerance to shear loading is much lower than that of compression (McGill, 2002). The practice of returning injured workers to the job prior to being symptoms free may only serve to reinforce the impaired motor program. If the motor control changes remain in place after a patients symptoms resolve then the patient is going to be exposed to increased loading permanently. A permanent change in motor recruitment, resulting in increased loading may provide one explanation for the increased risk of low back disorder for those with previous history, which is well documented in the literature (Burton, 1997; Ferguson and Marras, 1997; Kerr et al., 2001; Papageorgiou et al., 1996; Van Poppel et al., 1998).

#### 4.1. Limitations

This study had a sufficiently large population of patients and asymptomatic participants, however, the study could have examined patients in various structural low back disorder categories. Furthermore, evaluating patients multiple times during the recovery process may lead to a greater understanding of motor program recovery.

## 5. Conclusions

1. The left and right erector spinae activated significantly earlier in low back pain patients compared to asymptomatic participants yet peak sagittal position occurred later in low back pain patients compared to asymptomatic participants.
2. The right latissimus dorsi, right and left erector spinae, and right and left external oblique were on longer in low back pain patients than in the asymptomatic participants during the manual material handling tasks.

3. The region of lift influenced the difference between low back pain patients and asymptomatic participants. The kinematic measures showed greater differences in the knee, waist-far and knee-far region between patients and asymptomatic participants.
4. The weight of the lift influenced the difference between the low back pain patients and asymptomatic participants. The lower two weight levels had greater EMG differences between patients and asymptomatic participants than the higher two weight levels.

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### References

- Arendt-Nielson, L., Graven-Nielson, T., Svarrer, H., Svensson, P., 1995. The influence of low back pain on muscle activity and coordination during gait: a clinical and experimental study. *Pain* 64, 231–240.
- Burton, A.K., 1997. Spine update: back injury and work loss: biomechanical and psychosocial influences. *Spine* 22, 2575–2580.
- Cailliet, R., 1991. *Low back pain syndrome*, 4th ed. F.A. Davis Company, New York.
- Danneels, L., Coorevits, P., Cools, A., Vanderstraeten, G., Cambier, D., Witvrouw, E., De Cuyper, H., 2002. Differences in electromyographic activity in the multifidus muscle and the iliocostalis lumborum between healthy subjects and patients with sub-acute and chronic low back pain. *Eur. Spine J.* 11, 13–19.
- Descarreaux, M., Blouin, J., Teasdale, N., 2004. Force production parameters in patients with low back pain and healthy controls study participants. *Spine* 29, 311–317.
- Ferguson, S., Marras, W., 1997. A literature review of low back disorder surveillance measures and risk factors. *Clin. Biomech.* 12, 211–226.
- Floyd, W., Silver, P., 1995. The function of erector spinae muscles in certain movements and postures in man. *J. Physiol. (London)* 129, 184–203.
- Hemborg, B., Moritz, U., 1985. Intra-abdominal pressure and trunk muscle activity during lifting. II. Chronic low-back patients. *Scand. J. Rehab. Med.* 17, 5–13.
- Hodges, P., Moseley, G., Gabrielson, A., Gandevia, S., 2003. Experimental muscle pain changes feedforward postural responses of the trunk muscles. *Exp. Brain Res.* 151, 262–271.
- Hodges, P., Richardson, C., 1999. Altered trunk muscle recruitment in people with low back pain with upper limb movement at different speeds. *Arch. Phys. Med. Rehabil.* 80, 1005–1012.
- Kaigle, A., Wessberg, P., Hansson, T., 1998. Muscular and kinematic behavior of the lumbar spine during flexion–extension. *J. Spinal Disord.* 11, 163–174.
- Kerr, M., Frank, J., Shannon, H., Norman, R., Wells, R., Neumann, W., Bombardier, C., 2001. Biomechanical and psychosocial risk factors for low back pain at work. *Am. J. Public Health* 91, 1069–1075.
- Latash, M., 1998. Implications for motor rehabilitation. In: Latash, M. (Ed.), *Neurophysiological basis of movement*. Human Kinetics, Champagne, pp. 229–237.
- Lariviere, C., Gagnon, D., Loisel, P., 2000. The comparison of trunk muscles EMG activation between subjects with and without chronic low back pain during flexion–extension and lateral bending tasks. *J. Electromyogr. Kinesiol.* 10, 79–91.
- Lawrence, R., Helmick, C., Arnett, F., Deyo, R., Felson, D., Giannini, E., Heyse, S., Hirsch, R., Hochberg, M., Hunder, G., Liang, M., Pillemer, S., Steen, V., Wolfe, F., 1998. Estimates of the prevalence of arthritis and selected musculoskeletal disorders in the United States. *Arthritis. Rheum.* 41, 778–799.
- Leinonen, V., Kankaanpaa, M., Luukkonen, M., Hanninen, O., 2000. Back and hip extensor activities during trunk flexion/extension: effects of low back pain and rehabilitation. *Arch. Phys. Med. Rehab.* 81, 32–37.
- Luo, X., Pietrobon, R., Sun, S., Liu, G., Hey, L., 2004. Estimates and patterns of direct health care expenditures among individuals with back pain in the United States. *Spine* 29, 79–86.
- Magill, R., 2004. *Motor Learning and Control Concepts and Applications*, 7th ed. McGraw Hill, Boston.
- Marras, W., Fathallah, F., Miller, R., Davis, S., Mirka, G., 1992. Accuracy of a Three Dimensional Lumbar Motion Monitor for recording dynamic trunk motion characteristics. *IJIE* 9, 75–87.
- Marras, W., Ferguson, S., Burr, D., Davis, K., Gupta, P., 2004. Spine loading in patients with low back pain during asymmetric lifting exertions. *Spine J.* 4, 64–75.
- Marras, W., Mirka, G., 1993. Electromyographic studies of the lumbar trunk musculature during the generation of low-level trunk acceleration. *J. Orthop. Res.* 11, 811–817.
- McGill, S., 2002. *Low back disorders Evidence-Based Prevention and Rehabilitation*. Human Kinetics, Champagne.
- Newcomer, K., Jacobson, T., Gabriel, D., Larson, D., Brey, R., An, K., 2002. Muscle activation patterns in subjects with and without low back pain. *Arch. Phys. Med. Rehabil.* 83, 816–821.
- Ng, J., Richardson, C., Parnianpour, M., Kipper, V., 2002. EMG activity of trunk muscles and torque output during isometric axial rotation exertion: a comparison between back pain patients and matched asymptomatic controls. *J. Orthop. Res.* 20, 112–121.
- Ohio Bureau of Workers Compensation, 2004. *Physician's Report of Work Ability MEDCO-14*. BWC-3914.
- Papageorgiou, A., Croft, P., Thomas, E., Ferry, S., Jayson, M., Silman, A., 1996. Influence of previous pain experience on the episode incidence of low back pain: results from the South Manchester Back Pain Study. *Pain* 66, 181–185.
- SAS, 2001. *SAS Language*. SAS Institute Inc., Raleigh, NC.
- Shirado, W., Ito, T., Kaneda, K., Strax, T., 1995. Flexion-relaxation phenomenon in the back muscles. A comparative study between healthy subjects and patients with chronic low back pain. *Am. J. Phys. Med. Rehabil.* 74, 139–144.
- Sihvonen, T., Partanen, J., Hanninen, O., Soimakallio, S., 1991. Electric behavior of low back muscles during lumbar pelvic rhythm in low back pain patients and healthy asymptomatic controls. *Arch. Phys. Med. Rehab.* 72, 1080–1087.
- Triano, J., Schultz, A., 1987. Correlation of objective measure of trunk motion and muscle function with low back disability ratings. *Spine* 12, 561–565.
- Van Dieen, J., Selen, L., Cholewicki, J., 2003. Trunk muscle activation in low-back pain patients, an analysis of the literature. *J. Electromyogr. Kinesiol.* 13, 333–351.
- Van Poppel, M., Koes, B., Deville, W., Smid, T., Bouter, L., 1998. Risk factors for back pain incidence in industry: a prospective study. *Pain* 77, 81–86.